Demand Elasticity in Transactive Energy Systems

David P. Chassin and Sahand Behboodi

***Abstract*—Transactive energy has been proposed to facilitate integrated economic and technical scheduling, dispatch and control of distributed energy and demand response resources as increasing levels of intermittent renewable energy resources begin to challenge the economic viability, security and reliability of bulk electricity systems. This letter presents an important relationship between the elasticities of energy demand, capacity demand and ramping demand. The implications of this relationship are briefly examined in terms of technology development, utility and aggregator business models, and regulatory oversight with particularly emphasis on retail competition and retail tariff design.**

***Index Terms*—transactive energy, transactive control, electricity demand elasticity, retail markets, real-time pricing, retail competition**

I. Introduction

Recent research has consistently shown that demand response (DR) can participate in all electricity markets, including energy, capacity, and regulation [1]. Transactive control and Powermatcher were proposed and demonstrated in the field as approaches that could unify the scheduling, dispatch and control of all distributed energy resources, including DR, on the retail side [2]. Since then there is growing interest in the broader concept of transactive energy in both Europe and North America [3]. In addition a number of important technical contributions have been made to support transactive energy systems, including the design of device controllers [4], real-time pricing [5], and retail market designs, in various jurisdiction in North America and elsewhere.

However the fundamental behaviors and properties of transactive systems remain a largely an open research area. From the viewpoint of power system and control engineering, this is a critical gap and to this day it stands as a significant barrier to the widespread adoption of transactive control systems–utilities are hesitant to adopt a control strategy in the absence of a clear and validated mathematical framework to study and prove the stability, robustness, and reliability against all hazards.

One important aspect of this gap is the nature and role of DR elasticity of energy, power and ramp resources in electricity markets. This letter briefly presents a result that the authors believe may be of significance to researchers in transactive energy and transactive control insofar as it establishes a strong and potentially useful connection between the elasticity of energy, power and ramp response resources in electricity markets, both wholesale and retail. This relationship is examined and its implications are discussed briefly with respect to the design of DR controllers, utility and demand aggregator business models, and regulatory oversight of electricity markets, especially in the context of retail competition.

II. Analysis

Consider the energy consumption $q(p,t)$ at the energy price p and time t, the price varying also in time. The power demand is

$$s(p,t) = \frac{\partial q(p,t)}{\partial t}$$

and the ramp rate is

$$r(p,t) = \frac{\partial s(p,t)}{\partial t} = \frac{\partial^2 q(p,t)}{\partial t^2}.$$

We know the energy demand elasticity is

$$\eta_q(p,t) = \frac{p}{q(p,t)} \frac{\partial q(p,t)}{\partial p}$$

and if we assume that short term energy elasticity (i.e., 1 hour or less) is the constant η_q, then we must have

$$s(p,t) = \frac{p}{\eta_q - 1} \frac{\partial s(p,t)}{\partial p},$$

and thus the power demand elasticity

$$\eta_s = \frac{p}{s(p,t)} \frac{\partial s(p,t)}{\partial p} = \eta_q - 1.$$

By a similar reasoning we find that the ramp demand elasticity is

$$\eta_r = \frac{p}{r(p,t)} \frac{\partial r(p,t)}{\partial p} = \eta_s - 1$$

and we identify a previously unrecognized but potentially important relation between the energy, power and ramp response elasticities with respect to energy price:

$$\boxed{\eta_q = \eta_s + 1 = \eta_r + 2} \qquad (1)$$

We make the following observations based on Eq. (1).

1. *When any one of the ramp, power, or energy demand elasticities is constant in time then they all are constant in time.* Thus it is only necessary to observe one constant elasticity to know them all.
2. *In the limit of absolutely inelastic energy demand, power demand elasticity is unitary.* This result implies that even though energy demand may be nearly inelastic, power and ramp demand can remain highly elastic.

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3. *Ramp demand elasticity is always highly elastic.* This suggests that for ramping DR resources, the supplier of ramp resources never has market power.

III. Discussion

The absence of concurrent energy, power and ramp pricing and DR data to validate Eq. (1) is noted. We believe those with access to field data on DR elasticity should examine their data to confirm whether and under what conditions Eq. (1) holds. In addition, we suggest the following research questions be considered in light of Eq. (1) and the observations made above.

A. Device Control

If a device that demands energy is designed to elicit information from the consumer for the purposes of developing a demand curve, then Eq. (1) implies that it is sufficient to obtain this information only for one of energy, power, or ramp responses and the other demand curves may be computed directly. It is not necessary to design a separate transactive control strategy for the energy, power, and ramp behavior of the device.

In addition, this result suggests that policies to prevent resources from bidding concurrently in energy, capacity and regulation markets may not conform to the underlying dynamics of transactive systems. Devices cannot decouple these behaviors from each other even if they wanted to. This fits well with markets that concurrently clear energy, capacity, and regulation prices and ensures that no device is provided conflicting or inconsistent price signals from the markets.

B. Business Models

Utilities and load aggregators must consider the market power implications of Eq. (1), insofar as they will often have monopoly market power as suppliers of energy DR resource while having monopsony market power as consumers of ramp response resources. We note in particular that because load is likely to supply ramping resources its market power is expected to be as low as it is for energy demand, while power response resources will likely be close to unitary elasticity. This is particularly important as utilities begin to shift revenue away from energy-based tariffs toward tariffs based on products and services that have greater downward substitutability.

However, if a customer is purchasing ramping DR to mitigate the intermittency of their own on-site renewables such as solar photovoltaic (PV) panels, then its market power increases. The presence of large numbers of such PV and DR-enabled consumers can be expected to create a rich and flexible retail market in which resources can be coordinated using only price signals. If the utility business model is based on revenue from trading activity rather than revenue from sales of net energy, capacity scarcity or ramping services, then it is likely to see greater stability in net revenue by becoming a market maker rather than a provider of last resort for these resources.

C. Regulatory Oversight

From the regulatory perspective, the utility as a market maker presents a new challenge. Historically, regulatory bodies have focused on authorizing retail tariffs because the utility is a natural monopoly. If the utility is a market maker who is reimbursed only for the cost of operating the system that enables trading and delivery among market participants, then the regulator now ensures that the utility's market and operation costs are fair and equitable.

However the regulator is now also concerned with whether the market is being manipulated by any of the participants. As a result regulators must work with utilities to determine whether any customer or load aggregator is exerting excessive market power. The methods for this kind of monitoring are well-known from other markets. But we expect that certain particulars will be unique for retail electricity markets, particularly in light of the conditions that gives rise to Eq. (1). This problem is complicated by the tight coupling of energy, power and ramping, as a result of which mitigating the utilities' energy monopoly power may not be sufficient to mitigate their monopsony market power for ramping services or vice-versa.

IV. Conclusions

Transactive energy facilitates integrated economic and technical scheduling, dispatch and control of demand response resources as intermittent renewable energy grows and challenges the economic viability, security and reliability of bulk electricity systems. We have shown that there exists an important and simple relationship between the elasticities of energy demand, capacity demand and ramping resources. Data collection from existing demand response systems is needed to validate this result. But the strong coupling of energy, power, and ramping response elasticities may have important consequences on how we design, deploy and operate demand response controls, on which utility business models are preferred, and on how we adapt our regulatory oversight mechanisms to better monitor transactive energy systems.

References

[1] D. S. Callaway, "Tapping the energy storage potential in electric loads to deliver load following and regulation, with application to wind energy," Energy Conversion and Management, vol. 50, no. 5, pp. 1389–1400, 2009.

[2] K. Subbarao, J. C. Fuller, K. Kalsi, A. Somani, R. G. Pratt, S. E. Widergren, and D. P. Chassin, "Transactive control and coordination of distributed assets for ancillary services," Tech. Rep. 22942, Pacific Northwest National Laboratory Richland, Washington (USA), 2013.

[3] Y. Chen and M. Hu, "Balancing collective and individual interests in transactive energy management of interconnected micro-grid clusters," Energy, vol. 109, pp. 1075–1085, 2016.

[4] D. P. Chassin, J. Stoustrup, P. Agathoklis, and N. Djilali, "A new thermostat for real-time price demand response: Cost, comfort and energy impacts of discrete-time control without deadband," Applied Energy, vol. 155, pp. 816 – 825, 2015.

[5] W. Hogan, "Time of use rates and real-time prices." Online at http://www.hks.harvard.edu/fs/whogan/Hogan_TOU_RTP_Newark_082314.pdf, August 23 2014. Retrieved 10-Nov-2016.