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Stochastic energy procurement of large electricity consumer considering photovoltaic, wind-turbine, micro-turbines, energy storage system in the presence of demand response program

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ABSTRACT

This paper proposes a stochastic energy procurement problem (SEPP) for large electricity consumer (LEC) with multiple energy procurement sources (EPSs) considering the effects of demand response program (DRP) and energy storage system (ESS). The EPSs contain power market (PM), bilateral contracts (BCs), micro-turbines (MTs), and renewable energy sources (RESs). Moreover, the RESs include photovoltaic (PV) systems and wind-turbines (WT). The ESS and DRP are incorporated in the SEPP by the LEC's decision-maker to reduce the expected energy procurement cost (EEPC). Meanwhile, the uncertainty models of market price, load and RES output power are considered in the SEPP formulation. The error of forecasting of market price, load, temperature and radiation of PV systems are modeled using the normal distribution for generating the related scenarios. Also, the weibull distribution is used to generate variable wind speed scenarios for WT output power uncertainty modeling. Furthermore, the fast forward selection based on Kantorovich distance approach is used for the scenarios reduction. Finally, the influences of ESS and DRP on EEPC are investigated, and four case studies are used to illustrate the capability of the proposed SEPP. The obtained results demonstrate the efficiency of the proposed stochastic program.

1. Introduction

In a restructured electricity market, the large electricity consumers try to acquire their electricity demand at minimum cost from the power market. To reduce the effects of market price variation, large consumers utilize the alternative energy procurement resources, such as the power market, bilateral contracts, and even self-owned generating units [1]. Emerging the renewable energy resources, such as wind-turbine [2] and photovoltaic systems [3], has provided new options for electricity consumers to procure their required energy in the restructured electricity markets from different energy resources. Also, the energy storage system is integrated with hybrid wind and PV systems [3,4]. Moreover, the consumers can participate in the demand response program [5,6] to reduce their total energy procurement cost.

1.1. Literature review

Various aspects of participation of large consumers in the power market for purchasing their owned electricity demand have been investigated in the literature. The necessity of large consumer participating in electricity market is elaborated in [7]. In [8], the optimal response of electricity consumer to the pool prices is presented. The optimal procurement and bidding strategies in the electricity markets are presented in [9] for the decision maker of consumer. In [10], the profit maximization problem is solved by a retailer for selling energy to customers. Available procurement options for customers in electricity market are addressed in [11]. In [12], the large consumer procures its electricity demand by assuming that all required data are available. A mean–variance method is used in [13] to solve the same problem. Also, the problem is formulated and solved by stochastic programming in [14]. In [15], a local electricity distribution company (LDC) is considered to procure the demand with minimum cost from bilateral contracts and power market. Moreover, the problem is solved in [16] by considering the tolling agreement as another energy procurement source. In [17], a theory framework is proposed to determine the forward-contract

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Nomenclature

Indices

h index of blocks of cost function for micro-turbines
i index for modeling of minimum ON-time and OFF-time limits running from 1 to max {MUT_j, MDT_j}
j index of micro-turbines
l index of bilateral contracts
s index of scenario
t index of time (h)

Parameters

B number of bilateral contracts
$c(s,s')$ auxiliary function used to calculate the distance between scenarios s and s' of a random variable
C_t^B operation cost of battery storage at time t ($/MW h)
C_t^{wind} operation cost of wind-turbine at time t ($/MW h)
C_t^{PV} operation cost of PV system at time t ($/MW h)
$D_K(.)$ Kantorovich distance of two probability distributions
$DRmax$ maximum size of load participation in DRP
$G_{t,s}^a$ insulation at time t in scenario s
G_{a_0} insulation at the standard condition (W/m^2)
$incmax$ maximum size of load increase at each time
$load_{t,s}^0$ initial load at time t in scenario s
MUT_j, MDT_j minimum up/down time of micro-turbine j (h)
N_h number of generation blocks of micro-turbines
N_{MT} number of micro-turbines
N_s number of scenarios
$NOCT$ normal operating cell temperature of PV system
P_s probability of each scenario s after the scenario reduction
$P_{j,h}^{MAX}$ output size of block h of jth unit of micro-turbines (MW h)
$P_{l,t}^{\max}$ maximum capacity relating to contract l at time t (MW)
$P_{l,t}^{\min}$ minimum capacity relating to contract l at time t (MW)
p_r rated power of wind-turbine (MW)
$P_{t,s}^{wind,\max}$ maximum available power wind-turbine at time t in scenario s
$P_{t,s}^{M,\max}$ maximum available power PV system at time t in scenario s
$P_{charge}^{\max}, P_{disc}^{\max}$ maximum charging/discharging power at time t in scenario s
$P_{Max,0}^M$ maximum power at the standard condition
R_j^{up}, R_j^{down} ramp up/down rate limit of micro-turbine j (MW/h)
$S_{j,h}^{MT}$ related cost of block h of jth unit of micro-turbines ($/MW h)
T number of times
$T_{t,s}^a$ temperature at time t in scenario s
$T_{M,0}$ module temperature at the standard condition
$Up_{i,j}, Dn_{i,j}$ auxiliary variable for the MUT/MDT constraints
$V_{t,s}^w$ wind speed at time t in scenario s
V_r, V_{ci}, V_{c0} rated, cut-in and cut-out wind speed (m/s)
$X_b^{\max}, X_b^{\min}$ maximum/minimum energy stored in battery storage
Ω set of scenarios initially generated
Ω' set of preserved scenarios after the scenario reduction process
χ, η charging/discharging efficiency of battery storage
$\lambda_{t,s}$ market price at time t in scenario s ($/MW h)
$\lambda_{l,t}$ electricity price of contracts l at time t ($/MW h)

Variables

$DR_{t,s}$ potential of DRP implementation (the percentage of participation) at time t in scenario s
$ldr_{t,s}$ shifted load by DRP at time t in scenario s
$load_{t,s}$ new load considering DRP at time t in scenario s
$load_{t,s}^{inc}$ load increase of time t in scenario s
$Inc_{t,s}$ size of load increase at time t in scenario s
$P_{l,t}^{BC}$ purchased power from the bilateral contract l at time t (MW)
P_t^{BC} total purchased power from the bilateral contracts at time t (MW)
$P_{t,s}^p$ purchased power from the power market at time t in scenario s (MW)
$P_{j,t,s}^{MT}$ produced power from the jth unit of the micro-turbine at time t in scenario s (MW)
$P_{j,h,t,s}^{MT}$ power relating to block h of jth unit of micro-turbines at time t in scenario s (MW h)
$P_{t,s}^{charge}, P_{t,s}^{disc}$ charging/discharging power of battery storage (MW) at time t in scenario s (MW)
$P_{t,s}^{wind}$ produced power from the wind-turbine at time t in scenario s (MW)
$P_{t,s}^{PV}$ produced power from the PV system at time t in scenario s (MW)
$P_{t,s}^{wind}$ purchased power from wind-turbine at time t in scenario s
$P_{t,s}^{PV}$ purchased power from PV system at time t in scenario s
s_l binary variable, "1" if bilateral agreement l is selected, and 0 otherwise
$U_{j,t}^{MT}$ binary variable, "1" if the micro-turbine j is on at time t, and 0 otherwise
$U_{t,s}^{charge}, U_{t,s}^{disc}$ binary variables, "1" if charging/discharging of battery storage at time t in scenario s
$X_{t,s}^b$ stored energy in battery storage at time t in scenario s

purchase to obtain the minimum procurement cost using the load duration curve (LDC). Different types of energy procurement resources such as call/put options, interruptible contracts and future contracts are reviewed in [18]. A stochastic optimization model for determining the optimal forward loads and selling prices to consumers by a single retailer is proposed in [19–22], subject to a value at risk constraint. In [23,24], the information gap decision theory is used to assess different acquisition strategies for large consumers. A fuzzy-based decision-making system is presented in [25] for energy procurement from alternative resources. Also, the second-order stochastic dominance is developed in [26] for mid-term scheduling problem of large industrial consumers.

In this paper, a stochastic energy procurement problem (SEPP) is proposed for an LEC. Also, the RESs including PV, WT, MT and ESS are considered and then the renewable sources output power, market price and load uncertainties are modeled. Furthermore, the fast forward selection based on Kantorovich distance has been used for scenarios reduction. Finally, the effects of DRP and ESS are studied on deterministic and stochastic energy procurement cost function in four case studies.

1.2. Novelty and contributions of this research

To the best of our knowledge, no stochastic energy procurement problem for large consumer considering the renewable energy resource (RER) in the presence of ESS and DRP has been reported in the literature. Also, the effects of ESS and DRP on EEPC are studied in this paper, the time-of-use (TOU) rate of DRP has been