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A novel two-stage stochastic programming model for uncertainty characterization in short-term optimal strategy for a distribution company

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ABSTRACT

In order to supply the demands of the end users in a competitive market, a distribution company purchases energy from the wholesale market while other options would be in access in the case of possessing distributed generation units and interruptible loads. In this regard, this study presents a two-stage stochastic programming model for a distribution company energy acquisition market model to manage the involvement of different electric energy resources characterized by uncertainties with the minimum cost. In particular, the distribution company operations planning over a day-ahead horizon is modeled as a stochastic mathematical optimization, with the objective of minimizing costs. By this, distribution company decisions on grid purchase, owned distributed generation units and interruptible load scheduling are determined. Then, these decisions are considered as boundary constraints to a second step, which deals with distribution company's operations in the hour-ahead market with the objective of minimizing the short-term cost. The uncertainties in spot market prices and wind speed are modeled by means of probability distribution functions of their forecast errors and the roulette wheel mechanism and lattice Monte Carlo simulation are used to generate scenarios. Numerical results show the capability of the proposed method.

1. Introduction

Power industry all across the world has faced some severe challenges, particularly over the past two decades. During these years, the industry structure has moved from the vertically integrated structure to a more competitive one in which new entities have been appeared in the market framework, the most significant ones being the Generation Companies (GENCO), regulated transmission companies and load serving entities [1].

In this context, various actors are able to obtain benefits from the introduction of Distributed Generation (DG), but new challenges have also emerged. Indeed, while the renewable energy usage reduces environmental emissions, variations in renewable energy generation (due, for example, to uncertainty in wind power) can cause several issues to the power system operator [2] and retailers consequently encounter uncertain and volatile pool based energy price. Moreover, the generation cost of these energies is usually higher than the expected price of the pool [3].

Retailers can play the role of Distribution Company (DISCO), which has become more remarkable as DG technology development and its penetration have increased into the distribution networks. A retailer that assumes the function of DISCO and becomes responsible for electric energy supply has to deal with the tradeoff between different electric energy resources and the uncertainties which characterize them [4]. Stochastic programming can be an

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Nomenclature

n	Set of all buses in the system
t	Set of operating hours
s	Set of scenarios
i	Set of forward contract
g	Set of buses with owned DG units
TD	Considered time slots in one day
NF	Total number of forward contract
NDG	Total number of owned DG units
NIL	Total number of IL contract
$Nload$	Total number of loads
DA	Day-ahead values
HA	Hour-ahead values
F	Forward contract values
G	Owned DG units values
$grid$	Grid values
$COST^{DA}$	Day-ahead cost
COST_t^{HA}	Hour-ahead cost
UT_g^G, DT_g^G	Minimum up-time and down-time of DG units
$\mathrm{R}_{\mathrm{UP},g}^{\mathrm{G}}, \mathrm{R}_{\mathrm{DN},g}^{\mathrm{G}}$	Ramp-up and ramp-down limits for DG units
$\mathrm{v}_{\mathrm{g,T}}^{\mathrm{G}}$	Number of hours that unit g has been on (+) or off (−), at the end of hour t
A_g^G, B_g^G C_g^G, CQ_g^G	Operating cost parameters of DG units
CS_g^G, CD_g^G	Start up and shut down cost of DG units
$\lambda_{i,t}^F$	Price of forward contract
$\alpha_t^{IL},\ \beta_t^{IL}$	Cost parameters of IL contract
$\mathrm{P_g^{Gmin}, P_g^{Gmax}}$	Minimum and maximum DG's active
$\mathrm{Q_g^{Gmin}, Q_g^{Gmax}}$	Minimum and maximum DG capacity limits for reactive power
$\mathrm{L_{t,s}^{IL,DA}}$	Fraction of the total demand for participation in ILs decision in day-ahead scheduling
$\mathrm{L_{n,t}^{IL,HA}}$	Fraction of the load for participation in ILs contract in hour-ahead scheduling
$\rho_{\mathrm{t,s}}^{\mathrm{grid,DA}}$	Day-ahead electricity market price.
$\rho_{\mathrm{t}}^{\mathrm{grid,HA}}$	Hour-ahead active power market price.
$\rho Q_t^{grid,HA}$	Hour-ahead reactive power market price.
MSR_g^G	Maximum sustained ramp rate (MW/min)
QSC_g^G	Quick start capacity
$P_{i,t}^F$	Amount of forward contract
$\mathrm{P_{g,t,s}^{G,DA}}$	Power generated by DG units in day-ahead
$\mathrm{P_{g,t}^{G,HA}}$	Active power generated by DG units in hour-ahead
$Q_{g,t}^{G,HA}$	Reactive power generated by DG units in hour-ahead
$\mathrm{P_{t,s}^{IL,DA}}$	Amount of ILs decision in day-ahead
$\mathrm{P_{n,t}^{IL,HA}}$	Contracted amount of IL in hour-ahead
$Q_{n,t}^{IL,HA}$	Amount of reactive ILs in hour-ahead
$\mathrm{P_{t,s}^{grid,DA}}$	Power purchased from external grid at market price in day-ahead
$\mathrm{P_t^{grid,HA}}$	Active power purchased from external grid at market price in hour-ahead
$Q_t^{grid,HA}$	Reactive power purchased from external grid at market price in hour-ahead
$\mathrm{W_{g,t,s}^G}$	Binary variables denoting DG unit commitment status decisions
$\mathrm{X_{g,t,s}^G}$	Binary variables denoting DG start-up decisions
$\mathrm{Y_{g,t,s}^G}$	Binary variables denoting DG shut-down decisions
$\mathrm{M_{t,s}^{IL}}$	Binary variable denoting the selecting or not the IL decision in day-ahead scheduling
$\mathrm{U_{n,t,s}^{IL}}$	Binary variable denoting the selecting or not the IL contract at each bus in hour-ahead scheduling
$\mathrm{WD_{g,t}^{G,HA}}$	Binary variable for providing non-spinning reserve when it is off

appropriate tool to solve such problems in electric energy trade.

So far, many research works have been devoted to DISCO's operation and planning strategies. From the operation viewpoint, in Ref. [5], the DISCO's operation cost has been minimized in a day-ahead market planning with DGs and Interruptible Loads (ILs). Then, the energy procurement cost (from market, investor-DGs owned and utilities-DGs owned) and the cost paid for the not-supplied loads have been minimized. Moreover, another framework has been shown in order to decrease the DISCOs' risk caused by market price volatility: the optimal decisions on the actual input energy to DISCOs, DG generation planning and IL involved at a bus have been made almost in real-time. This work excluded the uncertainty.

Mashhour et al. [6] have proposed a model for DISCO with high capacity of DG installed based on hour-ahead scheduling. In this model, DISCO was in charge of energy provision and energy procurement based on pool market. In Ref. [7] a multi-period energy acquisition model for DISCO has been proposed in a day-ahead market with contracts on DG and IL. The energy purchasing has been described by means of a two-step optimization problem aimed at maximizing DISCO's profits, accounting for the interactions between DISCOs' strategies. A model for DISCO's energy acquisition market, comprising DGs and ILs with pool-based and bilateral contract market structure, has been presented by Palma-Behnke et al. [8]. Liu et al. [9] have proposed a criteria that takes into account the risk of selling energy in different market structures, including day-ahead, balance and reserve power markets with the objective of minimizing the total electricity cost. In these studies, the portfolio theory has been mainly used assuming the contract price known due to estimation or negotiation.

In the research work performed by López-Lezama et al. [10], a two-stage optimization problem has been presented to define the optimal price for DG contracts in distribution networks. The model considered both the maximization of the profit of DG owner from energy procurement and the minimization of the cost of DISCO to satisfy the demand.

Ref. [11] utilizes nodal hourly electricity pricing to provide a distribution company with a mechanism to specify the day-ahead hourly retail prices according to the load features while including dispatchable and non-dispatchable DGs as well as storage units of battery type. Moreover, Ref. [12] uses a responsive load model to specify the day-ahead hourly prices with the objective of optimizing the DISCO's profit taking into consideration the load demand elasticity and the benefit of consumers while the DISCO possesses smart grid infrastructures such as smart meters and two-way communication system enabling the company to take diverse pricing mechanisms. Another research work devoted to proposing a two-stage model for the DISCO operation in a deregulated