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Uncertainty-based electricity procurement by retailer using robust optimization approach in the presence of demand response exchange

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ABSTRACT

In this paper, robust optimization approach is proposed to handle market price uncertainty in which the upper deviation from forecasted value of pool price will be considered for risk analysis for a retailer. Objective of this paper is minimization of energy procurement cost for retailer from pool market, forward contracts and demand response programs (DRP). Therefore, three new designs of demand response (DR) programs have been proposed in this study which retailer can use to procure their required energy. These new DR schemes consist of pool-order option, forward-DR and reward-based DR contracts. The robust optimization approach examines the retailer's performance at risk-averse and risk-neutral strategies, in which risk-neutral explains the normal performance of retailer, and risk-averse explains the risky performance of retailer. The proposed robust scheduling of retailer is modeled via MIP model which can be solved using CPLEX solver under GAMS software. The achieved results show that the retailer cost in risk-neutral strategy is reduced due to use of new DR schemes. Also, in risk-averse strategy, retailer cost reduction is more than the risk-neutral strategy use of new DR schemes.

1. Introduction

Before of the creating demand-side management (DSM) plans, retailers can be only procured their energy through the pool market and forward contracts [1]. But, due to the existing uncertainty in the pool market price, this option is difficult to use in the day-ahead market by retailers. In addition, after creating of demand side management (DSM), retailers are able to supply some of their energy using of DR programs [2]. The most important benefits of using DR are to flatten load curves and reduce energy cost in peak hours [3]. Also, DRP is an efficient option for risk and cost reduction for retailer under uncertainty condition.

1.1. Literature review

In [4], a solution is presented to find optimal energy supply for electricity retailers based on binary imperialist competitive algorithm and binary particle swarm optimization. Also, pool market and bilateral contracts are used in [5] to obtain an optimal strategy of electricity retailers to procure their energy in electricity market. In [6], the problems of setting up contracts on the suppliers and end-user side to aim of maximizing the profits of the retailer are reviewed in which the result are presented at an acceptable level of risk. In [7], stochastic programming framework based on risk-constrained is presented to choose forward contracts which retailer should sign in order to maximize their benefits. In order to consider the uncertainties in both electricity prices and loads, Ref. [8] proposed a multistage stochastic optimization approach, which permits the specification of conditional-value-at-risk requirements to optimize hedging across intermediate stages in the planning horizons. Also, in [9] a new stochastic approach is considered to model uncertainty for retailer in order to maximize its total expected rate of return. Researchers in [10], in order to find the optimal sale price of electricity and determine the electricity procurement policy of a retailer, a mixed-integer stochastic programming is presented. In [11], constraint of financial risk associated with the market price uncertainty is considered using of expected downside risk in the mixed-integer stochastic optimization problem. In [12], to determine the sale price of electricity and manage a portfolio of different contracts in order to procure its demand, a decision-making framework is proposed. In [13], from the retailer's viewpoint, a model is provided to set price changes in time-of-use tariffs in order to encourage customers to shift their loads. Ref [14] proposed a bi-level programming approach in order to solve the medium-term decision-making problem of retailer. In this ref, a retailer decides its level of involvement in the futures market and in the pool as well as the selling price offered to its potential clients with the goal of maximizing the expected profit at a

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Nomenclature

Set

t	time period (week)

Parameters

$f_{po}^{pen}(t)$	penalty of not running pool-order DR in time period t (\$/MWh)
$P_{f,b}^{DR,MAX}(t)$	highest demand in block b of forward DR f in time period t (MWh)
$\bar{P}_j^{DR}(t)$	demand in j^{th} step of reward-base DR in time period t (MWh)
$P_{f,b}^{MAX}(t)$	highest demand in block b of forward contract in time period t (MWh)
$P_{po}^{MAX}(t)$	highest demand in pool-order DR in time period t (MWh)
$P^{req}(t)$	value of purchased power by retailer in period t (MWh)
$\bar{R}_j^{DR}(t)$	highest value in j^{th} step of reward-based DR in time period t (\$/MWh)
$\lambda_{po}(t)$	price of pool-order DR in period t (\$/MWh)
$\lambda_{f,b}^{DR}(t)$	price of block b of forward DR f option in time period t (\$/MWh)
$\lambda_{f,b}^{F}(t)$	price of the block b of forward contract f in time period t (\$/MWh)
$\widetilde{\lambda}^{p}(t)$	forecasted pool market price (\$/MWh)

Numbers

N_{BDR}	number of blocks in forward DR
N_F	number of forward contracts
N_{FB}	number of blocks in forward contracts
N_{FDR}	number of contract in forward DR
N_J	number of steps in reward-base DR
N_{po}	number of pool-order options

Variables

$C(FDR)$	total cost of forward DR program (\$)
$C(F)$	total cost of forward contracts (\$)
$C(PO)$	total cost of pool-order options (\$)
$C(P)$	total cost of power procurement from pool market (\$)
$C(RDR)$	total cost of reward-base DR
$P^{DR}(t)$	purchased power from reward-base DR in time period t (MW)
$P^{p}(t)$	purchased power from pool-order in time period t (MW)
$P^{FDR}(t)$	purchased power from block b of forward DR f in time period t (MW)
$P_{f,b}^{DR}(t)$	purchased power from block b of forward contract f in time period t (MW)
$P^{p}(t)$	purchased power from the pool market in time period t (MW)
$R^{DR}(t)$	value of reward in time period t (\$/MWh)
$R_j^{DR}(t)$	value of reward of step j in time period t (\$/MWh)
$v_{DR,j}(t)$	binary variable that shows which step is executed in time period t
$v_{po}(t)$	binary variable which is 1 if pool-order is run in time period t
$\lambda^{p}(t)$	actual pool market price (\$/MWh)

given risk level. In addition, authors in [15] introduced game theory as an efficient method for the optimal operation of home MGs, which is offers an advanced retail electricity market. As a good work, authors in [16] in an integrated energy system, proposes the pricing and operation strategy considering of DR for a MG retailer. In [17], information gap decision theory is used to evaluation different strategies for a retailer under pool price uncertainty, which this method can be used as a tool for assessing the risk, levels, considering whether a retailer is risk-taking or risk-averse regarding its midterm strategies. Ref. [18] paid to explanation of demand response (DR) programs in deregulated electricity markets, which the definition and the classification of DR as well as potential benefits and associated cost components are presented. Ref. [19] analyzes the effect that the market structure can have on the elasticity of the demand for electricity. It then describes how the consumers' behavior can be modeled using a matrix of self- and cross-elasticities. In [20], a new demand response, which called consumer preference, based demand response model introduced in a game-theoretic framework. In addition, Ref. [21] introduced a clear reserve market in the presence of uncertain responsive loads using of information gap decision theory (IGDT) concept.

Robust optimization approach is clearly in uncertainty modeling. In Robust optimization approach is analyzed solution optimally under forecasting errors in two risk-neutral strategy and risk-averse strategy which risk-averse strategy modeled worst condition for uncertain parameter. Nevertheless, IGDT is analyzed effects of various amounts of deviation from optimal solution on the uncertain parameter.

In [22], responsive load economic model is presented that is a model based on price elasticity and customer benefit function. In [23], formulation and analysis of a new scheme of DR program targeting retail customers who are equipped with smart meters yet still face a flat rate. In [24], a two-way digital communication infrastructure proposed for future, which will be used in the demand-side energy management system between users. In [25], end-users performances are analyzed in the restructured electricity market in order to deal with existing threats. In order to find the optimal energy management scheduling scheme for each end-users and utility company, a distributed real-time algorithm is proposed in [26]. The consumer's hourly behavior in response to hourly changes in market prices introduced using of optimal analysis in [27]. In [28], the time-of-use poring for the electricity market is used. Also in the mentioned reference with an illustrative example, the welfare gains/losses are analyzed after an implementation of TOU pricing scheme over the single pricing scheme. In [29–33], the technical concepts of DR are discussed. For example, details on the control and management of electrical loads like air conditioners, water heater, and cooling systems is expressed. A new method for the exchange of DR has been created in [34,35], which DR is a public good. In [36], a method has been developed for the exchange of DR in which DR is trade directly between the buyer and seller in a pool-base market. In addition, mentioned method has been improved in [37], which examine the economic and technical perspectives of critical peak pricing plan as an active demand response (DR) program. In [38,39], the formulation of three known types of DR include load curtailment, load shifting and fuel substitution is introduced in which consumers can decide participation in mentioned DR programs. In order to evaluate the capacity of load curtailment in industrial consumers, stochastic programming approach has been used in [40].

In the retail market, retailer can use DR programs to reduce their risk. For example, in [41], to control uncertainty in the pool market, interruptible loads have been used. In [42], two interruptible loads contracts, pay-in-advance and pay-as-you-go have been evaluated as a retailer's energy resource. In [43], self-production is introduced as a source for reducing the risk of market price fluctuation. In [44], presents a multiperiod energy acquisition model for a distribution company (Disco) with distributed generation (DG) and interruptible load (IL) in a day-ahead electricity market. Also, in [45], interruptible loads are introduced as energy for distribution companies in the day-ahead market. Finally, in [46], a robust optimization method is used to pool price uncertainty modeling in order to obtain optimal bidding strategy