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Extended utilization of electric vehicles and their re-used batteries to support the building energy management system

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Abstract

This study focuses on the utilization of EVs and their used batteries to support the building energy management system (BEMS). The main objective of this utilization is to perform a load leveling in which the peak load demand is shifted to the off-peak hours. Both theoretical and experimental studies were conducted to measure the feasibility of this utilization. Experimental test bed has been developed consisting of five EVs, five used EV batteries, and a PV panel. Load leveling is planned by BEMS in 24 hours priorly. EV availability including its position and battery condition is provided by vehicle information system. The developed system proved that utilization of EVs and their used batteries are feasible, hence, can be applied to support BEMS.

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Keywords: electric vehicle, used battery; load leveling; building energy management system; peak shaving

1. Introduction

A greater attention is being directed to battery powered vehicles including pure electric vehicle (EV) and plug-in hybrid electric vehicle (PHEV). This is due to some factors including the rise of oil and gas prices, the advances in battery technology and its material leading to better performance and lower cost. Unfortunately, a wider dissemination of EV also faces some constraints including still high investment cost, long charging time, and short driving range. Although the running cost of EV is lower than conventional gasoline, it cannot stand out sufficiently the total initial investment cost [1]. Hence, further technological and economical schemes are demanded to generate competitive benefits of EV, hence improving the dissemination of EV. Recently, the extended utilization of EV into different applications has been proposed and developed including utilization for grid support and emergency power back up.

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The utilization of EV to support the grid electricity, especially when they are parked and connected to charging poles has been studied by some researchers [2, 3].

The main advantage of EV for grid support is that both charging and discharging behaviors are controllable leading to the possibility for scheduled charging and discharging. In vehicle-to-grid (V2G) system, a control signal from certain grid operator or energy management system (EMS) can send a request for power to a number of parked and plugged EVs to feed their electricity to the grid or conversely to store the electricity from the grid. V2G can be realized when minimally three essential requirements are fulfilled: (1) electricity connection among EV and grid, (2) communication which facilitates control flows between EV and operator, and (3) metering system for fair measurement [4]. V2G technology allows several ancillary services to the electricity grid including load leveling, spinning reserve, and storage [5]. Moreover, as EV is mobile, it can be utilized as energy carrier to deliver the cheap electricity in different place and time. Battery covers a large share of the total cost of EV. In addition, as the number of EVs increases, the quantity of their used batteries also increases accordingly. It is generally mentioned that EV battery is replaced once its storage drops to about 70-80% of its initial capacity due to shorter driving range [6]. The utilization of used EV batteries as stationary energy storage is considered able to improve the overall economic efficiency of EV as well as decreasing the environmental impacts due to longer battery end-of-life [2, 7, 8].

Although the implementation of EVs and their used batteries for grid support have been studied for more than a decade, almost all those studies focused mainly on basic theoretical analysis and simulation. A very lack of research and development which are focusing on practical experiments and their analysis have been performed. This study focuses on the implementation of EVs and their re-used batteries to support the building energy management system (BEMS), especially in term of load leveling and peak cutting. Both conceptual and experimental studies were performed and analyzed.

2. EV Utilization for Grid Support

2.1. Integration of EV to BEMS

This study focuses on the integration of EVs and their used batteries to BEMS, called as vehicle to building (V2B) system. BEMS, as a member of community energy management system (CEMS), manages the overall energy flows in a certain building, optimizes its economic performance, and communicates with CEMS as an upper entity. Fig 1(a) shows the schematic diagram of developed V2B system. BEMS manages both its own demand and supply of electricity.

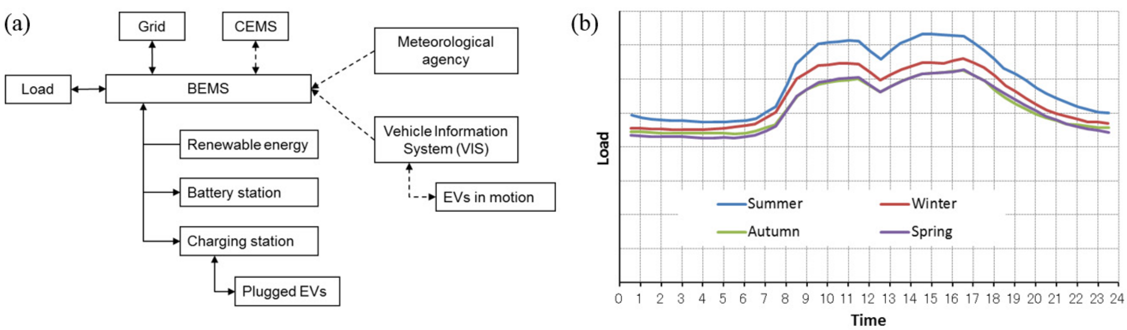

Fig. 1. (a) Schematic diagram of the developed BEMS system, (b) Typical average load in different season

BEMS basically requests, manages and integrates some information from different sources: its own load, meteorological agency, vehicle information system (VIS), electric utility, and CEMS. The meteorological agency provides weather information to BEMS which is used to predict the possibly generated renewable energy and building load, especially loads related to air conditioning and lighting. In addition, VIS provides the EV information consisting of its position, estimated arrival time and battery state of charge (SOC). Furthermore, BEMS also requests the electricity condition and price information from electric utility. BEMS can fully control EVs plugged in to its charging poles and used EV batteries in terms of their charging and discharging behaviors.

The load in the building basically can be divided into the base load and fluctuating load. Fig 1(b) shows the typical average load in different season of the building, especially the commercial building in Japan as used in this study. The base load is the minimum amount of demand to power the system operating over 24 hours. On the other hand, the fluctuating loads relate strongly to the air conditioning and lighting and are influenced mainly by weather and human behavior. The highest total demand usually occurs in summer and is followed by the winter. The loads in autumn and spring show almost similarity to each other. In addition, two peaks loads exist in a weekday: before noon and after noon peak loads.

EV owners are assumed to be the employee working in the building. To join the program, EV owner can have a direct contract with the building management or through another entity such as an aggregator who will manage all of the services including payment. However, a direct contract with the building management is considered to be able to maximize the profit for both sides.

VIS can be a part of certain EMS, the aggregator or it becomes an independent operator. It is responsible for communicating with EVs and sending the data to the aggregator or EMS. In general, VIS is responsible to provide EV information which is used for coordination of EV charging/discharging. This coordination is very important to maintain the balance of electricity distribution and avoid any peak load in certain community or EMS. Moreover, VIS can also provide the information to the EV owner concerning the available ancillary programs offered by EMS or aggregator.

2.2. Load leveling

Load leveling aims to lower the peak of total power consumption by shifting the load in a period of time in which the power is consumed at most. Hence, load leveling deals with the management of both supply and demand of electricity by shifting the demand from peak hours to off-peak hours. In this study, building load leveling is performed through the utilization of PV, plugged EVs and used EV batteries which are connected to BEMS.

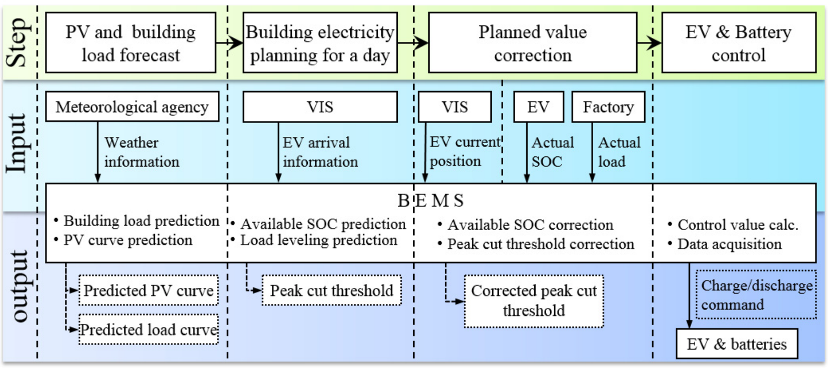

Fig. 2. Concept of load leveling for BEMS utilizing EVs and their used batteries

Fig 2 shows the developed concept of load leveling for BEMS. As in Japan, the amount of used electricity (kWh) is counted for every duration of 30 min, all of electricity amount (kWh) in this study is calculated as the accumulation value for 30 min duration. Furthermore, the prediction value is calculated by BEMS for the next 24 hours. BEMS requests an information of local weather forecast from meteorological agency to estimate the electricity curve which could be generated by PV and also calculate the building load curve. When EVs are departed, EVs send their information of battery SOC and current position to VIS in interval of several seconds to minutes for updating purpose. Based on the updated data, BEMS will correct its load curve and peak cut threshold.

3. Experimental Test Bed

Fig 3 shows the overview of the experimental test bed for load leveling in FEMS utilizing EVs and their used batteries and load duration curve to calculate the peak cut threshold. Black solid and blue dotted lines represent the electricity and information flows, respectively. Each five EVs and used EV batteries having capacity of 16 kWh and solar panels with capacity of 20 kW are installed. The used EV batteries were collected from same type of EV after 1 year usage. The used EV batteries, basically, are part of BEMS and fully controlled by BEMS.

The peak cut threshold can be calculated based on electricity price and electricity capacity (such as the contracted electricity capacity). However, in this study, peak cut threshold was calculated only on the consideration of available sources capacity for load leveling. To obtain the peak cut threshold, a one day load duration curve from the average weekdays demand in the same month of last year was created initially and subtracted by the predicted PV generation for each corresponding time. Furthermore, peak cut threshold, P_t, can be calculated based on Eq 1.

$$for\ L_n > Pt$$

$$\Sigma L_n = n\ P_t + \Sigma P_{ev,m} + \Sigma P_{bat,m} + P_{pv} \tag{1}$$

where, L, P_t, P_{ev}, P_{bat}, P_{pv}, n, and m are load for 30 min, peack cut threshold, available power from EV, available power from used battery, generated electricity from PV, number of load higher than peak cut threshold, and number of EVs and used batteries, respectively.

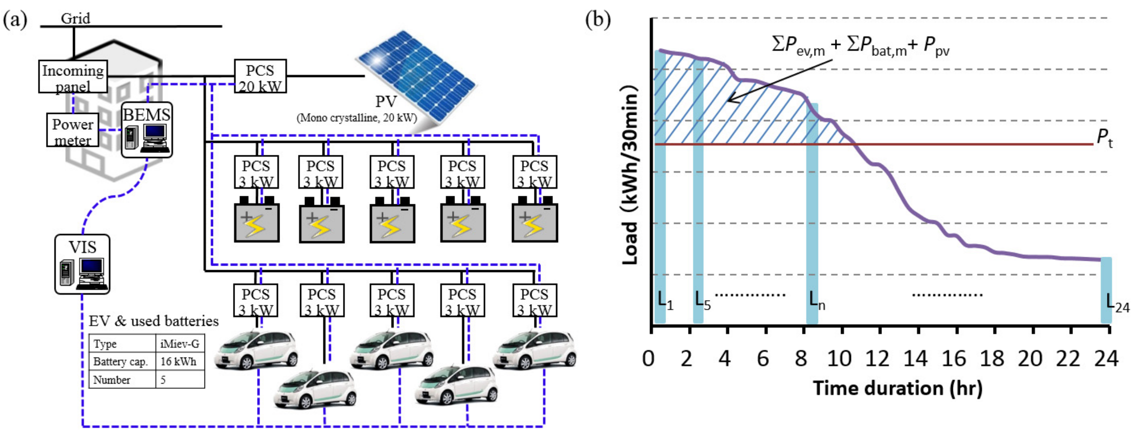

Fig. 3. (a) Overview of developed experimental test bed, (b) load duration curve to calculate the peak cut threshold.

The charging and discharging threshold for both EV and used EV battery were fixed at 90% and 40%, respectively. Furthermore, due to limitation of available battery capacity of both EVs and used EV batteries, load leveling for peak load was designated to start from 12:00 to 24:00 (12 hours duration). During motion, EVs send the data in each 10 s interval to VIS for data updating which will be transmitted further to FEMS.

4. Results and Discussion

Fig 4(a) shows the result of experimental test of load leveling consisting of grid load, building load, generated PV, and charged/discharged EVs and used EV batteries for one sample weekday. Building load is defined as the original load required for the building to operate which is basically not influenced by load leveling test. Grid load is the electricity purchased from the grid. Light green blocks in the positive side represents discharged electricity from EVs and used EV batteries. On the other hand, the same color of blocks in the negative side means charged electricity to EVs and used EV batteries, respectively.

Fig 4(b) shows the amount of peak cut by each battery, EV and PV. The used batteries have the most stable and largest peak cut share compared to EVs and PV. Used batteries are fully controlled by BEMS performing load shifting. On the other hand, the share of EV in peak cutting depends to the battery availability which, in turn, is influenced strongly by the EV usage.

The peak shaving is scheduled to start from 12:00 and the afternoon peak load generally starts from 13:00. As the peak load reach the value higher than the calculated peak cut threshold, BEMS sends the control value to both EVs and used batteries to discharge their electricity. Hence, the grid load can be reduced. Unfortunately, as the available electricity form EVs and used batteries in this study is significantly lower than the total demand of the building, peak shaving only could be done is some durations of time. Although the load leveling test was conducted in limited time, the grid load was reduced and the rest of building load can be covered by generated power from PV and discharged power from EVs and used batteries. Based on the results, it is believed that as the number of EVs participating in this load leveling program increases, the effect of load leveling could be achieve more significantly. Therefore, a longer peak shaving (including both before and after noon peak load) and lower peak cut threshold could be achieved correspondingly.

Some further challenges related to utilization of EV and its used batteries in supporting certain EMS relates to some issues related to battery degradation, demand forecast, and EV availability forecast. Battery degradation becomes one of the bottle necks in the utilization of EV and its used batteries as it will cause a decrease in the total storage capacity. In addition, the accuracy to demand forecasting is also one important key to success as it deals strongly with the air conditioning demand which actually becomes the largest part of fluctuating load.

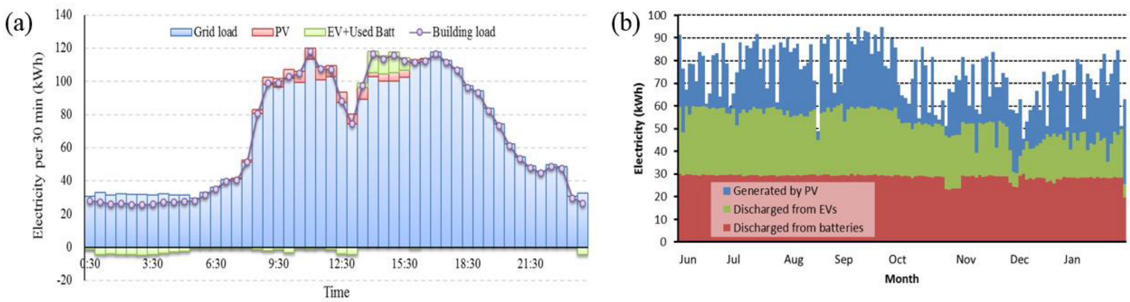

Fig. 4. (a) Experimental test result of one week day load leveling, (b) peak cut amount per day by each battery, EV and PV.

5. Conclusion

The extended utilization of EVs and their used batteries has been studied both theoretically and experimentally to support the electricity in certain building. The load leveling test showed that by setting a peak cut threshold and controlling the charging/discharging behaviors of EVs and used batteries, the electricity load of the building can be cut and shifted. Furthermore, the used batteries showed a relatively stable and largest share in peak cutting.

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Biography

Muhammad Aziz received B. Eng., M. Eng., and D. Eng. degrees from Kyushu University, Japan, in 2004, 2006 and 2008, respectively. He is currently an assistant professor at Tokyo Institute of Technology, Japan. He has authored about 100 peer-reviewed journals, book chapters, and proceedings especially in energy systems, process design, and smart grid.