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Role of residential demand response in modern electricity markets

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ABSTRACT

Electricity generation must match the demand at each instant, following seasonal patterns and instantaneous fluctuations. Thus, one of the biggest drivers of costs and capacity requirements is the electricity demand that occurs during peak periods.

This paper reviews market-related problems of modern electric grids and possible solutions to address them. In particular, one techno-economical solution, namely residential demand response programs enabled by a smart grid, is analyzed and modeled in detail. The implications of this solution from both economic and policy perspectives are discussed.

The analysis results in several insights: first a local optimum does not generally lead to a global optimum, especially for complex markets; second, in this approach, there exists a disconnection between the locus of the problem (electric utilities) and the locus of the solution (change of demand); third, any techno-economic solution must be carefully designed and global impact should be evaluated to ensure that the final objective is achieved; and fourth, two-way communication is an essential requirement for the successful deployment of smart grids.

Contents

1. Introduction

Electricity is an instantaneous commodity that is expensive to store. Therefore, currently electricity generation must match the demand at each instant, responding to seasonal patterns and instantaneous fluctuations. Thus, one of the biggest drivers of costs and capacity requirement is the electricity demand that occurs during peak periods, particularly during the hours between 5 p.m. and 7 p.m. – when residents return home and prepare meals – and during excessively hot and cold days. These peak periods require utility companies to maintain operational capacity to meet such a high demand. This requisite peak capacity is often outdated, expensive, and underutilized. For example, the International Energy agency has estimated that a 5% lowering of demand would have resulted in a 50% price reduction during the peak hours of the California electricity crisis in 2000/2001 [1].

Electric utilities are extremely interested in finding a stable and sustainable solution to this sort of a problem, especially with expected widespread adoption of non-dispatchable[1] renewable power generation. Recently, smart grid technologies and demand

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[1] A term for an energy system that cannot be expected to provide a continuous output to furnish power on demand, because production cannot be correlated to load. The Energy Library: http://www.theenergylibrary.com/node/4041.

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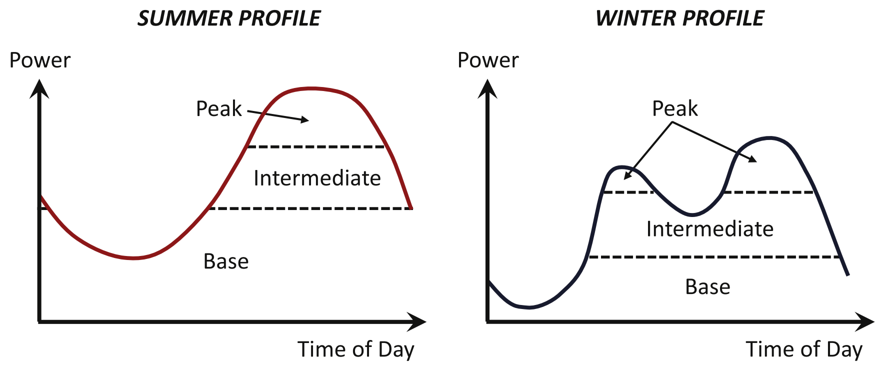

Fig. 1. Typical daily load power profile.

response programs have been proposed as a technical solution to make demand more flexible and able to adapt to power generation. Aghaei and Alizadeh present a review of challenges and opportunities for demand response programs in smart electricity grids equipped with renewable energy sources [2].

The current electrical power system is mostly mechanical, with little use of electronic sensors and control technologies. A smart grid, so-called because of the widespread use of sensors, communication technologies, computational abilities, and control systems, promises more efficient electricity generation, distribution, and consumption [3]. The smart grid requires the integration of various control and communication technologies that allow for continuous monitoring and real-time responses to demand variations and other conditions (e.g. weather changes, transmission or generation issues, etc.) [4]. For residential consumers, smart grid technologies might consist of the adoption of smart appliances and real-time demand monitoring and controlling [5]. However, currently, the rollout of smart grid technologies in the residential sector has focused on the replacement of old meters with smart meters. This allows for variable electricity pricing and the use of smart appliances.

A smart meter is an energy meter that is equipped with advanced electronics that can communicate with the energy provider and provide information about the consumer's energy use [6]. A smart appliance is one that is able to respond to external signals without direct action by the consumer [7]. In other words, the smart appliance responds to the signal sent to the smart meter automatically and independently. Smart appliances can be integrated into a network that automatically manages, monitors, and adjusts consumption in response to needs of the consumer, the availability of electricity supply, and signals from the electric utilities (i.e. the cost of energy) [8]. Optimal management of the whole system requires two-way communication between the smart appliances and the centralized controller of the electricity supplier in order to coordinate the needs of individual consumers and the needs of electric utilities. Alternatively, smart appliances can simply respond to external pricing signals, without communicating back their operating response to those signals nor communicate with each other. This requires only a one-way communication from the utility regarding the price of electricity.

Foundational to the implementation of the smart grid are demand response (DR) programs, which offer different incentives and benefits to consumers in response to their flexibility in the timing of their energy consumption in order to increase to overall efficiency of the system. These programs are needed in order to entice consumers to relinquish some control over their energy consumption. This paper focuses on the economic and policy impact of residential price-based demand response programs, focusing on time-of-use rates (TOU). A case study is simulated based on energy demand modeling [9,10] and distributed energy management [11] to simulate the effect of widespread adoption of tiered electricity pricing.

The paper is structured as follows: Section 2 introduces and analyzes the topic of the electricity market. Section 3 reviews the current literature on the topic. Section 4 presents a case study illustrating the result of the implementation of a one-way communication demand response program in the United States. Concluding remarks are offered in Section 5.

2. Definition of the problem: A distorted market

Fig. 1 reports typical summer and winter electricity demand curves for the PJM[2] region—showing base, intermediate, and peak load. Such curves might vary depending on geographical location and country, but the daily and seasonal variation in the demand remains a common issue for electric power generation around the globe.

To insure the stable operation of the electric system, and to ensure the security of supply in the face of uncertainty of available generation and variations in demand, the total generation capacity available to the system must often be significantly larger than the maximum demand, exacerbating the problem. A safety factor of 20% of excess capacity is reported in the literature [12], but in several regions of the United States this figure reached 40% in summer 2013, as reported by the U.S. Energy Information Administration [13].

In order to satisfy such a fluctuating demand, electric utilities are forced to maintain different generation assets [14]. Base-load electricity is provided by extremely reliable, inexpensive, and efficient power plants, which run continuously during the year (over 70% of the time), except in the case of repairs or scheduled maintenance. Such plants – including nuclear, hydroelectric, geothermal, and coal power plants – often take a long time to start up and are designed to work at their nominal capacity with a small degree of flexibility.

Intermediate power plants are operated between 20% and 70% of the time, with the objective of following the fluctuations of the load, curtailing their output in periods of low demand, such as during the night. These plants are typically coal- or gas-fired, including high-efficiency gas turbine combined cycles. Wind and solar power plants are typically considered intermediate power plants [14], since their operations are limited by the availability of the renewable sources exploited. Even though they are run as much as possible they do not achieve base-load availability, and they are hardly used to match peak demand, as they cannot be

[2] PJM is a regional transmission organization that coordinates the movement of wholesale electricity in all or parts of 13 states and the District of Columbia.