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Optimised performance of a plug-in electric vehicle aggregator in energy and reserve markets

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ABSTRACT

In this paper, a new model is developed to optimise the performance of a plug-in Electric Vehicle (EV) aggregator in electricity markets, considering both short- and long-term horizons. EV aggregator as a new player of the power market can aggregate the EVs and manage the charge/discharge of their batteries. The aggregator maximises the profit and optimises EV owners' revenue by applying changes in tariffs to compete with other market players for retaining current customers and acquiring new owners. On this basis, a new approach to calculate the satisfaction/motivation of EV owners and their market participation is proposed in this paper. Moreover, the behaviour of owners to select their supplying company is considered. The aggregator optimises the self-scheduling programme and submits the best bidding/offering strategies to the day-ahead and real-time markets. To achieve this purpose, the day-ahead and real-time energy and reserve markets are modelled as oligopoly markets, in contrast with previous works that utilised perfectly competitive ones. Furthermore, several uncertainties and constraints are taken into account using a two-stage stochastic programing approach, which have not been addressed in previous works. The numerical studies show the effectiveness of the proposed model.

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1. Introduction

1.1. Motivation and aim

Today, replacement of combustion vehicles with electric ones makes the management of this resource more important than before. Since the importance of energy conservation and environmental protections is growing, plug-in Electric Vehicles (EVs) can significantly affect the grid and play a major role in the future smart grid [1–4]. References [1–4] showed that, if there was not a comprehensive plan for EVs management, not only the EVs would deteriorate the conditions of distribution network, but also their charge time might be simultaneous with the system load peak and increase the stability, reliability and economic problems of the power system.

At any given time, at least 90% of the EVs are theoretically available to behave as a generation unit and participate in the electricity market [5,6]. Ref. [7] has indicated that, the daily average travel distance in the United States is less than 51 kilometres, leading an average time of 52 min to commute, although the commuting times vary from one city to another one. On this basis, in average, EVs are located in the parking spaces about twenty-three hours per day and the distance driven is less than the EVs' battery capacity. It can be concluded that, the entire energy of EVs is not consumed during daily travel [7].

Although EVs are able to provide various ancillary services [8], the simultaneous connection of numerous EVs to the network can be a major threat for the power quality and even the power system stability [9]. EV aggregator as a new player of the power market can aggregate the EVs and manage the charge/discharge of their batteries.

Recent advances in smart metering technologies provide a bi-directional communication between the utility operator and the consumers. To this end, the EV aggregators offer incentives to the EV owners, usually in the form of monetary rewards, to allow them to operate their EV batteries. In this context, smart metering devices can positively affect the future of smart grid by obtaining precise information and effective involvement of the EV owners. On the other hand, since a large number of managing and controlling data in the network imposes market participants to employ

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Nomenclature

Indices

i	index of Gencos
j	index of retailers
t	index of hours
v	index of EV owners
yr	index of years
ω	index of scenarios

Parameters

C_d	degradation cost because of utilising V2G
C_v^{EV}	battery capacity of EV v
FOR^{Agg}	aggregator's unavailability for generating
$P_{t,\omega}^{del}$	probability of being called to generate
P_{Energy}	EV's power limit for energy trade
P_{Res}	EV's power limit for supplying spinning reserve
PEV_{tot}	number of connected aggregator's customers
RU_i, RD_i	ramp up and down constraints
r_t^+, r_t^-	positive and negative imbalance ratios
$rate_{yr}^{ini}$	initial grow rates of customers
γ	factor of grow rate
η_v^C, η_v^D	charging and discharging efficiencies
η_{sys}	round-trip efficiency
$\pi_{t,\omega}$	occurrence probability of scenario ω

Variables

$Act_{t,\omega}^{Res}$	quantity of reserve activated by ISO
$D_{j,t,\omega}^{DA}, D_{j,t,\omega}^{RT}$	day-ahead and real-time bids of retailer j
E_Ω	expected value obtained from set of scenario Ω
$F_{t,k,\omega}, F_{t,k,\omega}^{cg}$	branch flow in normal and contingency states
$I_{i,t,\omega}$	variable of commitment of unit i
N_{yr}^{cust}	number of aggregator's customers
N_{yr}^{tot}	total number of EVs
$Offer_{t,\omega}^{Res}, Offer_{t,\omega}^{NRes}$	spinning and non-spinning reserve offers
$Offer_{t,\omega}^{En}$	offer to participate in energy market
$P_{i,t,\omega}^{DA}, P_{i,t,\omega}^{RT}$	day-ahead and real-time generation offers of unit i
$P_{i,t,\omega}^{Res}, P_{i,t,\omega}^{NRes}$	spinning and non-spinning reserves of unit i
$P_{v,t,\omega}^{G2V}$	energy of grid injected to EV v
$P_{v,t,\omega}^{V2G}$	energy of EV v injected to grid
$Profit_{yr}^{cust}$	EV owner's annual profit
$Profit_{yr}^{*}$	owner's profit from contract with other competitors
$SOC_{v,t,\omega}$	state of charge of EV v at time t
$SOC_{v,t,\omega}^{Disconnect}$	state of charge when disconnecting
$a_{i,\omega}, b_{i,\omega}, c_{i,\omega}$	estimated coefficients of cost function
$e_{j,\omega}, f_{j,\omega}$	estimated coefficients of revenue function
$r_{v,t,\omega}^{charge}, r_{v,t,\omega}^{discharge}$	rate of charge and discharge of EV v
$rate_{yr}$	annual grow rates of customers
$t_{Connect(v,\omega)}$	time of connection EV v to aggregator
$t_{Full(v,\omega)}$	time of obtaining full charge of EV
t_{Charge}	duration of charging
$t_{Energy}, t_{Reserve}$	duration of participation in energy and reserve markets
$y_{i,t,\omega}, z_{i,t,\omega}$	variables of starting-up and shutting-down
$\delta_{v,t,\omega}$	binary variable of charging or discharging of EV v
λ_{V2G}^{ContEn}	tariff for purchasing energy
$\lambda_{G2V}^{ContEn}, \lambda^{ContRes}$	tariffs for participating in the energy and reserve markets
$\lambda_{t,\omega}^{DA}, \lambda_{t,\omega}^{RT}$	day-ahead and real-time energy market prices
$\lambda_{t,\omega}^{Res}, \lambda_{t,\omega}^{NRes}$	price of spinning reserve market
$\lambda_{i,\omega}^{up}, \lambda_{i,\omega}^{down}$	estimated start-up and shut-down costs
$\Delta_{t,\omega}$	total deviation of balance market
$\Delta_{t,\omega}^+, \Delta_{t,\omega}^-$	positive and negative deviations of balance market

new computational methods to mitigate the system operation time, the utilisation of future advanced analysis techniques is required. Therefore, development of the future advanced analysis techniques can significantly facilitate the aggregation of EVs. Therefore, both smart metering technology and advanced analysis techniques (e.g. collective awareness systems [10] and cloud-based engineering systems [11]) are required to support the participation of EVs in the electricity markets and they can be an effective solution to increase the participation of EV owners in the markets.

As a matter of fact, the EV aggregators can provide connectivity communication capabilities for EV owners' components in order to connect them to the analysis system and they are responsible for the installation of the smart metres at EV owners' premises. This can reduce the technical complexity and the required efforts to increase the local computational resources at the level of each EV owner's component. On the other hand, the advanced techniques can improve the security of the mechanisms and consequently they can increase the robustness of collecting data by the aggregators.

In this paper, a new model is described to optimise the performance of the EV aggregator in electricity markets. The EV aggregator as a financial agent in the power market has to compete with other players to sell or purchase electricity in the day-ahead and real-time markets. In the business competition, the aggregator has to compete for keeping the existing customers and attracting new owners. In other words, the aggregator should struggle with other market participants in three sides: offering strategy with Generation companies (Gencos), bidding strategy (with retailers) and customers (also with retailers).

The aggregator is considered as a private entity who wants to maximise its own profit. The player is able to manage its customers' charge and discharge pattern using a direct control approach when they are plugged-in. The paper models that the EV owners can select their supplying company for buying/selling electricity, so the EV aggregator should compete with other market players to preserve and increase the number of customers by optimising its proposed prices in the contract. The competition of the EV aggregator for customers has not been addressed in previous works. The competition space of the aggregator is illustrated in Fig. 1.

The new model developed in this paper considers the impact of tariffs to motivate the owners to participate in the electricity market and to connect to the aggregator.

On this basis, short- and long-term objectives of the EV aggregator are simultaneously considered, involving both grid-to-vehicle (G2V) and vehicle-to-grid (V2G) capabilities. The short-term objective is to maximise the profit obtained from offering/bidding strategy of the aggregator in the electricity markets, while the long-term one is to maximise the profit resulted from grabbing the market share from other competitors. The participation of EV owners (both new and existing customers) in each month is also calculated, using a motivation function.

1.2. Literature review and contributions

Many reports have presented the advantages and disadvantages of EVs without V2G capability [9,12,13]. In [9], a stochastic programming method was presented to demonstrate the influence

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