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Potential Analysis and Interface Technology of Battery Swapping EVs

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Challenges for electric vehicle penetration include the prohibitive cost of the battery pack and a large amount of time for energy refueling. The concept of battery swapping can solve the latter problem; however, it is difficult to overcome the former while ensuring a long drive-range. Thus, this paper presents a conceptual electric vehicle that shares a part of the battery. We also propose an optimization model for its service infrastructure named Battery as a Service (BaaS).

The concept of BaaS-based EV (BaaS-EV) is shown in Fig. 1. The conventional EV with fixed batteries (all-fix) refuels the energy by battery charging as shown in Fig. 1 (a). The swapping EV (all-swap) refuels by the battery swapping as in Fig. 1 (b). The BaaS-EV has two different types of batteries and operation modes. While the shared battery is employed to drive in a long range as shown in Fig. 1 (c), it can be driven using only one of the batteries (fixed battery) on short-range drive (Fig. 1 (d)). The energy refuel of BaaS-EV is based on both charging and swapping (Fig. 1 (e)). This shareability can increase the utilization rate of the battery and reduce its cost. The BaaS infrastructure provides the users with recharged batteries on demand. In this concept, the frequent battery attach/detach at the station can increase user opportunity cost. Thus, a good quality of service (QoS) is required for BaaS infrastructure. A cost-efficient operation of BaaS with good QoS requires simultaneous optimization of the number of batteries, charging, and transportation costs. An optimization model for this problem is illustrated in Fig. 2. The model is formulated as a integer programming problem with decision variables of the number of batteries (system state x) and number of charged/transported batteries (control u). The user demands (λ) are introduced as model parameters. Since the problem is found to be minimum cost flow problem on an expanded station network, it can be solved efficiently even at a large scale.

We have conducted several case studies based on our optimization model. One of the results are shown in Fig. 3. The battery (C_{b2}), user opportunity (C_o), charging (C_h, C_f, C_c) and transportation (C_r) costs are compared for all-fix and BaaS EVs. The BaaS case has been parametrized using charger distribution parameter. When charger is inhomogeneously distributed (p_c is low), transportation cost (C_r) is increased. Although the cost benefit of BaaS-EV compared with all-fix EV is demonstrated in this case study, this result is based on many parameters which are actually dependent each other. Refinements of both modeling and parameter are required in future study.

We also review implementation technologies for BaaS infrastructure, such as power interface and battery packaging hardware. Wide range of technologies have to be combined for implementation of BaaS concept.

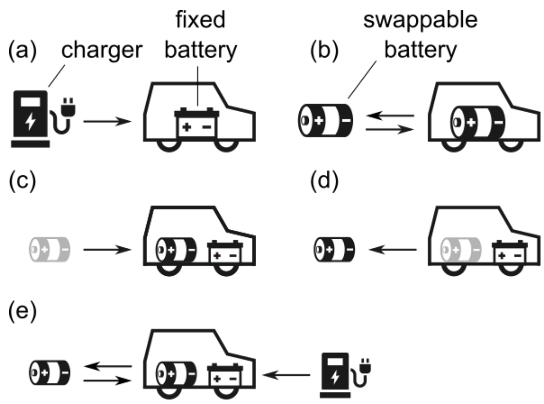

Fig.1. EV energy refueling and usage(a) All-fix EVs charges fixed battery. (b) All-swap EVs swaps the shared battery. (c) (d) BaaS-EV attach or detach shared battery on demand. (e) BaaS-EV refuels by charging and swapping.

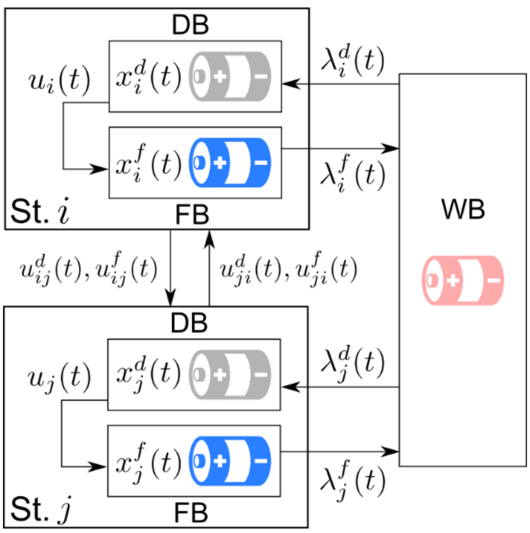

Fig.2. BaaS station network.

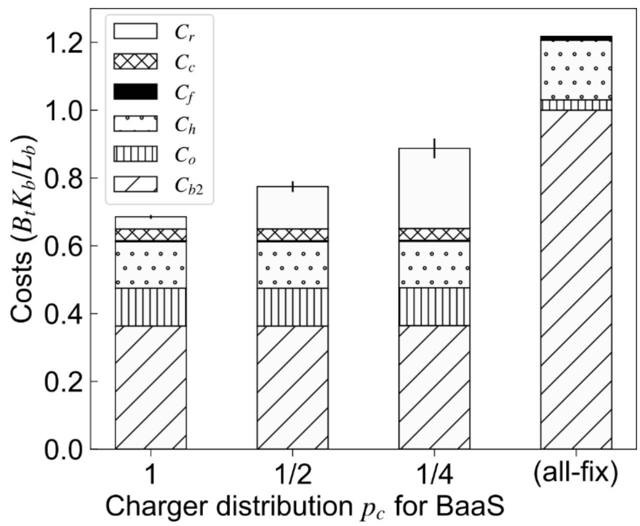

Fig.3. Total cost results from a case study.