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Risk-assessment of photovoltaic-wind-battery-grid based large industrial consumer using information gap decision theory

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ABSTRACT

In this paper, the energy procurement problem for a large electricity consumer is solved under various resources. In this problem, the uncertainty of pool market price is a big challenge to achieve optimal result. In this paper, the information gap decision theory has been proposed to handle the pool market price uncertainty. The results of information gap decision theory are presented in three different strategies for the large consumer. These three strategies include risk-averse, risk-neutral and risk-taker strategies which examine the large consumer risk at various prices in pool market. In addition, the results in all strategies point out the importance of demand response program in reducing the large consumer's costs. In the risk-neutral strategy, the large consumer cost with and without demand response program is $36,945 and $40,253 respectively. Therefore, the positive impact of demand response program has reduced large consumer cost about 8.2%. Large consumer resistance is 72.5% higher than the without use of demand response program mode in the risk-averse strategy. Finally, large consumer cost is 8% less than the without use of demand response program mode in the risk-taker strategy.

1. Introduction

The large industrial consumers can use several options to procure their energy. Pool market and bilateral contract are two important options, which are always available for purchasing energy (Nojavan et al., 2015a). In addition, the consumers can use wind turbines (Nojavan et al., 2017a) and photovoltaic systems (Majidi et al., 2017a) to provide some part of their energy. Also, the energy storage system is used to store energy during off-peak times (Majidi et al., 2017a; Najafi-Ghalelou et al., 2018). By creating demand side management, electricity consumers can also use demand response program (DRP) to reduce their costs, which in this paper time-of-use (TOU) program have been used to shift load from peak time to off-peak times (Rezaeipour and Zahedi, 2017; Litjens et al., 2017).

1.1. Literature review

In Kirschen (2003), the consumer's information is presented to participate in the energy market. Consumers react to changes in prices is called consumer elasticity (Daryanian et al., 1989). To make a proper decision for consumers to participate in the electricity market, bidding strategy is a good way which is presented in Liu and Guan (2003). The profit maximization problem is a big challenge when the retailers sell energy to consumers which presented in Nojavan et al. (2017b, 2017c). The energy of large electricity consumer procured in Conejo et al. (2005) with assuming all options are available. To solve some problems, mean-variance method and stochastic programing approach are used in Conejo and Carrion (2006), Carrión et al. (2007). In Woo et al. (2004a), consumers minimized their cost using bilateral contracts and pool market which buy from local electricity Distribution Company. In Woo et al. (2006), the problem is solved by assuming a new energy source that named tolling agreement. In Woo et al. (2004b), load duration curve was used to determine the forward-contract purchase in order to minimize consumer cost. Several types of energy procurement sources such as call/put options, interruptible contracts and future contracts are introduced in Deng and Oren (2006). A stochastic programing model is used to determine the optimal selling price and future loads in Nojavan et al. (2017d, 2015b, 2017e), Gabriel et al. (2006), subject to a value at risk constraint. In Zare et al. (2010a, 2010b), different consumers strategies are analyzed using information gap

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Nomenclature

Abbreviations

IGDT information gap decision theory
DRP demand response program
ESS energy storage system
PV photovoltaic
TOU time-of-use

Indices

t index of time
l index of bilateral contracts
j index of the self-generation units
h index of blocks of cost function for the self-generation units
i index for modeling of minimum ON-time and OFF-time limits running from 1 to max {MUT_j, MDT_j}

Parameters

T number of times (No.)
B number of bilateral contracts (No.)
N_h number of generation blocks of the self-generation units (No.)
N_j number of self-generation units (No.)
$DRmax$ maximum size of load participation in DRP (%)
$Incmax$ maximum size of load increase in each time (%)
χ,η charging/discharging efficiency of battery storage (%)
$load_t^0$ initial load at time t (MWh)
λ_t market price at time t ($/MWh)
$\lambda_{l,t}$ electricity price of contracts l at time t ($/MWh)
$P_{j,h}^{MAX}$ output size of block h of jth unit of the self-generation units (MWh)
$P_{l,t}^{\max}$ maximum capacity relating to contracts l at time t (MW)
$P_{l,t}^{\min}$ minimum capacity relating to contracts l at time t (MW)
$S_{j,h}^{DG}$ related cost of block h of jth unit of the self-generation units ($/MWh)
p_r rated power of wind-turbine (MW)
$P_t^{wind,\max}$ maximum available power wind-turbine at time t (MW)
$P_t^{M,\max}$ maximum available power PV system at time t (MW)
V_t^w wind speed at time t (m/s)
V_r,V_{ci},V_{c0} rated, cut-in and cut-out wind speed (m/s)
$P_{Max,0}^M$ maximum power at the standard condition (MW)
G_t^a insulation at time t (W/m^2)
G_{a_0} insulation at the standard condition (W/m^2)
T_t^a temperature at time t (°C)
$T_{M,0}$ module temperature at the standard condition (°C)
$NOCT$ normal operating cell temperature of PV system (°C)
$P_{charge}^{\max},P_{disc}^{\max}$ maximum charging/discharging power at time t (MW)
$X_b^{\max},X_b^{\min}$ maximum/minimum energy stored in battery storage (MWh)
R_j^{up},R_j^{down} ramp up/down rate limit of self-generation units j (MW/h)
MUT_j,MDT_j minimum up/down time of self-generation units j (h)
$Up_{i,j},Dn_{i,j}$ auxiliary variable for the MUT/MDT constraints (h)

Variables

C_t^B operation cost of battery storage at time t ($/MWh)
C_t^{wind} operation cost of wind-turbine at time t ($/MWh)
C_t^{PV} operation cost of PV system at time t ($/MWh)
$P_{l,t}^{BC}$ purchased power from the bilateral contracts l at time t (MW)
P_t^{BC} total purchased power from the bilateral contracts at time t (MW)
P_t^p purchased power from the power market at time t (MW)
$P_{j,t}$ produced power from the jth unit of the self-generation units at time t (MW)
$P_{j,h,t}^{MT}$ power relating to block h of jth unit of the self-generation units at time t (MWh)
P_t^{charge},P_t^{disc} charging/discharging power of battery storage at time t (MW)
P_t^{wind} produced power from the wind-turbine at time t (MW)
P_t^{PV} produced power from the PV system at time t (MW)
DR_t potential of DRP implementation (the percentage of participation) at time t (%)
ldr_t shifted load by DRP at time t (MWh)
s_l binary variable, "1" if bilateral agreement l is selected, and 0 otherwise
$U_{j,t}$ binary variable, "1" if self-generation units' j is on mode at time t, and 0 otherwise
P_t^{wind} purchased power from wind-turbine at time t (MW)
P_t^{PV} purchased power from PV system at time t (MW)
U_t^{charge},U_t^{disc} binary variable, "1" if charging/discharging of battery storage at time t
X_t^b stored energy in battery storage at time t (MWh)
$load_t$ new load considering DRP at time t (MWh)
$load_t^{inc}$ load increase of each time t (MWh)
inc_t size of load increase at time t (MWh)

Functions

$C(p,\lambda)$ procurement cost function of large consumer ($)
$\hat{\alpha}(C_r)$ robustness function (%)
$\hat{\beta}(C_o)$ opportunity function (%)

decision theory (IGDT) which renewable energy sources and energy storage system as well as effective load management are not considered. In Zarif et al. (2012), fuzzy-based decision-making method has been used to determine optimal energy procurement in the presence of alternative resources. In Zarif et al. (2013), Second-order stochastic method has been introduced for the mid-term scheduling problem which is developed for an industrial consumer.

From the perspective of forecasting methods, a prediction model based on multi-block forecast engine in Ghadimi and Firouz (2015), Ghadimi et al. (2017a, 2017b), price prediction for the energy market in Akbary et al. (2017), Gollou and Ghadimi (2017), Ebrahimian et al. (2018), load forecast based on hybrid forecast engine in Mohammadi et al. (2017), solar energy forecasting based on hybrid neural network and improved meta-heuristic algorithm in Abedinia et al. (2017), prediction of battery and wind-solar output in Mirzapour et al. (2017) and uncertainty modeling in Ahmadian et al. (2014) are studied.

In this paper, IGDT is used to examine the market price uncertainly. In presented method, there is no need to additional information such as the probability density function (PDF) of uncertain parameter. Unlike stochastic methods which results are dependent on probabilistic scenarios, IGDT provides accurate and efficient result which is firstly introduced in Ben-Haim (2001). Many methods are used to risk analysis, which gives the advantage of IGDT technique as the following:

1. This technique does not require any additional information such as the probability density function (PDF) of stochastic variables.
2. Unlike the stochastic programing methods that output variables are dependent on probabilistic scenarios, the result of IGDT is accurate and efficient.

Optimal energy management of IGDT-based models in the previous works has been investigated as follows: The optimal bidding strategy