Electrical Power and Energy Systems 101 (2018) 223–233

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

# Reliability-constraint energy acquisition strategy for electricity retailers

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ARTICLE INFO

*Keywords:*
Energy acquisition
Fuzzy number
IGDT
Point estimate method
Retailer

ABSTRACT

Electricity retailers desire to specify the energy acquisition strategy and selling prices in a way that maximize the expected profit, and convince consumers to choose them as the energy provider. Reducing selling price decreases retailers' income, and vice versa. Moreover, the higher selling price increases clients' switching probability to rivals that reduces the retailer's expected income. Therefore, the retailer faces a tradeoff between selling prices and clients' consumption. Additionally, fluctuations of wholesale prices, random demand, unexpected failures of self-generation facilities, and risk of rivals' strategies are other difficulties faced by retailers, and these uncertainty resources affect their profits. This paper presents a fuzzy Information Gap Decision Theory (IGDT) based framework for electricity retailers to specify the energy acquisition strategy. Uncertainty of wholesale price is modeled via unknown bounded intervals. Additionally, the Point Estimate Method (PEM) is proposed to cope with the uncertainty of rivals' strategies. Clients' reaction to retail-selling prices is incorporated into the proposed framework via fuzzy numbers. In order to model the availability of generating units, a novel scheduling framework considering the repair time for failed units, in addition to repair cost and forced outage rate (FOR) is presented in this research. Finally, IGDT methodology is applied to determine the retailer's energy acquisition strategy based on financial risk preferences. Performance of proposed model is evaluated via a case study, and the numerical results are discussed.

## 1. Introduction

Restructuring in electricity distribution networks leads to emerging a new marketplace that is known as the electricity retail market. This market is the final stage of providing the required energy of household consumers. Retailer companies are the point of sale between the generation companies and end-users. They have various options to provide clients' required energy such as the wholesale market, bilateral contracts, and self-generation facilities. Fluctuations of some parameters such as wholesale prices and clients' demand are inevitable, and neglecting uncertainty of these parameters may impose a great financial loss on retailers [1]. In competitive electricity markets, the forward contract is proposed as an effective alternative to hedge the financial risk of random wholesale prices. Self-generating facilities are other source of providing energy. Evidently, these units are not fully reliable and their unexpected outages after acceptance of bids and offers by the market operator enforce retailers to compensate the electricity shortage from the regulation market during committed periods. Moreover, retailers have to pay repair cost to recover failed generating units. Hence, the availability of self-generating units is another uncertainty resource that could imposes additional cost to retailers.

In a competitive electricity market, selling prices play a crucial role in negotiations between retailers and consumers. Evidently, the retailer's business could only be profitable if the income that depends on selling prices is greater than the supply cost. Selling price must be determined in a way that covers the supply cost, leads to an acceptable profit for the retailer, and encourages consumers to purchase energy from the retailer. By increasing selling prices, consumers may change their energy providers and choose another retailer. Hence, the risk of rivals' strategy is another uncertain parameter that must be assessed by the retailer. Impacts of this uncertainty resource depend on rivals' selling prices and clients' tendency to change or switch their energy providers. The switching tendency is affected by many factors such as social, economic, and cultural condition of consumers. Surprisingly, in some countries, even cheaper selling offers do not increase the consumers' motivation to choose another energy provider. For example, Danish households are less willing to switch suppliers compared to their Nordic neighbors. The main reason of this issue is that the electricity bill constitutes a small proportion of Danish end users' monthly income [2]. Therefore, to model the uncertainty of rivals' strategy, their selling prices and customers' switching tendency must be considered, simultaneously.

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https://doi.org/10.1016/j.ijepes.2018.03.032
Received 10 September 2017; Received in revised form 21 February 2018; Accepted 22 March 2018
0142-0615/ 

**Nomenclature**

| | |
|---|---|
| $Profit_{cr}^{RA}$ | critical profit of risk-averse retailer ($) |
| $Profit_{cr}^{RT}$ | critical profit of risk-taker retailer |
| $Inc_t$ | retailer's income within operation period $t$ ($) |
| $Inc_t^{RET}$ | income of selling power in retail market within operation period $t$ ($) |
| $Inc_t^{DA}$ | income of selling power in wholesale day-ahead market within operation period $t$ ($) |
| $Cost_t$ | retailer's supply cost within operation period $t$ ($) |
| $Cost^{DA}$ | cost of purchasing power from the day-ahead wholesale market ($) |
| | cost of purchasing power from the forward market ($) |
| $Cost^{SG}$ | operational cost of self-generating facilities ($) |
| $FC$ | fuel cost ($) |
| $RC$ | repair cost ($) |
| $RGC$ | cost of purchasing power from the regulation market ($) |
| $SDC$ | shutdown cost ($) |
| $SUC$ | startup cost ($) |
| $CC$ | cooling cost ($) |
| $P_t^L$ | hourly demand (MW) |
| $\overline{P}_t^{L,0}$ | initial hourly demand without considering the risk of rival retailers (MW) |
| $\overline{P}_t^{L,k}$ | initial hourly demand with considering the risk of rival retailer $k$ th(MW) |
| $P_t^{DA_S}$ | hourly sold power in the day-ahead wholesale market (MW) |
| $P_t^{DA_B}$ | hourly purchased power from the day-ahead wholesale market (MW) |
| $P_{b,f,t}^{FC}$ | hourly purchased power from $b$-block of forward contract $f$ within operation period $t$ (MW) |
| $P_{t,f}^{FC}$ | total hourly purchased power from forward contract $f$ within operation period $t$ (MW) |
| $P_t^{FC}$ | total purchased power from the forward market (MW) |
| $\overline{P}_{b,f,t}^{FC}$ | upper bound of $b$-block of forward contract $f$ (MW) |
| $P_{i,t}$ | hourly generating power of unit $i$ th within operation period $t$ (MW) |
| $P_i^{\max}$ | maximum allowed capacity of unit $i$ (MW) |
| $P_i^{\min}$ | minimum allowed capacity of unit $i$ (MW) |
| $\pi_t^{RET}$ | hourly retail-selling price ($/MWh) |
| $\pi_t^{DA}$ | hourly energy price of day-ahead wholesale market during operation period $t$ ($/MWh) |
| $\overline{\pi}_t^{DA}$ | estimation of day-ahead hourly price during operation period $t$ ($/MWh) |
| $\pi_{b,f,t}^{FC}$ | price of $b$-block of forward contract $f$ during operation period $t$ ($/MWh) |
| $\pi_t^{RG}$ | hourly regulation price ($/MWh) |
| $\pi_t^k$ | retail selling price of rival-retailer $k$ th during operation period $t$ ($/MWh) |
| $N_t^f$ | number of power blocks of forward contract $f$ during operation period $t$ |
| $N_{SG}$ | number of self-generating units |
| $N_\phi^k$ | set of selling-prices of rival $k$ th |
| $N_{riv}$ | number of rival-retailers |
| $\Xi$ | set of available forward contracts |
| $T$ | set of operation periods |
| $T_{C_{i,t}}^{On}$ | number of continuous on-time hours of unit $i$ up to hour $t$ (h) |
| $T_{i,\min}^{On}$ | minimum on-time of unit $i$ (h) |
| $T_{C_{i,t}}^{Off}$ | number of continuous off-time hours of unit $i$ up to hour $t$ (h) |
| $T_{i,\min}^{Off}$ | minimum off-time of unit $i$ (h) |
| $R_i^{Up}$ | ramp-up rate of unit $i$ (MW/h) |
| $R_i^{Down}$ | ramp-down rate of unit $i$ (MW/h) |
| $R_i^{SU}$ | startup ramp-rate of unit $i$ (MW/h) |
| $R_i^{SD}$ | shutdown ramp-rate of unit $i$ (MW/h) |
| $FOR_i$ | forced outage rate of unit $i$ th (%) |
| $Pr_r^k$ | probability of selling price $r$ th of rival $k$ th |
| $a_i,b_i,c_i$ | coefficients of cost function |
| $\lambda_t$ | variation bound of hourly day ahead price |
| $\Delta_t^k$ | hourly difference between selling prices of the retailer and rival $k$ th during operation period $t$ ($/MWh) |
| $A_t^k$ | fuzzy number of rival-retailer $k$ th during operation period $t$ |
| $\tau_{A_t^k}$ | membership function of $A_t^k$ |
| $\delta_{b,f,t}$ | binary variable of block $b$ of forward contract $f$ during operation period $t$ |
| $U_{i,t}$ | status binary variable of unit $i$ during operation period $t$ |
| $\mu_{i,t}$ | startup decision variable of unit $i$ during operation period $t$ |
| $\nu_{i,t}$ | shutdown decision variable of unit $i$ during operation period $t$ |
| $\rho$ | ratio of regulation and day-ahead prices |
| $\vartheta$ | profit deviation factor |
| $\zeta$ | ratio of day-head hourly price and its estimation |
| $\mu$ | expected value |
| $\sigma$ | standard deviation value |
| $\eta$ | standard location |
| $\theta$ | central moment |
| $w$ | weighting factor |

In recent years, various models have been presented in technical literature to specify the electricity retailer's strategy in the wholesale and regulation markets [3], forward contracts [4] as well as handling effects of uncertain parameters. It should be noted that smart control and metering devices enable household clients to adjust their consumption according to energy prices [5]. Therefore, the stochastic framework is addressed in [6–9] to evaluate effects of demand elasticity [6,7] and reward-based demand response programs [8,9] on the retailer's energy acquisition strategy. As mentioned before, retailers could supply the required energy of their consumer by self-generation facilities [10]. In [11], the retailer's strategy is developed in the presence of renewable energy resources. Modeling of uncertain parameters and the risk management methodology are main differences of presented models. The stochastic programming [12–14], game theoretical approach [15], clustering technique [16,17], robust optimization methodology [18,19], and heuristic algorithm [20] are proposed to evaluate the financial risk and behavior of random parameters.

Evidently, increasing the selling price has negative impact on demand of price-sensitive consumers. Hence, retailers face a tradeoff between selling price and clients' demand. In [21], the multi-objective methodology is addressed to determine the retailer's selling price and energy acquisition strategy. The profit maximization and risk minimization are two main objectives of a typical retailer [12–15]. For simultaneous optimization, bi-level programming [22,23] and multi-objective methodology [24] are proposed in some technical references. Moreover, conditional value-at-risk (CVaR) [13,14,16], expected downside risk (EDR) [22], and risk-adjusted recovery on capital (RAROC) [25] are most important methodologies which are used to quantify financial risk.

Although, many researches have evaluated uncertainties of wholesale price and demand, few models can be found that focusing on the uncertainty of rival retailer's strategy and availability of self-generation facilities. Therefore, uncertainties of wholesale price, rivals' strategies, and availability of generating units are modeled in this work, simultaneously. As mentioned before, the risk of rivals' strategies depends on their selling prices and clients' switching behavior. The main difficulty is modeling the switching tendency that depends on many factors. The fuzzy methodology is an effective tool for evaluating