Electricity market: Demand Response and price optimization

One of the main research objectives in Demand Response (DR) is the design and implementation of technologies and mechanisms to lower the electricity consumption via energy efficiency measures, and to improve the electricity consumption via demand shifting. Increasing energy efficiency requires a reduction of energy demand peaks by shifting part of the energy consumption in off-peak hours. This can be done via DR mechanisms and load control.

Demand shifting can provide a number of advantages to the energy system [1]:

- Load management can improve system security by allowing a demand reduction in emergency situations.
- In periods of peak loads even a limited reduction in demand can lead to significant reductions in electricity prices on the market.
- If users receive information about prices, energy consumption becomes more closely related to the energy cost, thus increasing market efficiency: the demand is moved from periods of high load (typically associated with high prices) to periods of low load.
- Load management can limit the need for expensive and polluting power generators, leading to better environmental conditions.

Potential benefits and implementation schemes for DR mechanisms are well documented in literature. DR programs can be defined as methods to induce deviations from the usual consumption pattern in response to stimuli, such as dynamic prices, incentives for load reductions, tax exemptions, or subsidies. They can be divided in two main groups: price-based and incentive-based mechanisms [2], [3] and [4].

- Price-based demand response is related to the changes in energy consumption by customers in response to the variations in their purchase prices. This group includes DR mechanisms like Time-of-Use (ToU) pricing, Real Time Pricing (RTP) and Critical-Peak Pricing (CPP) rates. If the price varies significantly, customers can respond to the price structure with changes in their pattern of energy use. They can reduce their energy costs by adjusting the time of the energy usage by increasing consumption in periods of lower prices and reducing consumption when prices are higher. ToU mechanisms define different prices for electricity usage during different periods: the tariffs reflect the average cost of generating and delivering power during those periods. For RTP the price of electricity is defined for shorter periods of time, usually 1 h, again reflecting the changes in the wholesale price of electricity. In RTP customers usually have the information about prices. CPP is a hybrid ToU RTP program. This mechanisms is based on the real time cost of energy in peak price periods, and has various methods of implementation.
- Incentive-based demand response consists in programs with fixed or time varying incentives for customers in addition to their electricity tariffs. Incentive-Based programs (IB) include Direct Load Control (DLC), Interruptible/Curtailable service (I/C), Emergency Demand Response program (EDR), Capacity market Program (CAP), Demand Bidding (DB) and Ancillary Service (A/S) programs. Classical IB programs include DLC and I/C programs. Market-Based IB programs include EDR, DB, CAP, and the A/S programs. In classical IBP, customers receive participation payments (e.g. discount rate) for their participation in the programs. In Market-Based programs, participants receive money for the amount of their load reduction during critical conditions. In I/C programs, participants are asked to reduce their load to fixed values and participants who do not respond can pay penalties based on the program conditions. DB are programs in which consumers are encouraged to change their energy consumption pattern and decline their peak load in return for financial rewards and to avoid penalties. In EDR programs, customers are paid incentives for load reductions duringemergency conditions.

Demand Response mechanisms and load control in the electricity market represent an important area of research at international level, and the market liberalization is opening new perspectives. This calls for the development of methodologies and tools that energy providers can use to define specific business models and pricing schemes.

Every actor in the electricity market has different objectives. For example, retailers and generators aim to maximize their own profit by reducing their costs. In contrast, customers would like their electricity bills as low as possible[5]. Game theoretical methods can also be used to capture the conflicting economic interests of the retailer and their consumers. Authors in [15] propose optimization models for the maximization of the expected market profits for the retailer and the minimization of the electricity cost for the consumer.

One implementation approach of DR mechanisms in the electricity market consists in defining economically and environmentally sustainable energy pricing schemes. In this field, optimization approaches to define dynamic prices have been proposed, and they focus on the definition of day-ahead prices for a period of 24 hours and for a single customer (or a single group of homogeneous customers). In [10], the response of a non-linear mathematical model is analyzed for the calculation of the optimal prices for electricity assuming default customers under different scenarios over a 24h period. [10] defines a model of an electric energy service provider in the environment of the deregulated electricity market. This problem studies the impact on the profits of several factors, such as the price strategy, the discount on tariffs and the elasticity of customer demand functions always over a 24h period.

Consumers may decide to modify their load profile to reduce their electricity costs. For this reason, it is important to analyze the effect that the market structure has on the elasticity demand for electricity. [6] proposes an elastic model to characterize the demand-response behavior and load management with ToU programs and it describes how the consumers behavior can be modeled using a matrix of self and cross-elasticities. [7] and [8] take into account also other schemes, and rely on the elastic model proposed in [6] to model the demand-response behavior. [9] assesses the impacts of ToU tariffs on a dataset of residential users in terms of changes in electricity demand, price savings, peak load shifting and peak electricity demand at sub-station level.

Response of the customers to the DR programs affects the daily load curve. Therefore, the Load Duration Curve (LDC) changes due to the responsiveness of the customers over a year and even the participation of the customers in DR programs can have considerable effects on the LDC [11]: the effects of DR need to be investigated over the daily time horizon. [1] has adapted elasticity model mentioned above to ToU based prices and considered scenarios over a 24h period to better identify trends and assess how the characteristics of the market and the customers affect the consumption annual profiles.

Consumption and cost awareness has an important role for the effectiveness of demand response schemes for pricing optimization. [12] describes a system architecture for monitoring the electricity consumption and displaying consumption profiles to increase awareness. [13, 14] study how customers respond to price changes, and which price indicators are more relevant on this respect.

References

[1] A. De Filippo, M. Lombardi, and M. Milano, Non-linear Optimization of Business Models in the Electricity Market. Springer International Publishing, 2016.

[2] M. Albadi and E. El-Saadany, “Demand response in electricity markets: An overview,” in In Proceedings of IEEE power engineering society general meeting, 2007, pp. 1–5.[3] M. Albadi and E. El-Saadany, “A summary of demand response in electricity markets,” Electric power systems research, vol. 78, no. 11, pp. 1989–1996, 2008.

[4] P. Palensky and D. Dietrich, “Demand side management: Demand response,” Intelligent Energy Systems, and Smart Loads, vol. 7, no. 3, pp. 381–388, 2011.

[5] J.S. Vardakas, N. Zorba, and C.V. Verikoukis, “ A Survey on Demand Response Programs in Smart Grids: Pricing Methods and Optimization Algorithms”, IEEE Communication Surveys & Tutorials, Vol. 17, no. 1, 2015.

[6] D. Kirschen, G. Strbac, P. Cumperayot, and D. de Paiva Mendes, “Factoring the elasticity of demand in electricity prices,” Power Systems, IEEE Transactions on, vol. 15, no. 2, pp. 612–617, May 2000.

[7] H. Aalami, M. Moghaddam, and G. Yousefi, “Demand response modeling considering interruptible/curtailable loads and capacity market programs,” Applied Energy, vol. 87, no. 1, pp. 243–250, 2010.

[8] H. Aalami, M. Moghaddam, and G. Yousefi, “Modeling and prioritizing demand response programs in power markets,” Electric Power Systems Research, vol. 80, no. 4, pp. 426–435, 2010.

[9] J. Torriti, “Price-based demand side management: Assessing the impacts of time-of-use tariffs on residential electricity demand and peak shifting in northern italy,” Energy, vol. 44, no. 1, pp. 576 – 583, 2012.

[10] J. Yusta, I. Ramrez-Rosado, J. Dominguez-Navarro, and J. Perez-Vidal, “Optimal electricity price calculation model for retailers in a deregulated market,” International Journal of Electrical Power & Energy Systems, vol. 27, no. 56, pp. 437 – 447, 2005.

[11] M. Samadi, M. H. Javidi, and M. S. Ghazizadeh, “The effect of time-based demand response program on ldc and reliability of power system,” in Electrical Engineering (ICEE), 2013 21st Iranian Conference on, May 2013, pp. 1–6.

[12] R. Tanaka, M. Schmidt, C. Ahlund, and Y. Takamatsu. An energy awareness study in a smart city lessons learned. In In Proc. of Intelligent Sensors, Sensor Networks and Information Processing (ISSNIP), 2014 IEEE Ninth International Conference on, pages 1–4. IEEE, 2014.

[13] I. Koichiro. Do consumers respond to marginal or average price? evidence from nonlinear electricity pricing. American Economic Review, 104(2):537—563, 2014.

[14] S. Borenstein. To what electricity price do consumers respond? residential demand elasticity under increasing-block pricing. Preliminary Draft April, 30, 2009.

[15] M. Zugno, J. M. Morales, P. Pinson, and H. Madsen, “A bilevel model for electricity retailers participation in a demand response market environment,” Energy Econ., vol. 36, pp. 182–197, Mar. 2013.

Contributors:

Prof. Allegra De Filippo, Dr. Michele Lombardi and Prof. Michela Milano, University of Bologna