Applied Energy 183 (2016) 552–565

Contents lists available at ScienceDirect

Applied Energy

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

Reliability constrained decision model for energy service provider incorporating demand response programs

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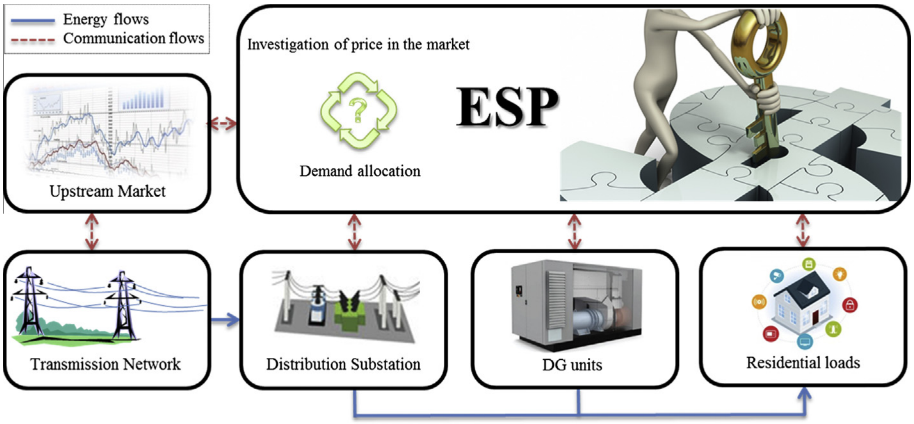
HIGHLIGHTS

- The operation of Energy Service Providers (ESPs) in electricity markets is modeled.
- Demand response as the cost-effective solution is used for energy service provider.
- The market price uncertainty is modeled using the robust optimization technique.
- The reliability of the distribution network is embedded into the framework.
- The simulation results demonstrate the benefits of robust framework for ESPs.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 18 May 2016
Received in revised form 3 September 2016
Accepted 6 September 2016

Keywords:
Energy service provider (ESP)
Demand response (DR)
Day-ahead market
Smart distribution network
Reliability
Robust optimization

ABSTRACT

Demand response (DR) programs are becoming a critical concept for the efficiency of current electric power industries. Therefore, its various capabilities and barriers have to be investigated. In this paper, an effective decision model is presented for the strategic behavior of energy service providers (ESPs) to demonstrate how to participate in the day-ahead electricity market and how to allocate demand in the smart distribution network. Since market price affects DR and vice versa, a new two-step sequential framework is proposed, in which unit commitment problem (UC) is solved to forecast the expected locational marginal prices (LMPs), and successively DR program is applied to optimize the total cost of providing energy for the distribution network customers. This total cost includes the cost of purchased power from the market and distributed generation (DG) units, incentive cost paid to the customers, and compensation cost of power interruptions. To obtain compensation cost, the reliability evaluation of the distribution network is embedded into the framework using some innovative constraints. Furthermore, to consider the unexpected behaviors of the other market participants, the LMP prices are modeled as the uncertainty parameters using the robust optimization technique, which is more practical compared to the conventional stochastic approach. The simulation results demonstrate the significant benefits of the presented framework for the strategic performance of ESPs.

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http://dx.doi.org/10.1016/j.apenergy.2016.09.014

Nomenclature

Indices

d	DG units
b	distribution network buses
f	fault occurrences
g	generator units
r	groups of the restoration load points for each fault occurrence
a	responsive appliances
B_f^{dam}	set of buses which are the damaged points for fault f
$B_{f,r}^{restore}$	set of buses which are the restoration points for fault f, and group r
$D_{f,r}^{restore}$	set of DG units which can supply the restoration load points for fault f, and group r
$g(n)$	set of generator units at node n
$k(n,.)$, $k(.,n)$	set of transmission assets with n as the “to” and “from” node, respectively
t, tt	time (h)
k	transmission elements (line or transformer)
n	transmission node

Parameters

AST_a	acceptable shift time for appliance a
$d_{n,t}$	active power load (APL) at node n and hour t
$PNR_{b,t}$	APL of nonresponsive loads at bus b and hour t
$PR_{a,b,t}$	APL of responsive appliance a, at bus b and hour t
ρ^{inc}	incentive price
DT_g, UT_g	min down/up time of unit g
$PDG_d^{\min}$, $PDG_d^{\max}$	min/max capacity of DG unit d
Γ	number of hours in which the uncertainty of electricity prices is considered
T	number of time periods
$\lambda_f^{failure/T}$	occurrence rate of fault f (failure rate) in the total time periods
PL_b	penetration level of active consumers at bus b
$\rho_{d,t}^{DG}$	power price of DG unit d at hour t
c_g	production cost of unit g
t^{repair}	repair time of distribution faulty elements
c_g^{SD}, c_g^{SU}	shutdown/startup cost of unit g
ρ_b^{ENS}	value of lost load (VOLL) at bus b

Variables

$PD_{b,t}$	APL at bus b and hour t
$PD_{f,b,t}^{fault}$	APL at bus b and hour t during fault f
$PS_{a,b,tt,t}$	APL of appliance a at bus b that is shifted from hour t to hour tt
$PSUB_t$	APL which is fed through the substation bus at hour t
$PDG_{d,t}$	active power of DG unit d at hour t
$P_{g,t}$	active power of unit g at node n and hour t
z_t, y_t	auxiliary variables
$s_{d,t}$	commitment state of DG unit d at hour t
$PC_{f,b,t}$	curtailed APL at bus b and hour t during fault f
Z, ξ_t	dual variables
ENS_b	ENS at bus b
$P_{k,t}$	power flow for transmission element k, at hour t
ρ_t^{grid}	power price of the substation bus at hour t (LMP value at node n^*)
$w_{g,t}$	shutdown binary variable of unit g at hour t (1 for shutdown, 0 otherwise)
$v_{g,t}$	startup binary variable of unit g at hour t (1 for startup, 0 otherwise)
$PS_{b,t}^{tot}$	total APL of bus b that is shifted to hour t

1. Introduction

1.1. Motivation and approach

Demand response (DR), as a key characteristic of the future smart grid, can provide several financial and technical benefits for electric power industries, such as, deferring capital intensive reinforcements [1], alleviating the need to use high-emission high-cost generating units [2], utilizing as ancillary services [3], tempering price spikes in the electricity market, mitigating the potential of market power [4], improving the operation of renewable energies [5,6], and cost saving in the electric bills of customers [7]. Moreover, it can be applied as a tool by energy service providers (ESPs) to manage the volatility of the electricity market prices [8].

In this work, DR is used to enhance the performance of ESPs in the smart distribution network. Proper applying DR problem provides special abilities for these entities, and could lead to more profit. On the other hand, participating in the upstream market and demand allocation in the downstream network are two main tasks of ESPs. These two tasks affect each other, and a simultaneous attention to them is needed for more efficiency.

To better understand, suppose that an ESP wants to reduce its energy purchase cost with applying DR. This entity initially forecast its load consumption, and participates in the electricity market. After market clearing, the values of locational marginal price (LMP) will be determined for the next 24 h. Now, applying DR and moving the load consumption to the less expensive hours will reduce the final purchase cost. However, moving the load consumption changes the LMP values in the substation bus of the distribution network. It is due to the dependencies between the load consumption and the prices. In this condition, the interactions between the load curve and price changes should also be considered. Disregarding the mentioned dependencies will limit DR capabilities.

Furthermore, delivering a high quality power with the least interruption to the customers is another challenge for ESPs, and ignoring this matter can increase the compensation costs. The cost of load shedding is the most important compensation cost which should be considered. DR implementation with changing the load curve can affect the service reliability of the distribution networks. Considering the reliability constraints in optimizing demand allocation can improve network efficiency, increase customer satisfaction, and decrease the final cost of ESPs.

Hence, a new two-step sequential framework is proposed in this paper, to enhance the performance of ESPs in the smart distribution network. The main problem includes a reliability constrained model to optimize the total cost of providing energy for the downstream network using DR. The subsidiary problem includes electricity market modeling. The load curve is determined in the main problem, and the amounts of the energy price under different conditions will be determined in the subsidiary problem, in a recursive manner. Such a framework guides ESPs to analyze how market clearing affects DR and vice versa.

Moreover, since the behaviors of other market participants are not fully predictable, the energy prices in each iteration are modeled as the uncertainty parameters. To this end, a robust approach as a recently gained substantial popularity method is applied. This approach has more advantages in practical applications, with respect to the stochastic methods. Robust model only needs moderate information about the uncertainty parameters, e.g., the range and the mean of the uncertain data (not an exact probability