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Robust performance of photovoltaic/wind/grid based large electricity consumer

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ABSTRACT

In this paper, a new optimization framework has been developed for optimal operation of large industrial consumer under time-of-use rate (TOU) of demand response program (DRP) considering pool market price uncertainty. In order to model mentioned uncertainty, interval optimization method has been implemented. Based on this approach, a bi-objective optimization problem with average and deviation costs as objective functions is generated to be minimized instead of a single objective function. So, the bi-objective problem is solved using weighted sum and fuzzy satisfying algorithms. In addition to mentioned algorithms, large consumer able to use TOU of DRP to be capable of shifting its demand from expensive intervals to off-peak intervals which can lead to reduce operating cost of large consumer. A sample model is simulated under GAMS optimization software within uncertainty of pool market price through mentioned algorithms and the results obtained from simulations revealed that in the case DRP is ignored by increasing average cost up to 4.32%, large consumer deviation cost representing uncertain of pool price has been reduced down to 87.22%. Moreover, in the case TOU is employed large consumer has paid 4.21% more to reduce uncertainty effect up to 85.43%.

1. Introduction

Energy, an essential issue around which a lot of concerns have been made is now being paid much more attention than before due to lack of energy resources. One of industries within which energy efficiency is important is power system industry in which energy consumers with different load levels are involved. Penetration of renewable energy resources like wind generation (WT) (Krauter, 2018) and photovoltaic system (PV) (Nojavan et al., 2017) can help large energy consumers to meet their energy demand in various scales. In addition to mentioned resources, other options like bilateral contracts (Rezaeipour and Zahedi, 2017), pool market (Fathabadi, 2017) and energy storage systems (Najafi-Ghalelou et al., 2018) are available for large consumer to sever energy demand.

The papers published about large energy consumers have been evaluated from different viewpoints in the following: pool market as one of energy resources has been available for large consumer to meet its energy demand through the purchased power from this market (Kirschen, 2003). Load management tools can help large energy consumers optimally meet its energy demand. The way these options can be effective on the economic performance of such consumers is studied in (Albadi and El-Saadany, 2008). In order to enhance and improve performance of large energy consumer in energy market, optimal bidding strategies and options has been available for large energy consumer in (Zare et al., 2010; Zare et al., 2010). Taking price elasticity and consumer benefit into account, demand response options have been available and molded for large energy consumer in (Aalami et al., 2010). Impressive and valuable options related to operation of large energy consumers in the energy market environment have been presented in (Sæle and Grande, 2011). Various types of market pricing are available. So, time-of-use rate of demand response program has been discussed in (Tang et al., 2005). Uncertainty based purchasing energy from energy market with uncertain features is a little bit challenging and this has been discussed in (Liu and Guan, 2003). Moreover, behavior of large energy consumer in the energy market with the mentioned features is discussed in (Daryanian et al., 1989). Large energy consumer participation in energy market subject to technical constraints and uncertainty of load is discussed in (Sharma et al., 2016). On the other hand, large consumer participation in energy market has been investigated without taking mentioned uncertainty into account in (Conejo et al., 2005). Popular algorithm namely mean–variance method has been implemented to control cost of purchasing energy from power market subject to cost-exposure restriction from bilateral contracts and pool market in (Woo et al., 2004). Total operation cost of local distribution system including cost of purchasing power from energy market has been minimized through a theory based algorithm in (Woo et al., 2004). In addition to energy market, tolling agreement has been

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Nomenclature

Indices

t	time index
l	index for bilateral contract
j	distributed generation units index
h	distributed generation units cost function block index
i	coefficient related to minimum ON/OFF time restrictions running from 1 to max $\{MUT_j, MDT_j\}$.

Variables

$load_t^{TOU}$	increased and decreased values of load in TOU [MW]
$load_t^{DRP}$	load with DRP consideration [MW]
$P_{l,t}^{BC}$	purchased power through bilateral contracts [MW]
P_t^{BC}	total purchased power through bilateral contracts [MW]
P_t^{P}	total purchased power through pool market [MW]
$P_{j,t}$	production of jth system of distributed generation systems [MW]
$P_{j,h,t}^{MT}$	power of hth block of jth system of distributed generation systems [MWh]
P_t^{charge}, P_t^{dis}	hourly charge/discharge power of ESS [MW]
P_t^{wind}	hourly production of WT [MW]
P_t^{PV}	hourly production of PV unit [MW]
s_l	binary variable used for bilateral contract states
U_{jt}	binary variable for ON/OFF states of distributed generation systems
U_t^{charge}, U_t^{disc}	binary variable for charge/discharge conditions of ESS
X_t^b	available energy within ESS
$f^M(X)$	average cost of large consumer
$f^W(X)$	deviation cost of large consumer

Parameters

T	number of hours within a day
B	available number of bilateral contracts
N_h	number of production blocks of distributed generation units
N_j	available number of distributed generation units
χ, η	efficiency related to charge/discharge processes of energy storage system (ESS)
$load_t^0$	large consumer base load to be supplied [MW]
λ_t	price of pool market [$/MWh]
$\lambda_{l,t}$	price determined for bilateral contracts [$/MWh]
$P_{j,h}^{MAX}$	maximum restriction of h of jth unit of distributed generation systems [MWh]
$P_{l,t}^{\max}$	bilateral contact maximum restriction [MW]
$P_{l,t}^{\min}$	bilateral contact minimum restriction [MW]
$S_{j,h}^{DG}$	related cost of block h of jth unit of distributed generation systems [$/MWh]
p_r	nominal restriction of WT [MW]
$P_t^{wind,\max}$	maximum restriction of WT
$P_t^{M,\max}$	maximum restriction of PV system
V_t^w	hourly value of wind speed
V_r, V_{ci}, V_{c0}	rated, cut-in and cut-out wind speed values [m/s]
$P_{Max,0}^M$	maximum power at the standard condition
G_t^a	hourly sunlight irradiation (W/m^2)
G_{a0}	hourly sunlight irradiation at the standard condition (W/m^2)
T_t^a	hourly ambient temperature
$T_{M,0}$	hourly module temperature at the standard condition
$NOCT$	rated operating cell temperature of PV unit
$P_{charge}^{\max}$, $P_{dis}^{\max}$	maximum restriction of charge and discharge of ESS
$X_b^{\max}$, $X_b^{\min}$	maximum/minimum restrictions of energy available in ESS
R_j^{up}, R_j^{down}	ramp up/down restrictions of distributed generation systems [MW/hour]
MUT_j, MDT_j	minimum up and down times of distributed generation systems [hour]
$Up_{i,j}$, $Dn_{i,j}$	coefficients related to MUT/ MDT restrictions
$DRP^{\max}$	maximum restrictions of DRP

set to be another energy resource in (Woo et al., 2006) in which total cost of large consumer due to power procurement from energy market has been minimized. Non-dominated sorting genetic algorithm has been implemented for optimum design of an islanded distribution system in (Ippolito et al., 2014). An optimization framework has been developed for a large consumer in (Zarif et al., 2013) in which uncertainty of availability of unit has been considered. Finally, an optimization framework has been developed for large energy consumer to optimize its energy consumption in (Vujanic et al., 2012).

The main contribution of proposed paper is interval based framework for uncertainty based operation of large consumer within uncertainty of market price in the presence of DRP. TOU, one of available load management programs in DRP has been exploited to shift some amount of energy demand from peak time intervals to off-peak intervals to enhance economic performance of large consumer. So, contributions of proposed paper can be briefly expressed as follows:

- Uncertainty based operation of large consumer under pool market price uncertainty.
- Bi-objective optimization problem with average and deviations costs of large consumer.
- Weighted sum technique is implemented for solving bi-objective problem.
- Fuzzy decision making approach is calculated trade-off solution between average and deviations costs.
- TOU of DRP is used to enhance economic operation of large consumer.

This paper is generally structured as follows: base mathematical formulation of large consumer optimal operation problem is presented in Section 2. Interval uncertainty modeling framework is described in Section 3. A sample case study is studied in Section 4 and conclusions are provided in Section 5.

2. Base mathematical formulation

Base mathematical formulation of large consumer optimal operation under severe uncertainty of pool market price in the presence of time-of-use rates of DRP has been presented in detail in the following.

2.1. Objective function

Total power procurement cost of large consumer is set in Eq. (1) that should be minimized as the cost function subject to technical limitations and constraints.

$$Min\ \left(\sum_{l=1}^{B}\sum_{t=1}^{T}\lambda_{l,t}P_{l,t}^{BC}+\sum_{t}^{T}\left(\lambda_t P_t^{P}+\sum_{j=1}^{N_j}\sum_{h=1}^{N_h}S_{j,h}^{DG}P_{j,h,t}\right)\right) \tag{1}$$

Objective function (1) is made from three individual terms. First term presents the cost of bought power through bilateral contracts. Also, the cost of purchased power from pool market is provided in second term. Finally, third term represents the cost of power generation by self-generation unit.