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Incentive-based demand response programs designed by asset-light retail electricity providers for the day-ahead market

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ABSTRACT

Following the deregulation experience of retail electricity markets in most countries, the majority of the new entrants of the liberalized retail market were pure REP (retail electricity providers). These entities were subject to financial risks because of the unexpected price variations, price spikes, volatile loads and the potential for market power exertion by GENCO (generation companies). A REP can manage the market risks by employing the DR (demand response) programs and using its' generation and storage assets at the distribution network to serve the customers. The proposed model suggests how a REP with light physical assets, such as DG (distributed generation) units and ESS (energy storage systems), can survive in a competitive retail market. The paper discusses the effective risk management strategies for the REPs to deal with the uncertainties of the DAM (day-ahead market) and how to hedge the financial losses in the market. A two-stage stochastic programming problem is formulated. It aims to establish the financial incentive-based DR programs and the optimal dispatch of the DG units and ESSs. The uncertainty of the forecasted day-ahead load demand and electricity price is also taken into account with a scenario-based approach. The principal advantage of this model for REPs is reducing the risk of financial losses in DAMs, and the main benefit for the whole system is market power mitigation by virtually increasing the price elasticity of demand and reducing the peak demand.

1. Introduction

The drawbacks of purchasing electricity at wholesale markets for the electricity end-users include the market uncertainty and the financial risks of buying at real-time prices. The participants of the wholesale market should always monitor the market, which is difficult for them and requires unrestricted access to the updated market information. Another barrier for the participation of the end-users in wholesale electricity markets is the lack of the required infrastructure (e.g., smart metering systems at the end-points) in most of the power systems.

The REPs participate in the wholesale market on behalf of the end-users. They shield the end-users from financial risks in the market and the real-time pricing issues, and the end-users pass the price risk onto the REPs. In other words, REPs are load aggregators or electricity suppliers that connect the end-users to the wholesale market. They are always at the risk of buying electricity at prices higher than their selling prices. Therefore, it is essential for them to manage contracts with the supply side in the pool market and with the demand side in the retail market to ensure expected returns [1]. They can implement a combination of approaches to manage the financial risks. Well-designed DR (demand response) programs reduce the consumption during the periods with high electricity prices. It also makes the demand bids more price elastic during the periods with higher prices or the periods with higher risk for the market power experience. Another possible solution is using the DG (distributed generation) units and the ESSs owned by the REPs during the price spikes. Instead of buying the whole electricity demand from the wholesale market, they can serve part of the loads with their light physical assets at the distribution network.

The REPs should determine the optimal bidding strategy for the DAM (day-ahead market) in an uncertain environment. They have

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Nomenclature

Indices

s	scenarios
t	time periods
b	buses
c	consumers
j	REPs
i	DG units
k	ESSs

Variables

$Payoff_j^{DAM}$	expected payoff of REP j in DAM ($)
d_b	purchase from the wholesale market by the REP for each time period (kW)
g_i	real power generation of DG unit i (kW)
u_i	binary decision variable showing the commitment status of DG unit i (1 if the unit is online and 0 otherwise)
v_i	binary decision variable for start-up status of DG unit i (1 if the unit starts up at the beginning of period t and 0 otherwise)
w_i	binary decision variable for shut-down status of DG unit i (1 if the unit shuts down at the beginning of period t and 0 otherwise)
δ_c	binary decision variable showing that the customer is able to reduce the consumption below the baseline power and should receive the financial incentives based on the terms and conditions of the DR program
$p_k^{in/out}$	charging/discharging energy of ESS k during each time period (kWh)
E_k^{stored}	energy storage level of ESS k at the end of each time period (kWh)
x_k	binary decision variable for discharging status of ESS k (1 if it is discharging and 0 otherwise)
y_k	binary decision variable for charging status of ESS k (1 if it is charging and 0 otherwise)
m_c	binary decision variable for the curtailment state of load c
FI	financial incentive for DR in DAM ($/kWh)
Δl	expected demand reduction of consumer c (kW)
DR	the amount of demand reduction that receives the financial incentives through DR programs (kW)

Parameters

τ	duration of each time period (h)
T	number of time periods
N_s	number of scenarios
ω_s	weight of scenario s
l_c	forecasted electricity consumption of consumer c (kWh)
LMP_b	forecasted LMPs at bus b ($/kWh)
R_c	retail electricity prices offered by the REP to customer c for electricity consumption ($/kWh)
c_i^F	fixed cost of DG unit i ($/h)
c_i^P	production cost of DG unit i ($/kWh)
c_i^{start}	start-up cost of DG unit i ($)
$G_i^{Min/Max}$	minimum/maximum power generation of DG unit i (kW)
$E_k^{Min/Max}$	minimum/maximum storage level of ESS k (kWh)
$\eta_k^{in/out}$	charging/discharging efficiency of ESS k
$R_k^{in,Min/Max}$	minimum/maximum charging rate of ESS k (kW/h)
$R_k^{out,Min/Max}$	minimum/maximum discharging rate of ESS k (kW/h)
c_k^{deg}	degradation cost of ESS k ($/kWh)
$FI_c^{Min/Max}$	minimum/maximum financial incentive for customer c ($/kWh)
$LMP_b^{forecast}$	forecasted hourly LMP at bus b ($/kWh)
$LMP_b^{error,s}$	forecast error of hourly LMP at bus b ($/kWh)
$l_c^{forecast}$	forecasted consumption of customer c (kWh)
$l_c^{error,s}$	forecast error of hourly load consumption for customer c (kWh)

Sets

Ω_j	the buses that the REP j serves loads in them
Ω_j^{b-c}	the customers served by the REP j at bus b
Ω_j^{b-DG}	the DG units owned by the REP j at bus b
Ω_j^{b-ESS}	the ESSs owned by the REP j at bus b

to make the optimal decisions based on uncertain and volatile LMP (locational marginal prices), uncertain supply offers and demand bids of other market agents and unpredictable energy consumption of their customers. In this situation, the stochastic programming is an appropriate tool for them to manage their financial risks.

The financial risk management strategies of REPs for short-term markets, compared with the GENCOs, have less been taken into account in recent research publications. In Ref. [2], the REPs determine the optimal portfolio to balance between the benefit and risk in day-ahead and real-time market with or without the bilateral contracts with GENCOs. The only way that the pure retailers in this deterministic model employ is managing the financial risks by vertically integrating with the GENCOs. In Refs. [3] and [4], the REPs respectively employ light physical assets and incentive-based DR programs to manage the financial risks and limit the potential for market power in DAMs. In Ref. [5], it has been demonstrated through numerical simulations that in the current market context, pure portfolios of contracts are incomplete risk management strategies compared to physical hedging.

In Ref. [6], the REPs procure a portfolio of demand-side and supply-side resources to tradeoff the profit against risks in serving loads. Spot market purchases, forward contracts, and DR programs in the form of interruptible contracts are collected in the REP (retail electricity providers)'s portfolio. The demand-side management models introduced in Refs. [2,7–10] are designed to be employed by the retailers. The proposed programs require continuous monitoring and control of electricity end-users over their consumption. These approaches theoretically promote the competition in the wholesale and the retail markets. However, in practice; the end-users do not show interest in plans that requires their continuous awareness about the consumption.

Entities like system operators or market operators look to be the ideal candidates for implementing DR programs [11]. They run DAMs, real-time markets and the electricity wholesale markets where the retailers and GENCOs participate to trade electricity. However, these entities are not usually well-equipped to deal with the individual end-users in most of the electricity markets. Therefore, the responsibility of implementing DR programs remains with the retailer in the foreseeable future [11]. In Ref. [12], three schemes are proposed to foster economic DR in the Midwest ISO. In all these schemes, the REPs in the form of LSE (load-serving entities) and CSP (curtailment service providers) play the main role. In Ref. [13], LSEs

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