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Optimal trading of plug-in electric vehicle aggregation agents in a market environment for sustainability

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HIGHLIGHTS

- Proposing a multi-stage stochastic model of a PEV aggregation agent.
- Reflecting several uncertainties using a stochastic model and appropriate scenarios.
- Updating bids/offers of PEV aggregation agents by taking part in the intraday market.
- Taking part in Demand Response eXchange (DRX) markets.

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ABSTRACT

Ever since energy sustainability is an emergent concern, Plug-in Electric Vehicles (PEVs) significantly affect the approaching smart grids. Indeed, Demand Response (DR) brings a positive effect on the uncertainties of renewable energy sources, improving market efficiency and enhancing system reliability. This paper proposes a multi-stage stochastic model of a PEV aggregation agent to participate in day-ahead and intraday electricity markets. The stochastic model reflects several uncertainties such as the behaviour of PEV owners, electricity market prices, and activated quantity of reserve by the system operator. For this purpose, appropriate scenarios are utilized to realize the uncertain feature of the problem. Furthermore, in the proposed model, the PEV aggregation agents can update their bids/offers by taking part in the intraday market. To this end, these aggregation agents take part in Demand Response eXchange (DRX) markets designed in the intraday session by employing DR resources. The numerical results show that DR provides a perfect opportunity for PEV aggregation agents to increase the profit. In addition, the results reveal that the PEV aggregation agent not only can increase its profit by participating in the DRX market, but also can become an important player in the mentioned market.

1. Introduction

1.1. Motivation

Electrification of transportation is a key element to enhance energy security by varying resources of energy, to support economic growth by forming advanced industries and, to conserve the environment by reducing pollutions [1]. Electric Vehicle Initiative (EVI) and International Energy Agency (IEA) reported that the global Electric Vehicle (EV) stock was more than 180,000 at the end of 2012 [2]. The market share of EVs can be significantly increased in most of countries, since some national targets for EV developments have been considered in the near future. On this basis, several policies have been implemented, such as incentives/-subsidies for the purchase cost of EVs and infrastructure requirements [1].

Moreover, according to the growth of energy sustainability concerns, Plug-in Electric Vehicles (PEVs) are a key element in

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Nomenclature

Indices (Sets)

d	demand response provider
k	block of price-quantity offer
i	plug-in electric vehicle
t	time
$\omega(\Omega)$	scenario

Parameters and variables

$Act_{t,\omega}^{Res}$	activated amount of reserve by system operator
$C^{battery}$	battery investment cost
$C^{\deg}$	degradation cost
$c_{d,t}^{k}$	offered price of demand response provider
$Cost_{t,\omega}^{Charge}$	cost of purchasing energy to charge PEVs
$Cost_{t,\omega}^{Obl}$	cost of purchasing energy to meet the aggregation agent obligations
$Cost_{t,\omega}^{Imb}$	cost of imbalance penalties
$Cost_{t,\omega}^{Intra}$	cost of purchasing from the intraday electricity market
$Cost_{t,\omega}^{DRX}$	cost of purchasing DR from intraday DRX market
$Cost_{\omega}^{Res}$	payment cost to PEV owners for taking part in the reserve market
$Cost^{Infra}$	annualized infrastructure cost
$Cost^{Wiring}$	wiring upgrade cost
$Cost^{On-board}$	on-board incremental cost
$CDRP_{d,t}$	cost of demand response provider
dr	yearly discount rate
$DR_{d,t}$	traded amount of DR in DRX
$DR_{d,t}^{\max}$	maximum offered capacity of DRP d
E_{Ω}	expected value resulted from set of scenarios
FOR^{Agg}	probability of inability to generate energy
$Income_{t,\omega}^{Res}$	income resulted from taking part in the reserve market
$Income_{t,\omega}^{Call}$	income resulted from delivering the delegated amount of reserve
$Income_{t,\omega}^{Energy}$	income resulted from participation in the electricity market
$Income_{t,\omega}^{Intra}$	income resulted from selling to intraday electricity market
$Income_{t,\omega}^{DRX}$	income resulted from selling DR to intraday DRX market
$Income_{\omega}^{Charge}$	income of charging the PEVs
$L^{battery}$	battery lifetime
N^{y}	life expectancy of device
$Offer_{t,\omega}^{Res}$	quantity of offer to reserve market
$Offer_{t,\omega}^{En}$	quantity of offer to energy market
$P_{t,\omega}^{del}$	probability of delivering the delegated amount of reserve
$P_{i,t,\omega}^{G2V}$	injection from grid to PEV i
$P_{t,\omega}^{Intra,buy}$	buying power in intraday market
$P_{t,\omega}^{Intra,sell}$	selling power in intraday market
$P_{i}^{\max}$	maximum power of PEV to participate in electricity markets
$P_{t,\omega}^{Sch}$	scheduled generation of the PEV aggregation agent
$P_{i,t,\omega}^{V2G}$	injection from PEV i to grid
$q_{d,t}^{k}$	offered quantity of demand response provider
r_t^+, r_t^-	positive and negative imbalance ratios
$SOC_{i,t,\omega}^{Disconnect}$	state of charge when disconnecting from the grid
$\Delta_{t,\omega}^{+}, \Delta_{t,\omega}^{-}$	positive and negative deviations
η_i^C, η_i^D	charging and discharging efficiencies
γ	maximum modification level in intraday markets
$\pi_{t,\omega}$	occurrence probability of scenario ω
$\lambda_{t,\omega}^{DA}$	price of day-ahead energy market
$\lambda_{t,\omega}^{Intra}$	price of intraday market
$\lambda_{t,\omega}^{Bal}$	price of balancing market
$\lambda_{t,\omega}^{Res}$	price of spinning reserve market
$\lambda_{t,\omega}^{DRX}$	price of DRX market
$\lambda_{t}^{ContRes}$	price of spinning reserve contract
λ_{t}^{ContEn}	price of energy contract

the sustainable energy systems [3,4]. Researches on the driving patterns reveal that the overwhelming majority of the EVs can be connected to the grid and trade energy with the electricity markets, while an ample part of the stored energy is eventually remained [5,6]. Currently, development of technologies of EVs causes an increase of the market share of these vehicles. Therefore, a massive amount of PEVs jeopardizes the power system's quality and stability [7,8] and as a result the management of this new resource have become unavoidable [9,10]. Depending on the level of deregulation of the market, some of the market players (e.g., Demand Response Providers (DRPs) and retailers) can manage the operation of PEVs [11]. In this paper, it is supposed that the market player's activities are totally disaggregated from each other.

On this basis, the PEV aggregation agent as a new player in the market is considered to manage the PEVs and control the discharge/charge of their batteries. The assumption is because PEV owners prefer to separate their PEV contracts from the other household consumptions for three reasons. First, the expenses of vehicles have always been separated from households' costs. Second, the PEV may have a major role in current expenditure of the household, since it can increase residential electricity consumption by approximately 50% [12]. Third, the PEV has a different nature compared to common electricity end-users due to its ability of charging/discharging, and consequently it can easily participate in different electricity markets [13].

The PEV owners' uncertain behaviour causes that the PEV aggregation agent should confront numerous challenges in order to contribute in electricity markets. The uncertain feature of this new market player can cause that its primary bids/offers have various deviations from the actual amounts and it consequently poses undesirable costs for the PEV aggregation agent. This is because of the inequity between the scheduled and actual consumption/production. Nevertheless, from the day-ahead session to the balancing one, the PEV aggregation agent is able to gather a number of new data in order to modify its primary bids/offers in an intraday market. Due to the high level of uncertainty of PEV owners' behaviour, the PEV aggregation agent requires to take part in short-time session markets, e.g., intraday market. It should be mentioned that, regarding the participation in the intraday markets, there are three major differences between the PEV aggregation agent and other market players:

- First, the main source of the thermal and especially renewable energy units to obtain profit is generally the electricity market. Therefore, these market players can directly achieve benefit from participating in the intraday markets because the mentioned markets enable them to cover their uncertainties