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Optimal energy pricing for consumers by electricity retailer

Sayyad Nojavan, Kazem Zare*

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

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ABSTRACT

In the smart grid, retail price determination by electricity retailer is necessary in the presence of hydrogen storage systems and plug-in electric vehicles under pool market price uncertainty. Therefore, in this paper, real-time pricing is proposed in comparison with time-of-use pricing and fixed pricing. Furthermore, an interval optimization approach is proposed for pool market price uncertainty modeling. In this approach, uncertainty-based profit function of retailer is reformulated as a deterministic bi-objective problem with average and deviation profits as the conflict objective functions which average profit should be maximized while deviation profit should be minimized. Furthermore, epsilon constraint method is used to solve the proposed bi-objective model in order to obtain Pareto solutions. Finally, fuzzy satisfying approach is used to select the trade-off solution from Pareto solutions. The obtained results show that average profit of retailer increases in the real-time pricing in comparison with time-of-use pricing and fixed pricing. Also, deviation profit of retailer decreases in the proposed interval optimization approach in comparison with deterministic approach. The proposed mixed-integer linear programming model is solved using CPLEX solver under GAMS optimization software. To validate the better performance of proposed model, three types of retail price determination under deterministic and interval optimization approaches are utilized and the results are compared with each other.

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 [1]. Retailer serves the consumers' demand by procurement power from available energy sources [2]. Also, the hydrogen storage systems (HSSs) [3] and the plug-in electric vehicles (PEVs) [4] are new options for energy storage system (ESS) which can be used by electricity retailer for more flexible of energy management [4]. Finally, retailer should manage the pool market price uncertainty for robust scheduling in versus price fluctuation [5].

1.1. Literature review

Retail price determination problem by electricity retailer are 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 [6]. Also, energy service provider analysis a techno-economic strategy in energy market [7]. Furthermore, in [8], optimal offering price of retailer for retail price determination to the consumers is obtained in order to maximize retailer' profit. Optimal demand function for a retailer is determined in power market in [9]. In [10], 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 [11] for modeling of relationship between customers and retailer. The risk-based energy management of retailer is studied in [12], while joint price and quantity risks are modeled by intra-day hedging portfolios in [13]. In [14], piecewise-linear bidding strategies are constructed by a stochastic framework linear model. Optimal offering price is determined by retailer using a clustering technique in [15]. Also, a non-dominated bidding curve of retailer is obtained from a two-step linear model [16]. Furthermore, in [17], energy pricing and dispatch problems of retailer are presented as a two-level model. Finally, in [18], in order to supply energy for price-sensitive consumers is modeled and obtained using a robust bi-level model.

It should be noted that in mid-term operation, in [19], a combined algorithm based on binary imperialist competitive algorithm and binary particle swarm optimization is used to schedule the optimal energy purchasing for a retailer. In [20], demand response program is used to manage peak load and reduce the procurement cost of a retailer. Retail price determination and optimal interruption policy are considered in [21]. Also, how to contract between generation company and end-user consumers is addressed in [22] while the profit of retailer is maximized in the presence of an acceptable level of risk. In [23], retailer determines retile price for selling to customers under risk assessment. In

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

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Nomenclature

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
RESs renewable energy sources
RTP real-time pricing
SOC state-of-charge
TOU time-of-use pricing

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

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_{c0} 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

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