Energy xxx (2015) 1–12

Contents lists available at ScienceDirect

Energy

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

Optimal real time cost-benefit based demand response with intermittent resources

N. Zareen [a,*], M.W. Mustafa [a], U. Sultana [a], R. Nadia [a], M.A. Khattak [b]

[a] Faculty of Electrical Engineering, Universiti Teknologi Malaysia (UTM), 81310, Skudai, Johor, Malaysia
[b] Faculty of Mechanical Engineering, Univeristi Teknologi Malaysia (UTM), 81310, Johor, Malaysia

A R T I C L E I N F O

Article history:
Received 3 November 2014
Received in revised form
4 June 2015
Accepted 25 June 2015
Available online xxx

Keywords:
Cost-benefit
Demand response
Elasticity
Game theory
Micro-grid
Renewable energy

A B S T R A C T

Ever-increasing price of conventional energy resources and related environmental concern enforced to explore alternative energy sources. Inherent uncertainty of power generation and demand being strongly influenced by the electricity market has posed severe challenges for DRPs (Demand Response Programs). Definitely, the success of such uncertain energy systems under new market structures is critically decided by the advancement of innovative technical and financial tools. Recent exponential growth of DG (distributed generations) demanded both the grid reliability and financial cost–benefits analysis for deregulated electricity market stakeholders. Based on the SGT (signaling game theory), the paper presents a novel user-aware demand-management approach where the price are colligated with grid condition uncertainties to manage the peak residential loads. The degree of information disturbances are considered as a key factor for evaluating electricity bidding mechanisms in the presence of independent multi-generation resources and price-elastic demand. A correlation between the cost–benefit price and variable reliability of grid is established under uncertain generation and demand conditions. Impacts of the strategies on load shape, benefit of customers and the reduction of energy consumption are inspected and compared with Time-of-Used based DRPs. Simulation results show that the proposed DRP can significantly reduce or even eliminate peak-hour energy consumption, leading to a substantial raise of revenues with 18% increase in the load reduction and a considerable improvement in system reliability is evidenced.

1. Introduction

In the new competitive electric power generation regime the usage of RERs (renewable energy resources) has gained considerable attention due to its economical and environmentally safer attributes over conventional counterparts [1]. Typically, the distribution network of an electric grid is comprised of small RER, different storage devices and end users connected via electric lines to each other called MGN (Micro Grid Network). It is acknowledged that MGN in the presence of RER is capable of improving the usage of energy, reduction of losses, and providing superior reliability. Despite their environmental friendly features all of them are not reliable, efficient and cost effective [2]. The limitations associated with the intermittency of generated energy from RERs and their dynamic behavior with time and weather are considered as the major obstacle for reaching a large market penetration. Therefore, determining the critical demand and supply equilibrium in the presence of RER is the key challenge for the successful operation of MGN [3].

Undoubtedly, SG (Smart Grid) approach being equipped with two-way modern communications and control technologies triggered major alterations in paradigm of the electricity market's organization and management. The notion of SG covers a broad applications spectrum ranging from hardware to software. This aids the utilities to identify and fix the imbalances between supply and demand instantaneously. It enables the more efficient management of consumer's electricity usage via different type of DSM (Demand Side Management)/DR (Demand Response) choices. DRPs can improve the reliability of MGN through load reduction, and thus defer the need of grid infrastructure upgradation. There are enormous opportunities for DRPs among residential customers and therefore, they represent a large untapped potential for DRPs [4].

In RTP-DRPs (Real-Time Pricing based Demand Response Programs), each residential customer responds individually to

* Corresponding author. Tel.: +60 7 5557011; fax: +60 7 556 6272.
E-mail address: naila.zareen@fkegraduate.utm.my (N. Zareen).

http://dx.doi.org/10.1016/j.energy.2015.06.126
0360-5442/

Nomenclature

r^k	reliability of the IMGN at time k
P^k_{CB}	cost-benefit price at time k
P^k_R	electricity Price at time k given by RA
β	maximum Customer's gain of profit in the bidding
γ	maximum Customer's loss in the bidding
δ^k	Bargain probability
PF^k_R	RA's profit expectation at time k
PF^k_D	DA's profit expectation at time k
$P(r^k \| P^k_{CB})$	estimation probability
C_1	restriction curve of market grid operation
C_2	optimal curve of market grid operation
P^k_{ini}	initial price
$E(k,k)$	price oriented Demand Elasticity
D^k_f	final demand
∂D^k_f	change in demand at time k
∂P^k_f	change in price
λ^k_Δ	total incentive gain
$F^k_{RCB-DRP}$	financial gain at time k
$\phi^k_{RCB-DRP}$	DA's net outcome
ν	percentage participation of customers in RCB-DRP
τ	speed of wind in meter/s
$\overline{\tau}$	mean wind speed
P^w_{avg}	wind power output average
τ_{c-i}	cut-in wind speeds
τ_N	cut-out wind speeds

Abbreviation

DA	Demand Agent
RA	Resource Agent
IMGN	Independent Micro Grid Network
IMGNO	Independent Micro Grid Network operator
SGT	Signaling Game Theory
DRP	Demand Response Program
RCB	Reliability-Cost-Benefit
SG	Smart Grid
DSM	Demand Side Management
IMGNC	Independent Micro Grid Network Controller
DR	Demand Response
RTP-DRPs	Real-Time Pricing based Demand Response Program

time dependent prices by shedding non-essential loads during peak price times and/or shifting energy consumption to low-price times. Recent researches have shown that despite several advantages that RTP-DRPs can offer, the lack of knowledge among the residential customers about how to respond to time-varying prices and the lack of effective estimation tools for their participation profitability are major barriers for fully utilizing the benefits of real-time pricing [5]. In fact, most of the recent residential load management activities are manually operated. This makes it difficult for residential customers to modify their demand (or offer their own generation resources e.g. EVs) accordingly to earn profit. Therefore, they usually do not effectively participate in trade of electricity markets, and tends to the failure of RTP-DRPs. Moreover; the reaction of residential customers to dynamic prices creates a feedback system that motivates the utility companies to model the customers' behavior in the process of determining the real-time prices. Implementing dynamic elasticity pricing faces many challenges due to the related information disturbances caused by intermittent generations and load responsiveness. The most difficult step is how to predict people's reaction to various dynamic energy prices, which calls for accurate behavioral models and practical algorithms.

In the past, numerous market oriented approaches for DRPs based upon producer-centric-ideas are introduced [6–16]. Most of the proposed solutions intend to collect consumer's data and process them for market regulation and planning. A blend of load shedding and control-based proposals towards the optimal management of DRPs is extensively studies. However, the highest contributors of uncertainty and variability with the different penetration level of RERs are not achieved yet in these approaches. In Refs. [17,18], a dynamic DR and DG (distributed generations) management approach is proposed in the context of smart micro-grid for a residential community. The DG management coordinates with DR and considers stochastic elements, such as stochastic load and wind power, to reduce overall energy consumption cost. In Refs. [19,20], a residential energy consumption scheduling framework is proposed, which attempts to achieve a desired trade-off between minimizing the electricity payment and the operation of household appliance in presence of real-time prices.

Hitherto, various game theoretic frameworks have also been utilized to investigate the DRPs in the literature. Mohsenian-Rad et al. [17] proposed an energy consumption scheduling game in which the consumers seek to minimize the costs of their daily electricity consumption by adjusting their hourly power consumption levels. Najmeh et al. [21] proposed a DRPs approach in which consumers seek to maximize their profit functions, whereas, the utility company seeks to maximize the aggregate profits of consumers. They obtained the optimal electricity pricing scheme aligning the solution of utility's optimization problem with that of consumers' problem. Samadi et al. [22] considered a mechanism design problem in which the utility company aims to maximize the aggregate profit functions of consumers using the knowledge of consumers' type values. Maharjan et al. [23] proposed a Stackelberg game to model the interplay between the utility company and consumers. Chen et al. [24] proposed a demand-supply matching game in which consumers selfishly seek to maximize their individual profits from load curtailment, while they are incentivized for curtailing their loads by the utility company. The authors also proposed a demand shaping game wherein customers are charged based on the spot price of electricity, and each customer seeks to maximize its profit function. In Ref. [25], utility companies, acting as leaders of the game, seek to maximize their revenues by adjusting the electricity prices, where as consumers, as followers of the game, aim to minimize their electricity costs by determining their electricity consumption levels.

In previous researches, DRPs have been mainly investigated from customers-utility point of view. They have focused on either profit maximization for utility companies or cost minimization for customers. But for both utility companies and customers, each of them tends to make its decision based on the reaction of the other [26]. The impact of dynamics of load price-responsiveness of RTP-DRPs in the electricity market has not been thoroughly investigated in the previous researches. Our work aims to bridge this gap among the existing researches. This has motivated us to consider the issue for benefit maximization of residential customers alongside with the revenue maximization for the utility provider with the above mentioned constraints/uncertainties of grid. In this context, a novel optimal decision making methodology is proposed

Please cite this article in press as: Zareen N, et al., Optimal real time cost-benefit based demand response with intermittent resources, Energy (2015), http://dx.doi.org/10.1016/j.energy.2015.06.126