A Price Mechanism Design for Energy Trading at Huge Parking Lots

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Abstract

In the recent years, electric vehicles (EVs) are considered as a key technology for achieving efficient transportation with high fuel economy and low pollution emissions. While most of researches on EVs always observe EVs as energy consumers, we look for a new angle where EVs are totally vacant resources during parking time. They then can sale their surplus electricity to parking lot operators (PLOs) where they are parking. By doing an energy business, EVs proprietors are going to enrich despite just leaving their unused EVs at parking lots. On the other hand, it helps PLOs to relieve the energy shortages at peak times as well as openly trade in energy. However, it is extremely difficult for PLOs to determine how much electricity it should buy from each EV and how much it should pay for that buying amount when the selling price is only known by each EV. Therefore, designing a price mechanism need to deal with this kind of information asymmetry. With this in mind, we adopt contract theory that is famous framework can overcome the information asymmetry to design a price mechanism for energy trading between EVs and PLOs. The simulation results illustrate that proposed mechanism not only attract more EVs to participate in the trade with PLO but also maximize the revenue of PLOs.

Key word: Price mechanism, electric vehicle, energy trading, parking lot, contract theory.

1. Introduction

In the recent years, electric vehicles (EVs) are considered as a key technology for achieving efficient transportation with high fuel economy and low pollution emissions [1]. However, people have progressively been concerning about charging problem, thus most of researches on EVs focus on charging problem [2, 3]. In these works, EVs are observed only as energy consumers in these studies but if we look for a new angle where EVs are totally vacant resources during parking time, EVs can become a potential energy supplier. Thank to wireless charging technologies, EVs from now can be charged without any human supports. These EVs equipped bidirectional charger then can not only draw the energy from the grid but also transfer energy back to the grid. Statistically, private EVs are parked roughly 23 hours per day [5]. During this parking time, the owners of EVs can remotely decide when to charge and discharge their EVs based on the real-time power grid price. Taking this advantage into energy trading, now is time to change the role between PLOs and EVs, PLOs becomes consumers and EVs turn into suppliers. By doing an energy business, EVs proprietors are going to enrich despite just leaving their unused EVs at parking lots. On the other hand, it helps PLOs to relieve the energy shortages at peak times as well as openly trade in energy.

As the same model of our previous work [5], we consider scenario where EVs park at huge parking lots of huge shopping malls, airports, etc. Evidently, these buildings are one of three largest energy consumption sectors [6]. By the reason of providing parking and charging services, we observe these building as EV parking lot operators (PLOs). PLOs are energy suppliers of EVs since they offer charging service for EVs. Generally, they purchase power from the grid with wholesale prices, then charge EVs with the retail prices. In spite of wholesale price, it will be expensive at the peak demand times. If they can get power from the cheaper sources, then it can save considerably money.

In this paper we conceive the idea of parking at PLOs of EVs into trading energy with PLOs that was proposed by us in the work [5]. However, in this study, we supposed that all Evs sale electrcity with the same price. This is not true in the practical scenerios. Realistically, electricity price is dymanic, the charging price of each EV thus are different and is not known by PLOs. PLOs need a price mechanism how they can determine a group EVs to buy electricity with the minimizing total payment prices. Besides, the price mechanism need to be designed such a way attracting the lagest number EVs to joint the trading. To address the problem, contract theory, which is a powerful tool from microeconomics, can be adopted to incentivize the trading participants based on their true types under information asymmetry [7].

In this work, we design an energy trading price mechasim at huge parking lots based on contract theory. We then compare the contract-based price mechanism of energy trading to a fractional Knapsack based one that was proposed in [5].

The remainder of this paper is organized as follows. The full sketch of system model is demonstrated in Section 2. In section 3 we show our problem formulation based on contract theory. Simulation results are shown in section 4. Section 5 summarizes the paper.

2. System model

In this study we consider a model system illustrated in Fig.1 composed of two types of entity: one PLO capable of charging EVs and set of n EVs $\mathcal{E}=\{e_1,e_2,...,e_n\}$ parked at PLO. Each EV before leaving PLO will send an energy trade agreement to PLO if they want to do business with PLO during parking time at here. PLO manages their client list and send the procurement of power to them whenever it has demand of investing on their EVs customers. Each EV i remotely submit their energy deal including sellable amount θ_i. PLO gathers all EV's offers and start the procedure of electing EVs who it should trade with. Finally, PLO send a notice to these EVs to informs how much energy that is bought, then an energy trading is processed.

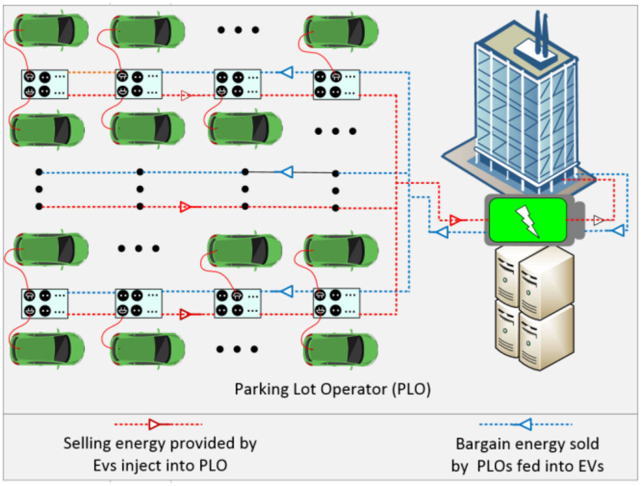

Figure 1: System model illustration

3. Energy trading price mechanism design

In this section we will discuss about contract theory, then design the price mechanism.

3.1. PLO modeling

When PLO needs electricity, it will buy from EVs who can offer electricity at a price lower than that in the traditional market. We denote D as the demand of PLO. Since the generation capacity of an EV is limited, it is common to buy electricity from multiple EVs.

Let a_i be the amount of electricity the PLO gets from an EV i. As a reward, the PLO gives a payment p_i to the EV accordingly. With a transaction (a_i, p_i), the PLO's utility is calculated as:

$$U_{PLO}=\delta_g * a_i - p_i (1)$$

To maximize its revenue in the transaction, a selfish and rational PLO should decide how much power it should buy from each of the EV and how much money it should pay.

3.2. EV modeling

Intuitively, the sellable amount a_i of each EV is obtained with different prices. We name this price as cost price that is private information which is only known to the EV itself.

To distinguish the heterogeneous EVs, we categorize them into N types according to their cost price with indices $\delta_1,\delta_2,...,\delta_N$. Without loss of generality, we assume that $\delta_1<\delta_2<...<\delta_N$.

The utility an EV i gets for selling a_i units of power is defined as

$$U_i(a_i,p_i)=p_i-\delta_g * a_i (2)$$

Since the PLO want to maximize its utility, it should adopt different buying price strategies toward different types of EVs with different cost prices.

3.3. Contract based price mechanism design

Our objective is fulfilled the demand of PLO with maximizing the utility. The PLO needs to determine how much power should be bought from an EV and how much it should pay.

To be a feasible scheme, the designed contracts should satisfy the Individual Rationality (IR) constraint and the Incentive Compatibility (IC) constraint, which are defined as follows.

*Definition 1: **IR constraint:*** A contract satisfies the individual rationality constraint if the utility of each type of EVs is guaranteed to be nonnegative, i.e.,

$$U_i(a_i,p_i)\geq 0, \forall i \in N (3)$$

where, U_i is the utility of type$-i$ EVs.

The IR constraint motivates the trading of the self-interested participants, since positive profit can be gained from the trading.

Definition 2: **IC constraint:** A contract satisfies the incentive compatibility constraint if the contract (a_i,p_i) chosen by the EVs of type$-i$ attains the highest utility they could obtain, i.e.,

$$U_i(a_i,p_i)\geq U_i(a_j,p_j), \forall i \in N (4)$$

The IC constraint makes the EVs of type$-i$ prefer the contract (a_i,p_i) over all other options. The IR and IC constraints are the basic conditions each EV must follow when it makes the trading decision. Besides, as each type$-i$ can supply the energy up to its maximum supplying capacity denoted as a_i^{max}, the price mechanism needs to care about the supplying capacity constraint. That means the contract strategy is not allowed to exceed the maximum supplying capacity of each type$-i$.

$$a_i \leq a_i^{max} (5)$$

In addition, PLO will procure electricity to achieve its requirement demand D.

$$\sum_{i=1}^{N} n_i a_i \leq D (6)$$

where n_i is the number of EVs that belongs to type-i.

The contract-based optimization problem for maximizing the revenue of PLO can be formulated as

$$\begin{aligned} \underset{(a_i,p_i)}{\text{maximine}} \quad & U_{PLO} = \sum_{i=1}^{N} \delta_g a_i - p_i \\ \text{subject to} \quad & U_i(a_i,p_i) \geq 0,\ i = 1,\ldots,N, \\ & U_i(a_i,p_i) \geq U_i(a_j,p_j),\ i,j = 1,\ldots,N; i \neq j, \\ & a_i \leq a_i^{max},\ i = 1,\ldots,N, \\ & \sum_{i=1}^{N} n_i a_i \leq D,\ i = 1,\ldots,N. \end{aligned} \quad (7)$$

We solve problem (7) by the GUROBI optimizer [8].

4. Simulation Results

In this section, we perform simulations to evaluate the performance of our proposed algorithm. We consider a system with 1 PLO and 80 EVs. Sellable capacity of EVs is uniformly selected between 10 KWh and 140 KWh. There are 0 types of EVs, whose cost price are chosen randomly in the set of (0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.45, 0.5, 0.55)$/KWh. The demand of PLO is chosen randomly within the range of [1, 7] MWh. The electricity grid price is assigned to 1$/KWh.

We compare our proposed approaches with fraction knapsack mechanism [5].

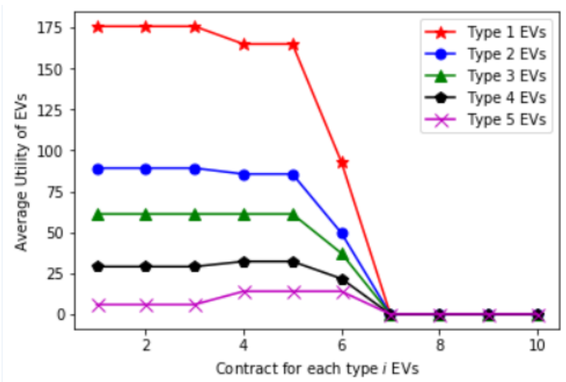

Figure 2: Utility of EVs under different contract strategies.

We firstly verify the correctness of IR and IC constraints by illustrating the average utility of EVs under different contract types. The results show that each EV gains the maximal utility at the contract item of its own type. At the other contract items their utility loses.

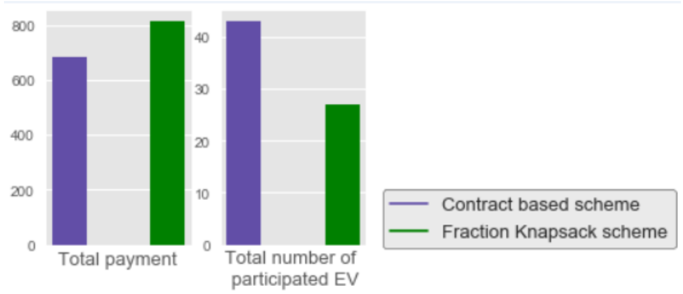

Figure 3: Performance under different algorithms.

Next, we compare our proposed to fraction knapsack-based mechanism over the total payment and the total number of participated EVs as shown In Fig. 3. It is obvious that our proposed method always outperforms the fraction knapsack-based mechanism. The PLO not only attracts more EVs to sell electricity but also minimizes its own payment. It means that PLO can maximize its own revenue.

5. Conclusion

In this study, an energy trading mechanism between PLO and EVs is designed based on contract theory framework. The simulation results illustrate that proposed algorithm can attract more EVs to participate in the trade with PLO. Moreover, PLO can maximize its own revenue. In addition, proposed algorithm outperforms fraction knapsack algorithm under various simulation scenarios.

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