Energy Trading at Huge Parking Lots: Trend to Change the Role between Suppliers – Parking Lot Operators and Consumers – Electric Vehicles

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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. Evidently, most of researches on EVs focus on charging problem and EVs are observed only as energy consumers in these studies. Unlike other works, we look for a new angle where EVs are totally vacant resources during parking time. EVs therefore can invest their batteries in energy trading with parking lot operators (PLOs) since they can inject energy back into gird. The role between PLOs and EVs then reverses presently, 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. The problem is illustrated as Fractional Knapsack problem, and we propose a greedy algorithm to achieve optimal power trading mechanism efficiently. The simulation results illustrate that proposed algorithm not only has proximity result to optimal algorithm but also outperforms compared to greedy algorithm in both total revenue and total buying energy.

Key word: Electric vehicle, energy trading, parking lot, fractional knapsack.

1. Introduction

In the recent years, EVs are considered as a key technology for achieving efficient transportation with high fuel economy and low pollution emissions [1]. However, people progressively concern about charging problem. Most of researches on EVs focus on charging problem and EVs are observed only as energy consumers in these studies [2, 3]. But if we look for a new angle where EVs are totally vacant resources during parking time, EVs can become a potential energy supplier.

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 [4]. We observe these building as EV parking lot operators (PLOs). PLOs are energy suppliers of EVs since they offer charging service for EVs. 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.

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.

In this paper we conceive the idea of parking at PLOs of EVs into trading energy with PLOs. The problem is illustrated as Fractional Knapsack problem. It is NP-hard problem, then we propose a greedy algorithm to achieve optimal power trading mechanism efficiently.

The remainder of this paper is organized as follows. The full sketch of system model is demonstrated in Section 2. In section 2 we show our problem formulation. Simulation results are shown in section 4. Section 5 summarizes the paper and draw some future works.

2. System model

In this study we consider a model system illustrated in Fig.1 composed of two types of entity: one PLO be 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 their parking time. 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, and selling price δ_i. PLO gathers all EV's offers and start the procedure of electing EVs who should it trades with. Finally, PLO sends a notice to these EVs to informs how much energy that is bought, then an energy trading is processed.

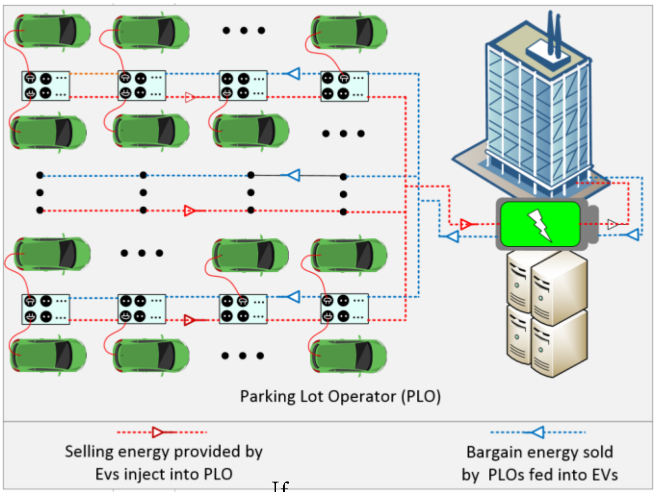

Figure 1: System model illustration

3. Problem formulation

From the side of PLO, their objective when doing energy trading is to maximize its total revenue that is observed as the excess of the grid's selling price δ_g over the EVs selling price δ_i. Therefore, the energy trading between PLO and EVs is formulated as an optimization of maximizing the total revenue of PLO while respecting buyer demand constraint ω that is total imperative requirement at that time. The buyer demand constraint can be described mathematically by an integer decision value x_i $(0 \le x_i \le 1)$ that denotes the fraction of energy bought from seller i.

Then the total revenue gained from n sellers EVs can be formalized as,

$$\begin{aligned} \text{Max} \quad & R = \sum_{i=1}^{n} (\delta_g - \delta_i)\theta_i x_i \\ \text{s.t.} \quad & \sum_{i=1}^{n} \theta_i x_i \le \omega \\ & x_i \in [0,1], \ \forall i \end{aligned} \qquad (1)$$

Since $x_i \in [0,1]$, the problem (1) is a case of fractional knapsack problem. The seller EVs are known as "items", and the first constraint is considered as "weight capacity" of a "bag". We then utilize a greedy algorithm to be achieve the optimal solution [6, 7]. The core concept behind this greedy algorithm is as follows: the seller EVs firstly are sorted in descending order according to the interest p_i that buyer receives when buying energy of EV i per energy unit, where

$$p_i = \frac{\delta_g - \delta_i}{\theta_i}.$$

The greedy method next is performed by picking a seller EV i in that order if its whole selling energy amount is less than or equal to the residual buying demand capacity $\overline{\omega}$ of the buyer. However, if the whole selling energy amount of i exceeds the residual capacity of knapsack, the buyer then purchases only a fraction of the amount from the remaining seller EVs. These decisions will be done by exploring properly the value of control variable x_i. The variable x_i hence is designed as

$$x_i = \begin{cases} 1 & \text{If } \theta_i > \omega - \overline{\omega} \\ \omega - \overline{\omega} / \theta_i & \text{If } \theta_i \le \omega - \overline{\omega} \end{cases} \qquad (2)$$

The detail of greedy algorithm is illustrated in algorithm 1

Algorithm 1: Fractional Knapsack based Energy Trading at POL.

Input: $\theta = [\theta_i]_{1\times n}$, ω, δ_g, $\delta = [\delta_i]_{1\times n}$

Output: R

1. Initialization: x_i = $[0]_{1\times n}$, $\overline{\omega}$=0, R = 0

2. Compute $P = [p_i]_{1\times n}$

2. Sort the sellers by p_i in descending order.

3. **for** i = 1 **to** n:

4.   **if** $\theta_i \le \omega - \overline{\omega}$:

5. x_i = 1

        $\mathrm{R} = \mathrm{R} + (\delta_g - \delta_i)\theta_i x_i$

6. $\omega = \omega + \theta_i$

7.   **else**:

8. $x_i = \omega - \overline{\omega} / \theta_i$

9. $\mathrm{R} = \mathrm{R} + (\delta_g - \delta_i)\theta_i x_i$

10.   break

11.   **end if**

12. **end for**

13. Return R.

4. Simulation Results

In this section, we perform simulations to evaluate the performance of our proposed algorithm. EVs capacity is uniformly selected from list [16, 18, 22, 24, 27, 90] based on capacity of six current popular EV types [8]. The sellable amount of each EV can be up to 90% its current available capacity. There are 100 EVs. The local peak constraint is set to 1000kWh [1]. The demand of each EVs is following a uniform distribution from 10kWh to 25kWh. For selling energy price and grid price are referred to these price in South Korea. The values can be found at Korean Electric Power Corporation KEPCO homepage [9], the selling price is uniformly distributed in range [52.5, 110.7] kRW, and the grid electricity price is picked as 178.7 (KRW/kWh).

We compare our proposed approaches with two other approaches: 1) The first approach is first come first serve (FCFS) mechanism. Who submits the selling request first, then it will be early accepted first. The process will be kept continuously until satisfying global peak constraint. 2) The second approach is optimal algorithm. A solution of the optimization problem (1) is found using general solver, the GUROBI optimizer [11].

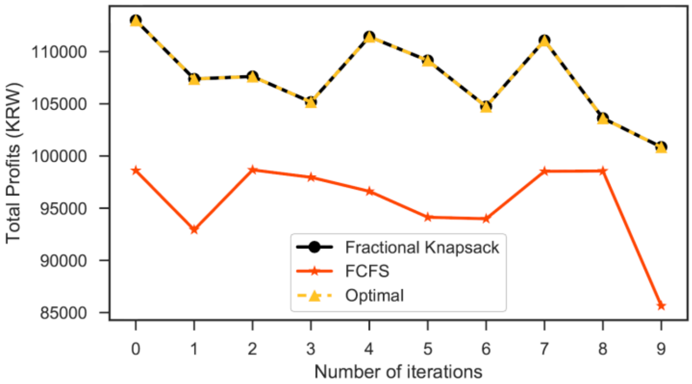

Figure 2: Total profits under different independent simulation running times.

We firstly evaluate the efficiency of our proposed by making a comparison between three algorithms over the total profits that the buyer can gain from doing business with EVs. The total received profit is shown In Fig. 3. It is obvious that our proposed method always outperforms the FCFS algorithm. Besides, the result of fractional knapsack algorithm and optimal algorithm are precisely equal all times.

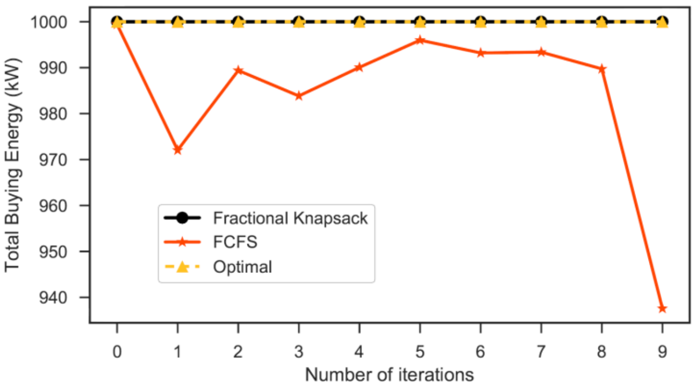

Figure 3: Total buying energy with different number of simulation iterations

The next simulation value is total buying energy over three algorithms that shown as in Figure 4. By dealing with the factional of sellable energy of each EVs, the proposal always supplies enough the demand energy amount of the buyer. Without fractional mechanism, the FCFS shows that there is mostly insufficient to meet the energy required demand. By flexible choosing clients with changeable energy amount, our fractional knapsack based approach ensures that it can provide energy amount as much as the demand if this amount is less than or equal to the total sellable of all parked EVs.

5. Conclusion

In this study, an energy trading mechanism between PLO and EVs is designed based on Fractional Knapsack framework. The simulation results illustrate that proposed algorithm has a proximity result to optimal algorithm in both total revenue and total buying energy. In addition, proposed algorithm outperforms FCFS algorithm under various simulation scenarios. Auction game and long-time trading policy are addressed as our future work.

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