

V2V Energy Sharing Mechanism: A Supplier–Demander Matching Game

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Abstract

Battery swapping station (BSS) is a place where EVs can swap their depleted battery for full-charged battery in short time. While most of studies focus on charging scheduling with scenario that depleted battery is always replaced by full-charged battery stored at BSS, we consider scenario that EVs can swap their depleted battery with other EVs. Our proposed mechanism is worth when BSS is insufficient of full-charged batteries in order to serve swap battery requests because it can relieve stress of high demand at BSS. In addition, the proposed V2V energy sharing design can not only decrease range anxiety of EVs, but also bring economic benefit to EVs owners. A mathematical model is formulated as one-to-one matching game. A matching based- V2V energy sharing algorithm is proposed to determine an optimal V2V pairing. We perform simulation to demonstrate the efficient of the proposed algorithm.

Key word: Electric vehicle, Battery exchange, Energy sharing, Battery swapping station, Matching game.

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]. Battery swapping station (BSS) model is proposed to reduce the charging time by allowing EVs swap their depleted battery for full-charged battery because charging at charging station takes long charging time. [2, 3,4].

The battery swapping station is deployed in real life by companies such as Tesla, NIO, and BJEV. Battery swapping process at BSS is composed of two steps. Firstly, BSS collects a depleted battery by unloading the depleted battery from a required swap EV. Next, BSS provides a full-charged battery by loading the full-charged into that EV. The swapping time only takes within tens of second to several minutes [4], it is even faster than filling a patrol car.

In addition, BSS are a great way to reduce the EV's cost since battery is an expensive component of an EV. By using the swap battery service, EV's owners only needs to pay the cost of EV without battery because batteries now own by BSS. Besides, the EV's owners are no longer concerned about battery lifetime. With these benefits, it much easier to own an EV.

Most of studies on BSS focus on charging scheduling at BSS to minimize the cost of BSS while satisfying demand of battery swapping [4, 5]. Unlike these works, we consider scenario where EVs can be demanders or suppliers depending on their battery level. EVs having depleted battery are demanders while EV having more battery can be suppliers. Our proposed model, V2V energy sharing, is motivated by a scenario when BSS is in high demand (not enough full-charged battery to swap battery for demanders). BSS then can operate V2V energy sharing mechanism to relieve stress of high demand at BSS, decrease range anxiety of EVs, and bring economic benefit to

EVs owners. In addition, suppose that there are few BSS and taxicabs belong to a company, by using our proposed method, the company can balance demand–supply between its BSS to not only increase service quality but also earn more money.

In this work, we design a supplier – demander energy sharing mechanism at based on matching game. We then compare the matching-based V2V energy sharing to greed-based mechanism.

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 matching game. Simulation results are shown in section 4. Section 5 summarizes the paper.

2. System model

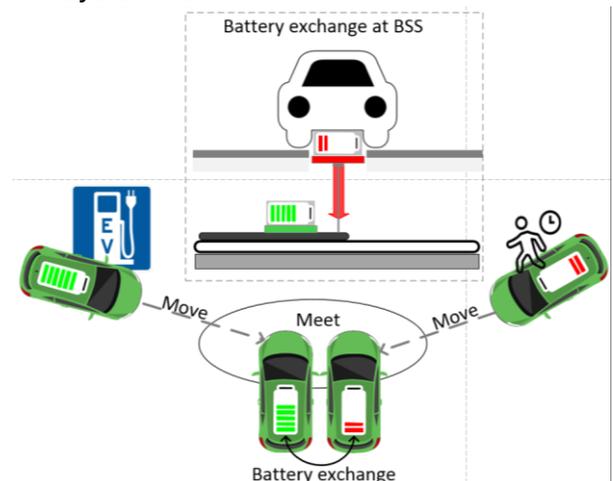


Figure 1: System model illustration

In this study, we present the system model of V2V energy sharing networks. As shown in Fig.1, the proposed system model is comprised one BSS and set of EVs. In such networks, there are two kinds of EVs, excess energy EVs as suppliers and lack energy EVs as demanders. The EV can establish a relationship by matching with another EV to share energy. The energy

sharing is processed as a supplier–demander battery exchange by meeting at BSS. The suppliers, and demanders are denoted by $S = \{1, 2, \dots, m\}$ and $D = \{1, 2, \dots, n\}$, respectively.

For all demanders $d \in D$ and suppliers $s \in S$, we introduce a binary variable $x_{d,s}$ that indicates whether d is assigned to exchange battery with s or not.

$$x_{d,s} = \begin{cases} 1 & \text{if } d \text{ is exchanged battery with } s, \\ 0 & \text{otherwise.} \end{cases} \quad (1)$$

Since state of charge (SoC) is a value that determines the current battery capacity as a percentage of maximum capacity. Each demander submits their desired SoC to BSS. The desired SoC is the battery level ensures the demander can reach its destination at exchange time of demander d denoted as $SoC_d^{desired}$. Each demander looks over the suppliers having battery that can maximize their desired SoC after exchanging with smallest meeting supplier waiting time.

Distance matrix: Let E_D , and E_S be a $D \times 1$, and $S \times 1$ distance matrixes keeping track the distance from each demanders, and suppliers to the Battery Swapping Station, respectively. Then e_d , and e_s are denoted as original Euclidean from current position of d , and s to the BSS, respectively.

Meeting time: Demanders EVs need to visit the BSS to exchange battery when having low SoC. Recall that this paper focus on situation, in which there is high exchange demand at BSS, but demanders cannot wait because of being in a hurry. Therefore, these demanders prefer exchange battery with other EVs by meeting at BSS. A meeting waiting time expresses how close is a pair (d, s) to the BSS, and it is defined as follows,

$$w_{d,s} = \frac{e_s}{e_d} \quad (2.1) \quad w_{s,d} = \frac{e_d}{e_s} \quad (2.2)$$

Exchanging satisfaction level: the exchanging satisfaction level presents of a pair (d, s) presents the demander satisfaction with battery of supplier s . It is calculated by E.q.3.

$$l_{d,s} = \frac{SoC_d^{desired}}{SoC_s^{arrival}} \quad (3.1) \quad l_{s,d} = \frac{SoC_s^{required}}{SoC_d^{arrival}} \quad (3.2)$$

where $SoC^{arrival}$ is the estimated SoC of EVs when arriving at the BSS while $SoC_s^{required}$ is required SoC of s to go to its derided destination.

3. Matching base V2V energy sharing

In this section, we model the two–sides energy sharing demander–supplier matching problem as a two–sides one–to–one matching game. A matching game is defined by two separate sets of players. Each

Algorithm 1: V2V energy sharing

Input: $P_d, P_s, \forall d, s$

Output: a matching μ

1. Initialization: $\mu_o = [x_{d,s}]_{D \times S} = [0]_{D \times S}$;
2. Calculate the preference lists of demanders and suppliers using Equation (4) and Equation (5)
3. Acceptance matrix $X = \{(d, s) | (d, s) \text{ prefer to each other}\}$;
4. Initialize temporary rejected matrix R ;
5. While R is nonempty:
 - 5.1. $d \leftarrow$ remove one element from R ;
 - 5.2. $d \in D$ sends its preference vector P_d to the next supplier that is going to apply;
 - 5.3 Supplier $s \in S$ updates its applicant list. The supplier s ranks the applicants by (11), and selects first choice demanders and rejects the rest;
 - 5.4 Update acceptance matrix X , for $\forall d \in D$;
 - 5.5 $R \leftarrow R \cup$ rejected demanders;
6. return a matching $\mu = X$

set of players evaluate one of another side using well–defined preference relations [6]. The concept of preferences is used to model the common and conflicting interest. The preference profiles built by the demanders and the suppliers are denoted P_d , and P_s , respectively. Let the tuple, (D, S, \succ_D, \succ_S) is our one–to–one matching design. Here, $\succ_D = \{\succ_d\}_{d \in D}$ and $\succ_S = \{\succ_s\}_{s \in S}$ represent the set of the preference relations of demanders and suppliers, respectively [6].

Definition 1 A matching μ is defined on the set $D \cup S$, which satisfies for all $d \in D$ and $s \in S$:

- 1) $|\mu(d)| \leq 1$ and $\mu(d) \in S \cup \emptyset$.
- 2) $|\mu(s)| \leq 1$ and $\mu(s) \in D \cup \emptyset$.
- 3) $s \in \mu(d)$ if only if $\mu(d) = s$.

Demanders’ Preferences: Each demander d firstly seeks a closest supplier s to maximize the meeting time. Secondly, they focus on a supplier who can offer a battery that can maximize its exchanging satisfaction level. Then, d ranks a supplier s in descending order based on the following ranking function:

$$R_d(s) = \left\{ \sum_{d \in D} [\alpha w_{d,s} + (1 - \alpha) l_{d,s}] x_{d,s} \right\} \quad (4)$$

Suppliers’ Preferences: Similar to demanders, suppliers also care about both the meeting time and the exchanging satisfaction level. Hence, each supplier s descendingly ranks the demander d according to

the following ranking function:

$$R_s(d) = \left\{ \sum_{s \in S} [\beta w_{s,d} + (1-\beta)l_{s,d}] x_{d,s} \right\} \quad (5)$$

As mentioned earlier, V2V energy sharing problem is formulated as one-to-one matching problem. Therefore, our goal is to find a stable matching, which is key concept as optimal result by using matching game. To seek a stable matching, the deferred-acceptance algorithm is deployed [7].

A stable matching is verified through the concept of blocking pair defined as follows:

Definition 2 A matching μ is stable, if only if no pair of $\{(d,s) | d \in D, s \in S\}$ blocks the matching. That is, $\nexists (d,s), \text{ s.t. } d \succ_s \mu(s), s \succ_d \mu(d)$.

Our proposed V2V energy sharing algorithm is presented in Algorithm 1. The result of this algorithm, μ , is a stable matching.

4. Simulation Results

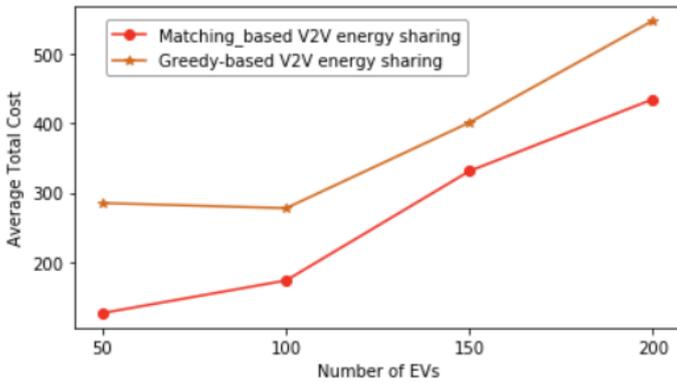


Fig. 2: Average total cost of matching-based V2V energy sharing, and Greedy-based energy sharing for different number of EVs

For our simulations, we consider a system wherein EVs are randomly distributed within a 500m radius of one BSS. It is assumed that total EVs is divided equally into two sets, demanders and suppliers. Assume that the arrival battery of demanders equal to the required battery of suppliers and it is randomly set in range [10%, 35%]. The desired battery of demanders, and the arrival battery of suppliers are randomly set in range [60%, 100%], [50%, 95%], respectively. For set of, the arrival battery and required battery are randomly set in range and [10%, 35%], respectively. α, β are set to 0.5.

We evaluate the average total cost of the V2V energy sharing under different algorithms. Since matching-based V2V energy sharing ensures that no demander can reach better supplier out of the supplier found by our matching-based algorithm. The results are shown in Fig. 2 that matching-based scheme

provides the smaller average total cost than Greedy-based scheme.

5. Conclusion

In this paper, we investigate V2V energy sharing problem to improve range anxiety and increase service quality of BSS. A mathematical model is formulated as one-to-one matching game. Simulation results show that the matching based-V2V energy sharing mechanism guarantees better total cost reduction than that of greedy approach. Prediction of battery exchange demand by using deep learning to seek an optimal charging plan is considered as our future work.

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