Solar Energy 171 (2018) 580–592

Contents lists available at ScienceDirect

Solar Energy

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

Interval optimization based performance of photovoltaic/wind/FC/electrolyzer/electric vehicles in energy price determination for customers by electricity retailer

Sayyad Nojavan*, Kazem Zare

Faculty of Electrical and Computer Engineering, University of Tabriz, Tabriz, Iran

ARTICLE INFO

Keywords:
Solar photovoltaic system
Hydrogen storage systems
Interval optimization approach
Plug-in electric vehicles

ABSTRACT

This paper proposes optimal management of hydrogen storage systems and plug-in electric vehicles in the scheduling of retailer under pool market price uncertainty which real-time pricing is determined in comparison with time-of-use pricing and fixed pricing. Also, pool market price uncertainty is modeled via proposed interval optimization approach for uncertainty-based profit function of retailer. In the proposed model, uncertainty-based profit function of retailer is reformulated as a deterministic bi-objective framework with average and deviation profits as the conflict objective functions which deviation profit should be minimized while average profit should be maximized. Furthermore, weighted sum approach is used to solve the proposed bi-objective model in order to obtain Pareto solutions. Finally, fuzzy decision-making approach is provided to select the trade-off solution from Pareto solutions. The proposed MIP-based model is implemented in GAMS software which can be solved using CPLEX solver. Deterministic and interval optimization approaches under fixed, time-of-use, and real-time pricing are utilized in the case studies and the results are compared with each other in order to show the effectiveness of the proposed model. The obtained results show that deviation profit of retailer decreases in the proposed interval optimization approach in comparison with deterministic approach. Also, average profit of retailer increases in the real-time pricing in comparison with time-of-use pricing and fixed pricing.

1. Introduction

In the smart grid, retailer can determinate the retail price to residential, commercial, and industrial consumers in order to maximize the expected profit (Nojavan et al., 2017a). Retailer serves the consumers' demand by procuring power from available energy sources (Nojavan et al., 2017b). Also, the hydrogen storage systems (HSSs) (Majidi et al., 2017c) and the plug-in electric vehicles (PEVs) (Fathabadi, 2018) are new options for energy storage system (ESS) which can be used for more flexible of energy management (Fathabadi, 2018). Finally, retailer should manage the pool market price uncertainty for robust scheduling in versus price fluctuation (Najafi-Ghalelou et al., 2018).

1.1. Literature review

Retail price determination problem by electricity retailer is classified to short-term and mid-term operation.

In short-term operation, the bidding curves of retailer are obtained in order to supply consumers in the deregulated electricity market (Nojavan et al., 2017c). Also, energy service provider analysis a techno-economic strategy in the energy market (Nojavan and Zare, 2018). Furthermore, in Nojavan et al. (2017d), optimal offering price of retailer for retail price determination to the consumers is obtained in order to maximize retailer's profit. Optimal demand function of a retailer is determined in power market in Hajati et al. (2011). In Ghazvini et al. (2015), a multi-objective framework is proposed for short-term scheduling of retailers in a retail market. In a dynamic price environment, a game theory model is provided in Zugno et al. (2013) for modeling the relationship between customers and retailer. The risk-based energy management of retailer is studied in Boroumand and Zachmann (2012), while joint price and quantity risks are modeled by intra-day hedging portfolios in Boroumand et al. (2015). In Fleten and Pettersen (2005), piecewise-linear bidding strategies are constructed by a stochastic framework linear model. Optimal offering price is determined by retailer using a clustering technique in Mahmoudi-Kohan et al. (2010). Also, a non-dominated bidding curve of retailer is obtained from a two-step linear model (Wei et al., 2015). Furthermore, in

* Corresponding author.
E-mail addresses: sayyad.nojavan@tabrizu.ac.ir (S. Nojavan), kazem.zare@tabrizu.ac.ir (K. Zare).

https://doi.org/10.1016/j.solener.2018.07.004
Received 27 April 2018; Received in revised form 10 June 2018; Accepted 2 July 2018
0038-092X/

Nomenclature

Index

b	bilateral contract index
h	segments index for generation block in linear modeling of DG units
i	auxiliary index for linear modeling of minimum ON-time and OFF-time constraints
j	DG unit index
t	time period index
v	electric vehicles index
z	segment index in the price-power curve of customers

Sets

B	number of bilateral contracts
H	number of production blocks of DG units
I	the maximum value of minimum ON-time and OFF-time value of DG units running from 1 to max {MUT_j, MDT_j}
J	number of DG units
T	number of time periods
V	number of plug-in electric vehicles
Z	number of segments in the price-quota curve

Variables

$A(l, z, t)$	binary variable to determine the retail price for selling to customers by the retailer from the offered price-power curve
C_B	purchased cost from the bilateral contracts
C_P	purchased cost from the pool market
C_{DG}	purchased cost from the DG units
$D(l, t)$	supplied customers' demand by the retailer
$N_{H2,t}^{FC}$	consumed hydrogen molar by fuel cell
$N_{H2,t}^{EL}$	produced hydrogen molar by electrolyzer
$P_{b,t}$	purchased power from each of the bilateral contracts
P_t^{BC}	total purchased power from all the bilateral contracts
P_t^P	purchased power from the pool market
$P_{j,h,t}^{DG}$	purchased power from the DG units
$Pc_{t,v}$	charged power of PEV
$Pd_{t,v}$	discharged power of PEV
P_t^{H2}	hydrogen tank pressure
P_t^{EL}	consumed power by the electrolyzer
P_t^{FC}	produced power by fuel cell
$R_R(l, t)$	the obtained revenue from each of the customers' group
s_b	binary variable to select the bilateral contracts
$SP(l, z, t)$	price of the interval of the price-power curve for the customers group
$SP^{RTP}(l, t)$	real-time selling price by the retailer for the customers group
$SP^{Fixed}(l)$	fixed selling price by the retailer for the customers group
$SP_L^{TOU}(l)$	time-of-use selling price in low load level determined by the retailer for the customers group
$SP_M^{TOU}(l)$	time-of-use selling price in medium load level determined by the retailer for the customers group
$SP_P^{TOU}(l)$	time-of-use selling price in peak load level determinedly the retailer for the customers group
$SOC_{t,v}$	SOC of PEV
$U_{j,t}^{DG}$	binary variable for on or off status of DG unit
$Uc_{t,v}$	binary variable for charging mode of PEV
$Ud_{t,v}$	binary variable for discharging mode of PEV
U_t^{EL}	binary variable for on or off status of electrolyzer
U_t^{FC}	binary variable for on or off status of fuel cell

Parameters

$Dn_{j,i}$	auxiliary parameter for linear modeling of MDT constraint
$D^{offer}(l, z, t)$	offered demand of customers group in the price-power curve
G_t^a	sun irradiation
G_{a0}	sun irradiation at the standard state
LHV_{H2}	lower heating value of hydrogen
$N_{H2,\max}^{FC}$	maximum rate of hydrogen molar in fuel cell
$N_{H2,\max}^{EL}$	maximum rate of hydrogen molar in electrolyzer
$NOCT$	normal operating cell temperature in PV system
$P_{\min}^{EL}$	lower limit of power in electrolyzer
$P_{\max}^{EL}$	upper limit of power in electrolyzer
P_{t0}^{H2}	hydrogen tank pressure in the first time
$P_{initial}^{H2}$	hydrogen tank pressure in the initial condition
$P_{\max}^{H2}$	upper limit of hydrogen tank pressure
$P_{\min}^{H2}$	lower limit of hydrogen tank pressure
$P_{\min}^{FC}$	lower limit of power in fuel cell
$P_{\max}^{FC}$	upper limit of power in fuel cell
Pc_v^{Min}	lower limit of power in charging model in PEV
Pc_v^{Max}	upper limit of power in charging model in PEV
Pd_v^{Min}	lower limit of power in discharging model in PEV
Pd_v^{Max}	upper limit of power in discharging model in PEV
$Ptr_{t,v}$	traveling requirement of PEV
P_b^{max}	upper limit of power in bilateral contracts
P_b^{min}	lower limit of power in bilateral contracts
$P_{j,h}^{MAX}$	rated block power in a piecewise linear curve of DG unit
P_t^{wind}	produced power by wind-turbine
p_r	rated power of wind-turbine
P_t^{PV}	produced power by PV system
$P_{Max,0}^M$	maximum power of PV panel at the standard state
R_j^{up}	ramp up amount of DG units
R_j^{down}	ramp down amount of DG units
$\mathfrak{R}$	gas constant
$S_{j,h}^{DG}$	rated block cost in a piecewise linear curve of DG unit
$SP^{offer}(l, z, t)$	offered price of customers in the price-power curve
SOC_v^{Min}	lower limit of SOC in PEV
SOC_v^{Max}	upper limit of SOC in PEV
T_{H2}	mean temperature inside the vessel
T_t^a	environment temperature
$T_{M,0}$	module temperature at the standard state
$Up_{j,i}$	auxiliary parameter to model the MUT limit
V_{H2}	overall tank volume
V_t^w	wind speed
V_r, V_{ci}, V_{co}	rated, cut-in and cut-out wind speeds
λ_t	expected pool market price
$\lambda_{b,t}$	bilateral contracts price
η_v^c	charging efficiency of PEV
η_v^d	discharging efficiency of PEV
η^{EL}	electrolyzer efficiency
η^{FC}	fuel cell efficiency

Abbreviations

BCs	bilateral contracts
DG	distributed generation
FP	fixed pricing
GAMS	general algebraic modeling system
HSSs	hydrogen storage systems
MIP	mixed-integer linear programming
PM	pool market
PV	photovoltaic
PEVs	plug-in electric vehicles