Consumers' Price Elasticity of Demand Modeling With Economic Effects on Electricity Markets Using an Agent-Based Model

Prakash R. Thimmapuram and Jinho Kim

***Abstract*—Automated Metering Infrastructure (AMI) is a technology that would allow consumers to exhibit price elasticity of demand under smart-grid environments. The market power of the generation and transmission companies can be mitigated when consumers respond to price signals. Such responses by consumers can also result in reductions in price spikes, consumer energy bills, and emissions of greenhouse gases and other pollutants. In this paper, we use the Electricity Market Complex Adaptive System (EMCAS), an agent-based model that simulates restructured electricity markets, to explore the impact of consumers' price elasticity of demand on the performance of the electricity market. An 11-node test network with eight generation companies and five aggregated consumers is simulated for a period of one month. Results are provided and discussed for a case study based on the Korean power system.**

***Index Terms*—Agent-based modeling, automated metering infrastructure, price elasticity of demand, smart grid.**

I. Introduction

IN deregulated electricity markets, market power and/or imbalances in the supply and demand associated with the marginal cost of the last unit dispatched have resulted in large fluctuations in wholesale electricity prices. In many of the existing electricity markets, only generation companies (GenCos) can respond to the price signals through supply-side offers to the independent system and/or market operator (ISO). The majority of consumers in deregulated markets have contracts with load aggregators or load-serving entities who, in turn, submit demand bids to the market operator. If the contract is a pass-through contract (i.e., the load aggregator charges the market price with some fixed profit margin), there is no incentive for the load aggregator to provide a mechanism for consumers to respond to prices. On the other hand, if it is a fixed price contract, consumers do not see the market prices and will not respond to price signals.

Moreover, because most consumers do not have access to hourly or daily electricity price information, their responses to price changes may lag behind. One potential consumer response, reducing consumption, occurs when consumers receive their monthly electricity bills. Another potential response, switching suppliers, usually occurs on an approximately monthly or annual basis, depending on the terms and conditions of supply contracts.

There has been considerable research on consumer response to electricity prices [1]. In addition, efforts have been undertaken recently to model and simulate the price elasticity in electricity markets [2], [3]. Such studies have shown that reductions in electricity consumption in response to prices, particularly by residential customers, are relatively inelastic in the short term; even high price increases produce fairly small changes in electricity usage. Large consumers, on the other hand, are relatively price sensitive.

Recently, AMI and smart grid have become widely accepted as promising technologies to provide increased awareness of electricity usage and cost to consumers. As a result, those technologies could enable consumers to overcome the technical and market barriers to participating in electricity markets through improved price elasticity.

In this paper, we have set up a model for exploring consumers' price elasticity of demand (via demand-side bidding) using EMCAS, an agent-based model that simulates the deregulated markets.

The remainder of this paper is organized as follows: Section II presents demand-side response modeling with price elasticity. Section III describes the experimental investigation and provides results and discussion. Section IV offers a real-world case study based on Korean electricity markets. Section V presents our conclusions.

II. Demand-Side Response Modeling With Price Elasticity

In economics literature, price elasticity (ε) is defined as the percentage change in demand or load (L) resulting from a percent change in price (P). For infinitely small changes in price, this can be expressed mathematically as:

$$\varepsilon = \frac{\delta L/L}{\delta P/P} = \frac{\delta L}{\delta P} \cdot \frac{P}{L} \tag{1}$$

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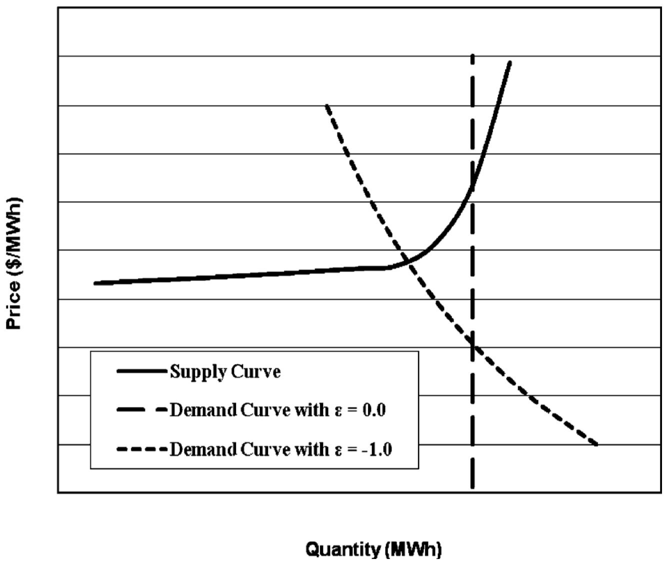

Fig. 1. Typical demand and supply curves.

TABLE I
ESTIMATES OF ELECTRICITY PRICE ELASTICITY

	Price Elasticity	
	Short-Run	Long-Run
Residential	-0.06 to -0.49	-0.45 to -1.89
Commercial	-0.17 to -0.25	-1.00 to -1.60
Industrial	-0.04 to -0.22	-0.51 to -1.82

where ε is the consumer's price elasticity of demand, δL is the consumer's change in load, δP is the price change, P is the forecasted energy price ($/MWh), and L is the consumer's base load (MWh).

The equation indicates that: a) a price elasticity of -1.0 means that a 1 percent increase in price will result in a 1 percent decrease in load, b) that zero price elasticity means that the consumers are insensitive to the price of electricity and that the load is unaffected by the price. In the latter case, the demand curve is a vertical line, as shown in Fig. 1. However, in electricity markets, the supply curve is more like a hockey stick, in which prices increase moderately for most of the supply curve except at the end, where prices increase dramatically with a steep slope. The demand responsiveness provides the greatest benefit in this region [4].

A. Estimates of Price Elasticity of Demand for Electricity

In general, measuring price elasticity is a complex task, and estimated elasticity coefficients usually have a wide range of uncertainty attached to them. It is common to differentiate between short- and long-run elasticity. Short-run elasticity describes the price-response from the system with its current infrastructure and equipment; long-run elasticity takes into account the investments that can be made (e.g., in energy conservation or alternative energy supply) in response to higher prices.

Table I lists examples of ranges of estimates for short- and long-run elasticity based on several studies [4]–[6]. However, because the studies were carried out in regulated systems, they might have limited validity for restructured markets. In general, one would expect the price elasticity of demand to increase with implementation of AMI and smart grid.

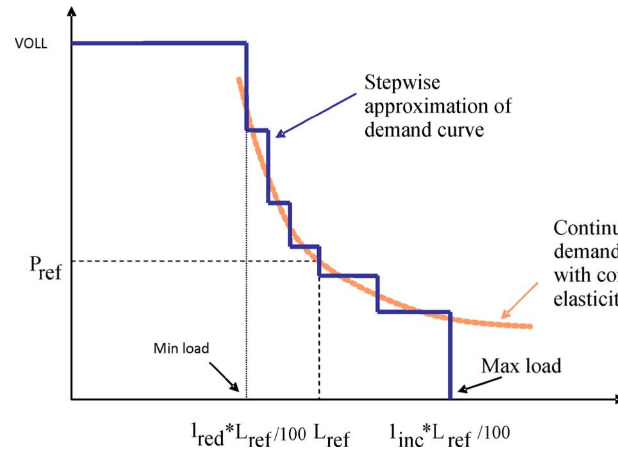

Fig. 2. Price elastic demand modeling.

B. Demand-Side Bidding and Market Clearing in the Day-Ahead Market

In the agent-based EMCAS model, consumers submit their demand to load aggregators who, in turn, submit the day-ahead hourly demand bid to the ISO. Similarly, the GenCos submit their day-ahead hourly offers to the ISO. The ISO runs the optimal load dispatch, optimal power flow, considering the transmission network, and determines the hourly locational marginal prices (LMPs) for every hour and for each bus in the system [7]. (The agent-based modeling framework is described in detail elsewhere [8], [9].) EMCAS offers an option to allow consumers/load aggregators to submit either inelastic or elastic demand bids. The shape of the demand curve that is bid into the day-ahead market is modeled by adjusting the following parameters for each individual consumer:

P_{ref}	Reference price
l_{red}	Limit for load reduction (percentage)
l_{inc}	Limit for load increase (percentage)
N_{red}	Number of steps on demand curve for load reduction
N_{inc}	Number of steps on demand curve for load increase

Fig. 2 shows a typical demand curve. The reference price, P_{ref}, is user input and is fixed for all hours, whereas L_{ref} is equal to the hourly loads and therefore changes from hour to hour. The minimum and maximum loads are determined by the parameters for the lower and upper limits.

If the price elasticity is constant for the entire demand curve, then (1) can be written as:

$$L = a \cdot P^{\varepsilon} \tag{2}$$

where a and ε (the elasticity) are constants, ε is a user input, and a can easily be calculated for each hour from L_{ref} and P_{ref}. Equation (2) is used to represent the demand-side bidding in the model. However, the continuous curve in Fig. 2 cannot be bid directly into the market; a stepwise approximation is necessary to calculate the market clearing as a linear programming (LP)