Energy 36 (2011) 5374–5384

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Demand response in electrical energy supply: An optimal real time pricing approach

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ARTICLE INFO

Article history:
Received 29 September 2010
Received in revised form
17 June 2011
Accepted 20 June 2011
Available online 27 July 2011

Keywords:
Demand response
Distribution network
Electricity markets
Load management
Real time pricing
Simulation

ABSTRACT

In competitive electricity markets with deep concerns for the efficiency level, demand response programs gain considerable significance. As demand response levels have decreased after the introduction of competition in the power industry, new approaches are required to take full advantage of demand response opportunities.

This paper presents DemSi, a demand response simulator that allows studying demand response actions and schemes in distribution networks. It undertakes the technical validation of the solution using realistic network simulation based on PSCAD. The use of DemSi by a retailer in a situation of energy shortage, is presented. Load reduction is obtained using a consumer based price elasticity approach supported by real time pricing. Non-linear programming is used to maximize the retailer's profit, determining the optimal solution for each envisaged load reduction. The solution determines the price variations considering two different approaches, price variations determined for each individual consumer or for each consumer type, allowing to prove that the approach used does not significantly influence the retailer's profit.

The paper presents a case study in a 33 bus distribution network with 5 distinct consumer types. The obtained results and conclusions show the adequacy of the used methodology and its importance for supporting retailers' decision making.

1. Introduction

The concept of Electricity Markets (EMs) appeared in the most developed countries as a consequence of power system deregulation and power sector restructuring [1]. Traditionally, the entities involved in power systems have determined tasks and are remunerated according to defined regulations. EMs involve a large number of players that are expected to act in a competitive environment, taking advantage of the adequate opportunities and strategies to accomplish their individual goals. Moreover, the whole power system should be able to attain global requirements, guaranteeing demand satisfaction within accepted reliability levels.

The implementation of EMs was expected to lead to relevant advantages concerning the increase in power system efficiency and price reduction due to the end of monopolies [1]. However, the experience has proved that some problems can occur [2–4], due to the very specific electrical energy characteristics which make some rules and methods usually used in other commodities markets not useful in the EMs context. This is mainly due to the unique characteristic of electrical energy that is a commodity, for which the balance between supply and demand must be assured at all moments. Moreover, electrical energy can only be stored in very limited quantities, because of technical and economic reasons.

One of the areas expected to grow in the scope of EMs is the Demand Response (DR), as it appears as a very promising opportunity for consumers and brings several advantages for the whole system [5,6]. This is due to the fact that power systems' infrastructure is highly capital-intensive and DR is one of the cheaper resources available to operate the system [7]. On the other hand, DR programs can provide the system operator with a determined load curtailment capacity which is highly valuable to deal with unexpected changes in both supply and demand levels.

The actual state of DR around the world has been summarized in [8]. Experiences of DR in the wholesale market are taking place in the United States [9], Europe [10], China [11] and also in other places around the world [2]. Some difficulties in the transition from a traditionally regulated industry to a competitive environment can be justified by the lack of retail demand response. However, it is accepted that time-dependent pricing (e.g. RTP) can benefit the sector's operation and investment [8].

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doi:10.1016/j.energy.2011.06.049

DR is not being as successful as expected in the context of competitive markets. In some cases, the EM implementation caused a reduction in demand participation [7], [12–15]. In the United States load management (LM) decreased 32% between 1996 and 2006 because of weak load management services offered by utilities [12]. This can be explained by the 10% reduction of the money spent in LM programs since 1990. Between 1996 and 2004, 32% of utilities stopped providing LM programs.

Demand Side (DS) has been unable to use all the business opportunities in the scope of EMs in a satisfactory way. This participation difficulty is verified for large DS players and also obviously applies to small DS players. Aggregation is being more and more used, therefore, the EM players can join their resources and efforts to obtain competitive advantage [14] in EM. However DR has very specific needs that even large aggregators face serious difficulties in dealing with.

In response to this, grid operators and utilities are taking new initiatives, recognizing the value of DR for grid reliability and for the enhancement of organized spot markets' efficiency [16]. However, the current state of the art does not answer the pointed problems and does not show any sign of finding the correct path so that the required solutions are obtained in a short time period. As the efforts that have been put in DR issues are very relevant, the poor results evidence the need to use a different approach to address DR issues [17].

This paper presents a work that contributes to such an approach which is centered in DemSi, a DR simulator developed by the authors. DemSi constitutes a platform to support decision making concerning DR in the scope of distribution networks, including technical validation of the solutions.

The paper also presents the use of DemSi by a retailer, to address a situation of energy shortage due to an incident in the network. Strategic load curtailment is obtained using real time pricing, fixing the price variations for each consumer or consumer type so as to maximize retailer's profit.

After this introduction, Section 2 presents the most important concepts related to demand response, shows the importance of demand response in the context of electricity markets, and explains the recent DR experiences. Section 3 describes the Demand Response Simulator (DemSi), with special focus on practical application in the presented case study. Section 4 presents a case study concerning the procurement of a load reduction by the retailer. Finally, Section 5 presents the most important conclusions of the presented work.

2. Demand response concepts and programs

The management of consumers' behavior or the actions that result from this management are usually referred as demand response, load management and Demand Side Management (DSM). Traditionally this is done in the context of utility load management programs, during the periods of higher demand [18], essentially with the objective of peak shaving.

DR includes all intentional electricity consumption pattern modifications by end-use customers and the incentive payments that are intended to change the timing, level of instantaneous demand, or total electricity consumption [19]. These incentives are mainly used at times of high wholesale market prices or when system reliability is jeopardized [12].

The way that electric energy is bought and sold is being changed by new business opportunities created by electricity markets. These opportunities include consumer participation which can directly influence market results [14,15,20] and can be defined over longer or shorter periods either in the context of capacity markets or directly through bilateral contracts.

2.1. Price elasticity

Price elasticity rate is a measure used in economics to evaluate a good or service demand response to a change in its price, i.e. percentage change in the demanded quantity on response to one percent change in price [21]. The formula for the price elasticity of demand is expressed in (1), where *Quantity* is the quantity of the usage of the good or service and *Price* is the price of this good or service [22].

$$\varepsilon = \frac{\Delta \text{Quantity}/\text{Quantity}}{\Delta \text{Price}/\text{Price}} \tag{1}$$

In the case of electricity consumption, this is a measure of the intensity on how the usage of electricity changes when its price changes by one percent.

There are two types of price elasticity of demand, namely own-price elasticity and substitution elasticity. Own-price elasticity measures how customers will change the consumption due to changes in the electricity price, regardless to the period of variation. This rate is expected to be negative since a price increase should cause a reduction on load. Substitution elasticity is related to the time shifting the electricity consumption of electricity within a certain period (e.g. a day or a week).

A DR approach using the price elasticity has been presented in [7]. This work uses an optimal power flow for economic dispatch including load forecast. The market prices for each period of the next day are calculated considering the price elasticity, and a new load forecast is obtained. With the new load forecast, market prices are updated to verify the positive influence of demand response in market prices. The effectiveness of DR programs in case of system contingency is demonstrated.

In [23], price elasticity has been used to fix the demand participation in several DR programs. These programs are ordered in function of the priority from the point of view of the ISO, utility, customer, and regulator. Weights are associated to operation criteria and adjusted for each type of player. It had been referred that the presented algorithm can be used as a toolbox to overcome market operation problems.

Generally, studies considering the concept of price elasticity of demand combine market conditions and consumer's flexibility to analyze the benefits of DR whereas the present work uses price elasticity to determine the market signals (energy price) which are necessary for obtaining the desired response level of demand, for example in case of a supply shortage.

2.2. Characteristics of DR programs

Demand response programs can be divided in two wide groups, namely price-based demand response and incentive-based demand response [12].

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 time-of-use (TOU), real time pricing (RTP) and critical-peak pricing (CPP) rates. For different hours or time periods, if the price varies significantly, customers can respond to the price structure with changes in energy use. Their energy bills can be reduced if they adjust the time of the energy usage taking advantages of lower prices in some periods and reducing consumption when prices are higher. Currently, the response to price-based demand response programs by adjusting the time of consumption is entirely voluntary. However, some advantages of mandatory response can be found (see Section 2.3).