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Chapter 6

Load Leveling Utilizing Electric Vehicles and their Used Batteries

Muhammad Aziz and Takuya Oda

Additional information is available at the end of the chapter

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Abstract

The increase of electric vehicles (EVs) has led to some challenging problems and opportunities, especially related to electricity issues. The uncontrolled charging and discharging of EVs can reduce the quality of electricity grid due to frequency and voltage instabilities. However, the optimized utilization of EVs also offers high potential for ancillary service including frequency control and storage. The adoption of EVs and used EV batteries is expected to be able to improve the total economic performance of EVs as well as reduce the environmental impact. In this chapter, the utilization of EVs, together with their used batteries, to support the electricity (load leveling) in a small-scale energy management system (EMS) is analyzed and demonstrated. The demonstration bed consists of five EVs, five used EV batteries, and photovoltaic (PV) panels. The EMS forecasts the load of the office building and the possibly generated power from PV panels. In addition, it also calculates the potential of EVs which are available for joining the load leveling program. EMS will control all the charging and discharging behaviors of connected EVs and used EV batteries, therefore the grid load can be maintained to be lower than the calculated peak-cut threshold. It is found that the utilization of EVs to support small-scale EMS through direct contract is feasible, and hence applicable. At the end of the chapter, some suggestions earned from demonstration test are also listed for further consideration.

Keywords: vehicle-to-grid, used battery, load leveling, small scale, energy management system

1. Introduction

The massive dissemination of electric vehicles (EVs) is believed to be able to improve the total energy efficiency of the vehicles as well as reduce the emission of greenhouse gases and oil consumption [1]. In Japan, considering that the gasoline price, total annual driving distance, electricity price during night time, and fuel consumption of both gasoline-fueled vehicle and EV are 110 JPY l^{-1}, 10,000 km, 12 JPY kWh^{-1}, and 15 km l^{-1} and 6 km kWh^{-1}, respectively, the total operational cost of EV may be less than 30% of gasoline-fueled vehicle. Furthermore, the acceleration in the development of EV also has been influenced strongly by some various factors including fluctuating oil and gas prices, successful advancements in battery technology, and broader supporting infrastructure [2,3]. Unfortunately, there are still some challenging problems to expand in a broader scope of the community including high capital cost, long charging time, and relatively short travelable distance [4]. In addition, although the operational cost of EVs is cheaper than the conventional gasoline-fueled vehicles (internal combustion engine–based vehicles), the initial cost of EV is still higher due to high production cost.

To further reduce the initial and operational costs of EV (increase its economic performance), innovative value-added utilization of EV is requested. Furthermore, massive deployment of EVs can disturb significantly the grid electricity, especially when individual charging of EVs in large capacity and number occurred. According to [5], in case that a half of vehicles in Kanto (Tokyo and its surroundings) area are transformed to EVs and half of them are demanding a quick charging simultaneously, about 7.31 GW of additional electricity supply is required. Recently, to give an answer to the above problems, the idea of vehicle-to-grid (V2G) has been proposed and investigated [6–8].

The adoption of EVs to support the electricity of grid or any electricity-related system becomes possible because of controllable charging and discharging behaviors resulting in the possibility of scheduled and coordinated charging and discharging. Therefore, the parked and connected EVs can be assumed as a largely bundled battery which is able to consume (absorb) the electricity from the grid, store it, and release back to the grid. In addition, V2G can be achieved when minimally three fundamental preconditions are totally satisfied: (1) an electricity line connecting both EV and power grid, such as charging station, (2) a communication system transferring the information and control command between EV and grid operator, and (3) an accurate and trusted metering system facilitating fair service measurement [9]. Furthermore, in case that there is any demand for electricity, the grid operators and/or energy management system (EMS) are able to dispatch a control command instructing the connected EVs to discharge their stored electricity to the grid. On the other hand, they can instruct the connected EVs to absorb the electricity due to surplus of electricity or decrease of electricity demand. Therefore, the balance between supply and demand, as well as quality of grid electricity can be maintained.

V2G provides various possible ancillary services to the electricity grid or any electricity-related system such as load leveling and spinning reserve. In addition, the distributed EVs also can be assumed as a large-scale energy storage (battery) which is potential to be bundled and utilized to minimize the effect of fluctuating supply. As EVs are moving from and to different times and places, they also could be employed as an energy carrier transporting the electricity in different places and times due to some factors such as electricity price difference and emergency condition. From the economic analysis, the massive adoption of EVs to give ancillary service to the grid (V2G) is considered beneficial because the projected profit is still significantly higher than the initial cost of EVs, especially the battery including the consideration of battery wear and life cycle [4]. This feasibility study has been performed based on the actual data of EVs, especially the life cycle of battery.

Until now, battery cost stands as the highest share in total EV production cost. In addition, as the number of produced EVs increases, the number and total capacity of the used batteries increase accordingly. According to [10], the EV batteries are generally replaced after their storage capacity drops to about 70–80% of its initial capacity. The decrease in battery capacity leads to shorter possible driving range. Therefore, although these used EV batteries are not appropriate anymore for EVs, they can be reutilized as a stationary energy storage (stationary battery). This kind of battery utilization is believed to be able to further improve the overall economic performance of EV as well as reduces their impacts to the environment because it can lengthen the battery end-of-life. The study on the utilization of EV batteries acting as stationary battery to take part in ancillary service to certain EMS or grid can be found in several literature [11, 12].

Several studies focusing on theoretical analyses of the application of both EVs and used EV batteries have been conducted well. However, those studies are generally lack of experimental investigation including demonstration tests and real application. This chapter deals mainly with the employment of EVs and used EV batteries in supporting the electricity in any typical small-scale EMS including both theoretical and experimental studies. In addition, the results from the demonstration test are also studied and analyzed.

2. Energy management system

Charging of EVs basically can be categorized into three different capacities: (a) slow charging with capacity lower than 4 kW, (b) fast charging with capacity of 10–20 kW, and (c) ultrafast charging with a maximum capacity of 50 kW or higher [13]. Ultrafast charging is conducted generally under high DC voltage and current. In Japan, this ultrafast charging follows the standard of CHAdeMO (the acronym of “charge de move”, equivalent to “move by charge”) which offers charging capacity of 10–50 kW. Until the end of 2015, there are about 6000 ultrafast chargers following CHAdeMO standard across Japan [14]. CHAdeMO chargers can facilitate bidirectional electricity flows resulting in possible charging and discharging of EVs. In addition, intelligent controlling system is also generally installed inside the charger, hence high level communication and control can be achieved.

The management of energy, especially the electricity, is usually coordinated and controlled by certain independent operator. In North America, independent system operator (ISO) and regional transmission operator (RTO) act as the independent and neutral organizations that are responsible to coordinate, control, and monitor the electric transmission throughout the state or region [15]. In addition, ISO and independent transmission operator (ITO) were established in Europe which are quite similar with ISO/RTO in North America. The main differences between the US-type ISO/RTO and the EU-type ISO/ITO are the absence of profit motives, and participation and transparency of all the involved stakeholders [16]. ITO in

Europe owns the assets and it belongs to certain stakeholders, but has a regulation to guarantee its independence. On the other hand, ISO is fully unbundled operator having no assets although still belongs to certain stakeholders.

In Japan, community energy management system (CEMS) has been proposed and demonstrated. The main purpose of CEMS is realizing a resilient and smart community, especially related to efficiency in energy utilization and minimization of CO_2 emission. The concept of CEMS comes from the demand to optimize the energy services, maximize the potential economy, and minimize the environmental impacts. CEMS coordinates and monitors all the energy supply and demand throughout the community, hence improving the comfort, security, and safety of the whole community members. In CEMS, the streams of energy and information are flowing simultaneously covering supply, demand, storage, and distribution. As a system, CEMS must be robust and secured because it deals with individual information and its authentication.

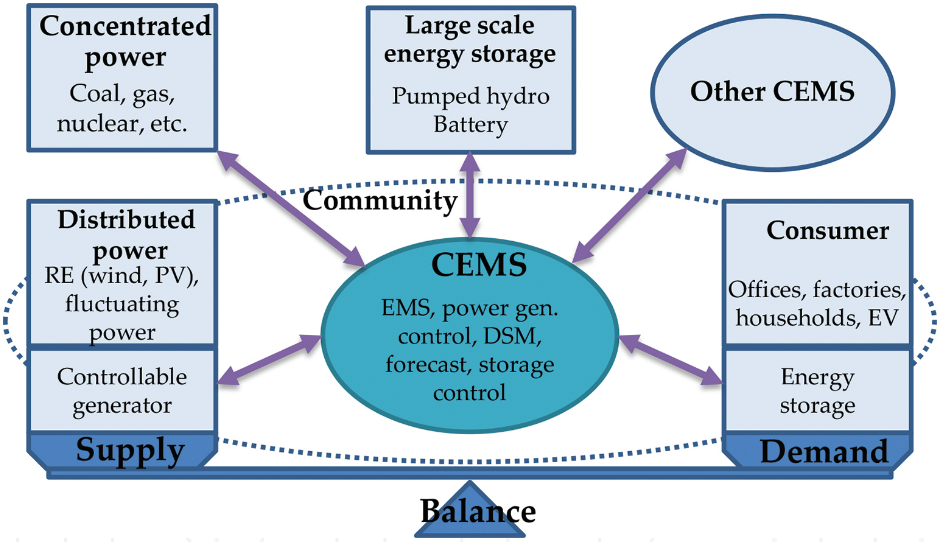

Figure 1. Basic concept of CEMS.

Figure 1 shows the basic concept of CEMS. CEMS has an important role of monitoring and controlling all the energy involved in the community. It becomes the core of efficient, secured, and optimized energy utilization throughout the community. CEMS is able to communicate with other entities inside and outside its authority. Inside the community, CEMS communicates intensively with its lower EMSs such as home energy management system (HEMS), building energy management system (BEMS), and factory energy management system (FEMS). In addition, it also may communicate directly with EVs distributed in the community which are not controlled under certain EMS. CEMS is also able to communicate with other

CEMS, large-scale energy providers (utilities), transmission operators, and energy storage operators.

Inside the community, CEMS initially forecasts both energy supply, especially generable renewable energy (RE) and demand. This forecast is usually performed based on historical (for several years before) and meteorological data. Furthermore, it calculates the most optimized energy balance in terms of quality, security, and economic cost. In case the energy balance between the supply and demand cannot be self-achieved inside the community due to lack of power generation capacity, high and fluctuating demand, and emergency condition, CEMS communicates with other CEMS, utilities, and energy storage providers to deliver or increase their power to the community. On the other hand, in case there is surplus electricity inside the community (due to high supply and/or low demand), CEMS can offer to other CEMS or utilities to buy this surplus electricity.

CEMS is also performing a demand side management (DSM). DSM includes efficient energy usage and demand response (DR) in demand side, instead of adding larger generation capacity at the supply side. DSM can be considered as a dispatchable resource, in which the consumer lower voluntarily their demand, therefore the grid quality can be maintained without any additional power supply.

3. EV involvement in energy management system

EVs can be applied to support the grid electricity, mainly providing energy storage and ancillary services, due to the above-mentioned characteristics. As energy storage, EVs can be charged when the electricity price is relatively low because of surplus electricity in supply side, including RE and excess power, and lower demand (such as during night time). Furthermore, the ancillary services which can be performed by EVs to support the grid electricity mainly cover frequency regulation (up and down regulations), electricity storage, and spinning (synchronous) reserve. Compared to other energy storages or generators, EVs have a very advantageous characteristic which is its ability to charge and discharge instantaneously their electricity once they received the command from the operator or EMS. The above-mentioned ancillary services are required to preserve the balance between supply and demand of electricity, therefore the electricity can be appropriately reliable.

To participate in the ancillary services, the EV owners are requested to have any service contract with the operator or EMS. Possible utilization contract schemes of EVs to support the grid electricity or any electricity-related system are shown in **Figure 2**. In general, the participation of EVs in the electricity market could be conducted through two types of participation contracts, they are direct and aggregator-based contracts. To facilitate a communication between EVs and operators, a real time data collection is conducted by vehicle information system (VIS) in a certain time interval from EVs covering battery state of charge (SOC), position (GPS data), and predicted arrival time. VIS might be owned and managed directly by EMS, aggregator or it is independent as service operator which provides EV information services to EMS and aggregator.

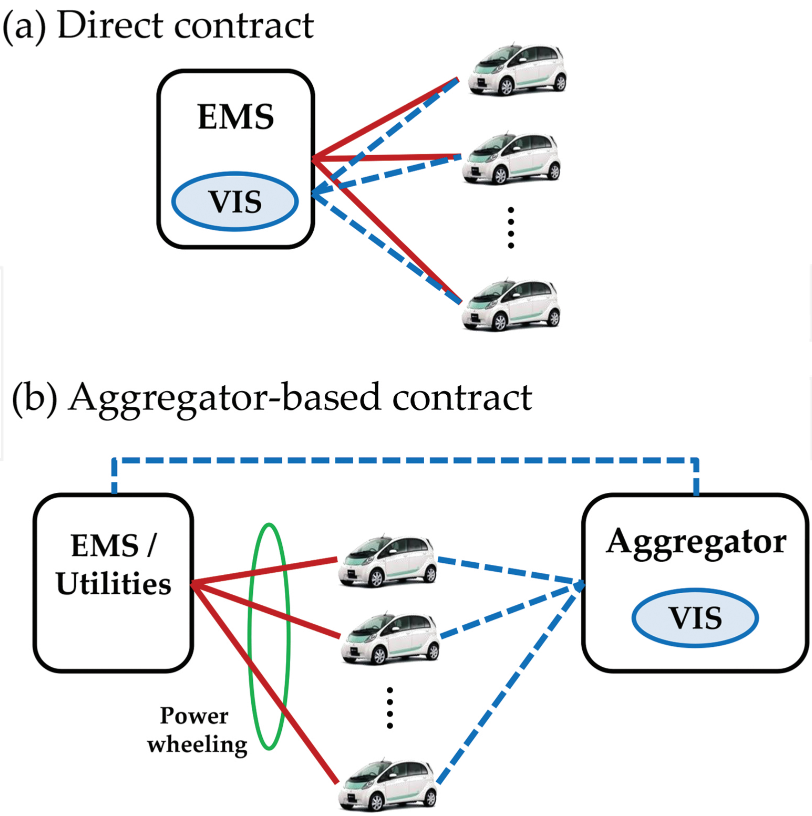

Figure 2. Possible contract schemes of EV in EMS: (a) direct contract and (b) aggregator-based contract.

In a direct contract, the EV owners have the service contract directly with the energy service providers (EMS). In this contract scheme, both the electricity and information are transferred privately and directly between EVs and energy service provider. Therefore, this type of contract is considered applicable for a relatively small-scale EMS, including BEMS and FEMS, and in where EVs are parked and connected to the chargers for relatively long time, for example during working hours. The main advantage of this type of contract scheme is the ability to optimize the profit for the involving entities (EV owners and EMS). Furthermore, controls for both charging and discharging are more simple and faster as EVs are directly and fully under control of EMS. The report in this chapter describes mainly on this type of contract scheme.

On the contrary, in an aggregator-based contract scheme, EV owners have service contracts with the aggregators which are providing and managing electricity services. Therefore, there is no direct contract between EV owners and EMS or other electricity-related entities. The information including EV position (GPS), battery condition (SOC), and estimated arrival time is basically coordinated by aggregator via VIS. Based on these data, the aggregator calculates the available number of EVs as well as the total capacity of the battery which is potential for power services. Furthermore, the aggregator can offer and negotiate for electricity services with other electricity-related entities including aggregators, EMS, and/or electricity utilities. It is assumed that this kind of contract scheme is suitable to be adopted for comparatively large-scale EMS or electricity utilities. The participating EVs are not only located in certain single place, but they might be distributed in different places as long as both electricity connection and communication are available and possible to perform ancillary services. The electricity absorbed from and discharged to the grid can be transferred through power wheeling service utilizing the available distribution and transmission lines. Aggregator acts as service operator, hence they offer some possible ancillary services to the EV owners. On the contrary, the EV owners have the right to select the offered ancillary service programs and receive the service fee from the aggregator.

Load leveling has a strong correlation with the management of both electricity demand and supply. The main objective is to lower the total grid load (electricity purchased from grid) during peak-load hours and avoid the electricity usage higher than the contracted power capacity by shifting the load from peak to off-peak-load hours. In this study, load leveling is conducted by employing both peak-shift and peak-cut. The former is defined as dislocating the electricity load during peak-load time to off-peak-load time. It can be performed by utilizing the stationary battery or other power storage devices which can absorb and store the electricity during off-peak-load time and discharge it during peak-load time. The latter is described as the effort to reduce the electricity which is purchased from the grid. In real practice, this can be conducted by generating its own energy supply especially during peak-load hours, such as RE, or by purchasing the electricity from other entities including the connected EVs. In the case that additional power supply is purchased from EVs, EVs are considered as energy storage and carrier which are storing and transporting the electricity from and to different times and places. Therefore, the economic performance of EVs can be improved by participating in this kind of ancillary services.

4. Charging behavior of EVs

Almost all of EVs adopt lithium-ion batteries to store the electricity with consideration of high-energy density, high stability, long lifetime, and relatively lower environmental impact. Charging and discharging behaviors of EVs are influenced by some factors including SOC and temperature [13]. Temperature influences some interface properties of the batteries including viscosity, density, dielectric strength, and ion diffusion capability [17]. Lower temperature results in poor charging and discharging performances because of lower performances of those properties as well as electrolyte limitation [18]. In addition, as temperature decreases, the transfer resistance increases [19].

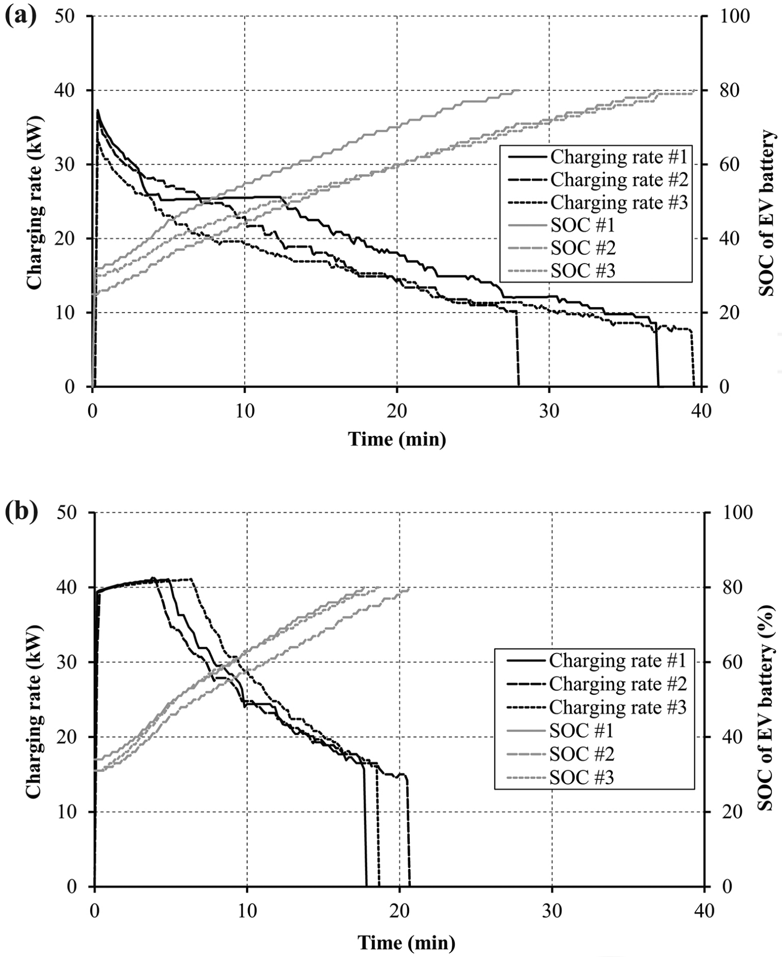

Figure 3. Relationship among charging rate, battery SOC, and charging time during EV charging in different seasons: (a) winter and (b) summer.

Aziz et al. [13] have performed an experimental study confirming the effect of battery SOC and temperature to the charging behavior of EVs in both summer and winter using DC ultrafast charger (maximum charging rate of 50 kW). **Figure 3** shows their experimental results, i.e., the relationship among the charging rate, battery SOC, and charging time. Generally, charging rate is influenced strongly by the SOC of battery. EVs with lower battery SOC can absorb higher electricity and their charging rate decreases gradually as their battery SOC increases. In addition, charging in relatively higher temperature (summer) results in higher charging rate, therefore shorter charging time can be achieved. Lithium-ion batteries are generally charged employing a constant current (CC)-constant voltage (CV) method. Charging under higher temperature leads to higher charging current, therefore shorter charging time can be realized.

5. Integration of EVs and their used batteries to small-scale EMS

The conceptual diagram of integration of EVs and used EV batteries in supporting the electricity in a small-scale EMS is presented in **Figure 4**. To take part in the ancillary services coordinated by EMS, there must be an initial contract between the EV owners EMS, either direct contract or aggregator-based contract through third entity such as an aggregator. Because of the mobility characteristic of EVs, their charging and discharging behaviors can be fully controlled by EMS in case EVs are connected to the designated charging stations. In addition, the used EV batteries are employed as stationary storage which are always connected to and managed completely by EMS. These used EV batteries are utilized mainly for peak-shift. Therefore, they are charged when the electricity price is low, such as during night time, and discharged during peak-load time or when the electricity price is relatively high, such as noon time. Hence, the amount of electricity which is purchased from the grid during peak-load time can be reduced, resulting in total low electricity cost.

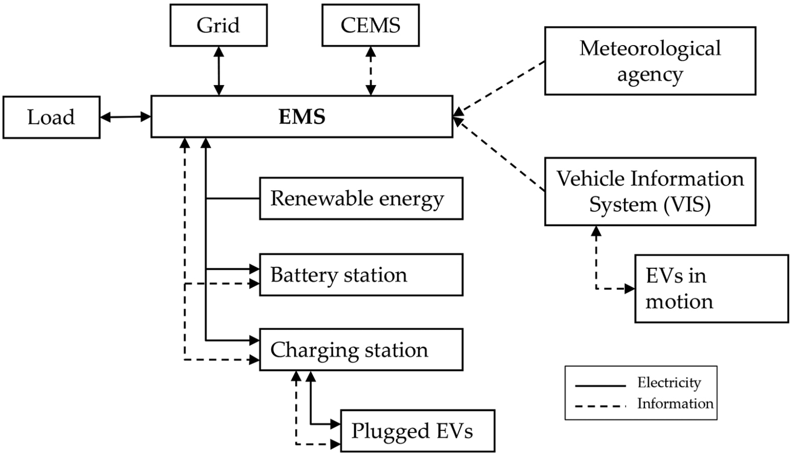

Figure 4. Conceptual diagram of integration of EVs and their used batteries to small-scale EMS.

EMS is basically controlling all the electricity flows including demand and supply sides. Some types of small-scale EMSs include BEMS, FEMS, and HEMS. A direct contract scheme is adopted in this case. EMS requests the required information from different sources covering its own demand (load), weather information from meteorological agency, EV information from VIS, electricity condition in the community from CEMS, and grid electricity condition from utility. Regarding the weather information, EMS generally has a service contract with certain meteorological agency providing the weather forecast in a certain interval of time in a day. Based on the received weather forecast, EMS will estimate its own load, including base load and fluctuating load. The former is generally defined as the minimum load which is required to run the system for sequential 24 hours. Therefore, this kind of load is usually constant along the day and insignificantly effected by the weather or human behavior. On the contrary, the latter is determined as the load which is influenced strongly by the surrounding weather and human behavior. The fluctuating load includes air conditioning, heating, and lighting. Moreover, the possibly generated electricity from RE, such as wind and solar, is also predicted by EMS utilizing the weather information received from meteorological agency.

Figure 5 represents the average total load of the office building, especially in Japan, in four different seasons. The highest total building load takes place in summer, and is followed by one in winter, due to air conditioning demand. In addition, building loads in both spring and autumn are almost similar, which are lower than one in winter. Furthermore, daily peak-loads occur twice in a day (weekday), i.e., before noon and afternoon peak-loads. This is because of the immediate drop of load following the lunch break for about 1 hour. The afternoon peak-load mostly takes place in a longer duration, which is about 3 hours, and is higher than the before noon peak-load. Moreover, the highest value of peak-load during summer takes place during afternoon time (13:00–16:00) due to cooling demand. On the contrary, this highest value of peak-load moves to evening time (16:00–17:00) during other three seasons (autumn, winter, and spring) due to heating demand.

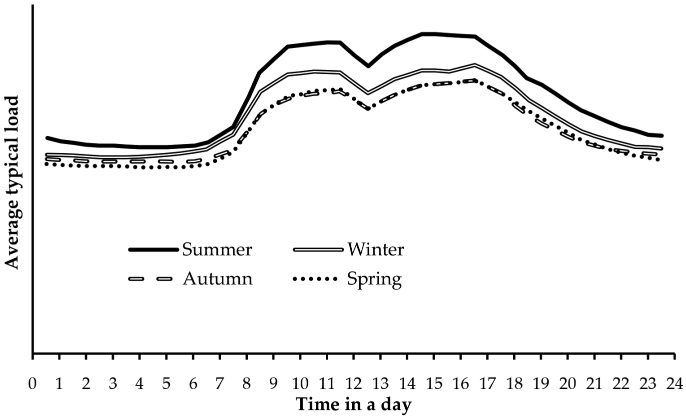

Figure 5. Average electricity loads for office building in different seasons.

EMS also receives the EV information from VIS including their position (GPS data), battery SOC, and predicted arrival time. In addition, VIS monitors and collects the information from its EV members wirelessly. It might be an independent service operator and a part of EMS or aggregator. It is responsible to communicate with each EV and provide the collected data to the EMS or aggregator in which VIS has a contract with. In addition, these data are used for coordinating both charging and discharging of EVs, maintaining the balance of electricity and avoiding any peak-load in EMS. Furthermore, VIS is also able to provide additional services to the EV drivers/owners concerning the available ancillary service programs which are being offered by EMS or aggregator. Hence, the EV owners can select according to their interests or conditions. Furthermore, EMS can request the electricity utilities to provide the information including the electricity condition and price in advance (such as one day ahead). This information is important to plan and optimize the electricity supply as well as calculate the amount of electricity which should be purchased from utilities. In addition, EMS also calculates the charging and discharging behaviors of both EVs and used EV batteries which are available according to the information provided by VIS.

Figure 6 shows the assumed one day specific curve of EV battery SOC during a weekday. EVs are departed in the morning and they reach the destination (office building) at around 9 am. In this study, EVs are used for peak-cut during the afternoon peak-load due to higher peak-load and limited number of EVs in a demonstration test. EV discharging is stopped in case that the peak-cut (load leveling) finishes or the SOC of EV batteries drops to minimum SOC (SOC_{min}). SOC_{min} might be determined by the EV drivers/owners, EMS, or aggregator. In addition, EVs leave the office building at around 6 pm with minimum battery condition (SOC_{min}). On the other hand, in case that the total building load is relatively low (such as in the morning, lunch break, and night) EVs might be charged to enhance their discharging capacity or extending their traveling.

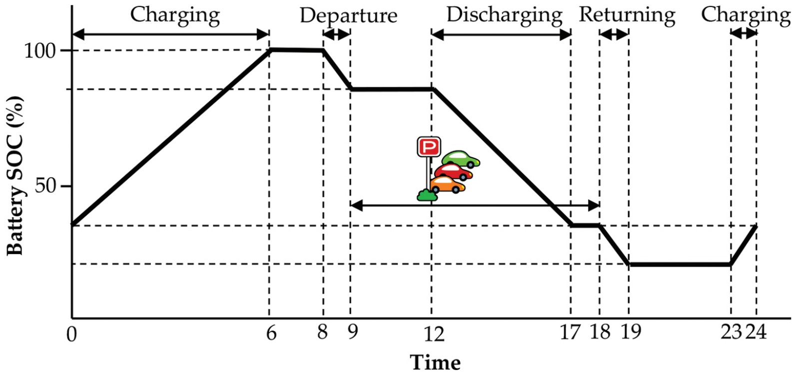

Figure 6. Typical SOC state of EVs in weekdays (commuting).

6. Suggested utilization system of EVs and their used batteries

Figure 7 presents the basic concept of load leveling which is developed for a small-scale EMS employing EVs, used EV batteries and RE generators including photovoltaic (PV) and wind. Four main continuous steps are proposed: (1) forecasting of the possibly generated RE and building load, (2) load leveling calculation including peak-shift and peak-cut, (3) value recalculation and correction, and (4) charging and discharging controls of both EVs and used EV batteries. The first step, load and RE forecasting, is basically conducted by EMS for 24 hours ahead. Furthermore, because the electricity amount in Japan is measured for a duration of 30 min, the electricity amounts (kWh) in this study are also measured and calculated as the total summation for a duration of 30 min.

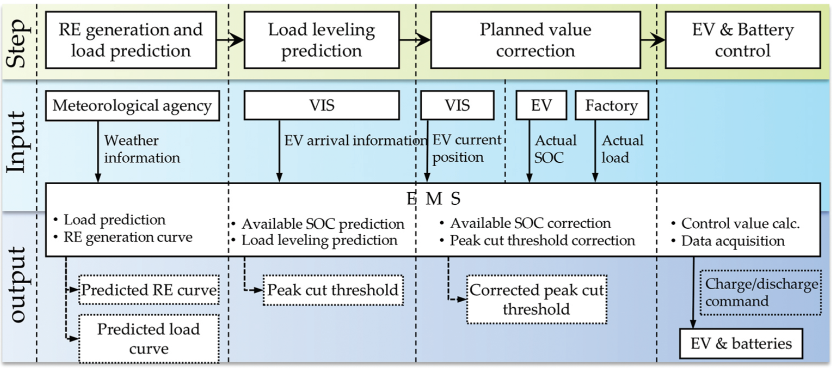

Figure 7. Developed load leveling concept utilizing EVs and their used batteries.

To forecast both load and possibly generated RE, EMS initially sends a request to meteorological agency to deliver the local weather forecast information. This weather information is very crucial for calculating the electricity which can be potentially generated by RE, such as PV and wind. Because the amount of RE generation is significantly smaller than the total load, in this study, this generated electricity from RE is used directly for peak-cut, hence it will be delivered directly and consumed entirely without being stored in the battery. Moreover, the weather information is also used to forecast the fluctuating load of the office building, especially to calculate the demand of air conditioning (cooling and heating) and lighting. The outputs from this first step include the predicted power generation from RE and daily load curves of the next day (defined as day starting from 00:00 to 24:00).

As the building load and possibly generated electricity from RE have been predicted, EMS will calculate the achievable load leveling (peak-cut) for the next day. In order to realize it, EMS sends a request to VIS to calculate and send the information related to the available EVs, including their battery SOCs, which will potentially participate for the load leveling program. This information is required to estimate the total available electricity which can be supplied by the EVs for load leveling.

In order to perform the given request by EMS, VIS initially collects the traveling schedule from the EV drivers (planned departure time and predicted arrival time). Next, EMS forwards this information, as well as calculates the total availability of EVs and their batteries, together with basic information including EV's ID. This registration of traveling schedule is conducted up to 24 hours before the planned departure. Finally, using the data from the first and second steps, EMS is able to estimate the peak-cut threshold which can be applied for the next day.

In this study, a peak-cut threshold is determined as the maximum electricity which is purchased from the electricity grid. To calculate this peak-cut threshold, some important factors need to be considered including price of electricity at the corresponding time, contracted power capacity, possibly generated electricity from RE, available electricity supply from other sources with low price, and potential energy storage.

In case that the electricity which is consumed by the office building rises resulting in the condition that the purchased electricity from the grid increases and reaches nearly the calculated peak-cut threshold, EMS immediately sends the control command to both connected EVs and used EV batteries to release their electricity supporting EMS to cover the demand. Therefore, the electricity purchased from the grid can be kept to be the same to or lower than the calculated peak-cut threshold. As a result, a higher price of electricity during peak-load time or penalty due to higher capacity than the contracted one can be avoided.

When EVs are not connected to the designated charging stations, such as in motion or being parked in other places, the information of EVs is sent wirelessly to VIS in an interval of several seconds to minutes (adding and renewing the information). Thereafter, VIS transmits the updated data to EMS. EMS will recalculate the potential availability of electricity from EVs. Moreover, EMS also recalculates the building load based on the present real load of building and real weather which is measured using thermometer and hygrometer. Next, EMS renews its energy management plan, especially the calculated peak-cut threshold.

Furthermore, when EVs arrive at the office building and are plugged to the designated charging stations, EV start to communicate directly with EMS and bypassing VIS through the charging lines. EMS will read the information from EVs and update the previous data received from VIS, especially the battery SOC. As EVs are connected directly to EMS via charging station, EVs are completely under EMS management. Therefore, their charging and discharging behaviors are controlled completely by EMS. After receiving the updated data from EVs, EMS recalculates the peak-cut threshold accurately. As the electricity demand reaches the updated peak-cut threshold, EMS sends the control command to EVs and used EV batteries to discharge their electricity. After finishing the load leveling, EMS can manage the charging for EVs, hence another peak-load due to uncoordinated EV charging can be avoided.

7. Demonstration test

Figure 8 shows the schematic diagram of the demonstration test bed developed in this study. Solid and dotted lines represent the electricity and information flows, respectively. In addition, **Figure 9** shows the pictures of the developed test bed. This demonstration test bed was constructed in the factory area of Mitsubishi Motors Corporation which is located in Okazaki, Aichi prefecture, Japan. Due to limited number of EVs and used EV batteries in this study, this test bed is connected to the electricity of the main office building (office building is considered as BEMS), and not to the whole electricity of the factory. PV panels having total maximum capacity of 20 kW is installed at the rooftop of the test bed as RE generator. In addition, five Mitsubishi EVs, i-Miev G, are participating in this demonstration test. The drivers are the employees who are working in the factory and EVs are used for commuting purpose. Therefore, EVs are basically available during working hours, especially during the day. They are parked and plugged to charging stations installed in the test bed. Furthermore, five used EV batteries are also employed as stationary battery. These used EV batteries are basically detached from the same type of EVs after about one year usage.

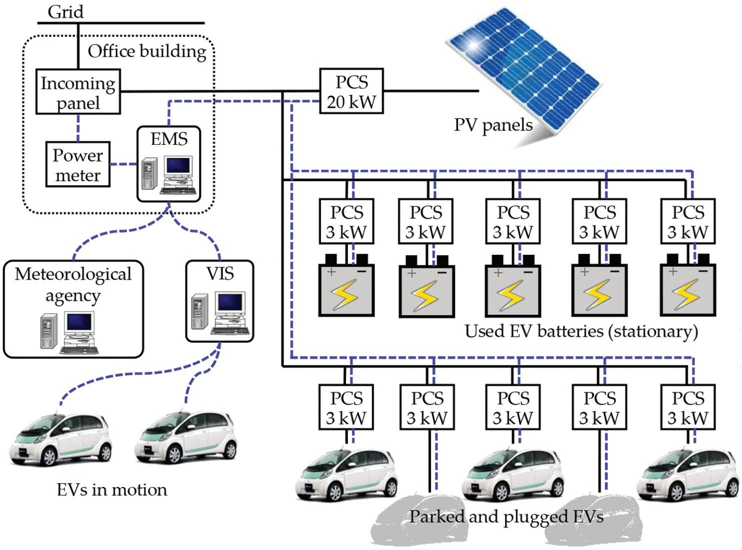

Figure 8. Schematic diagram of the developed test bed.

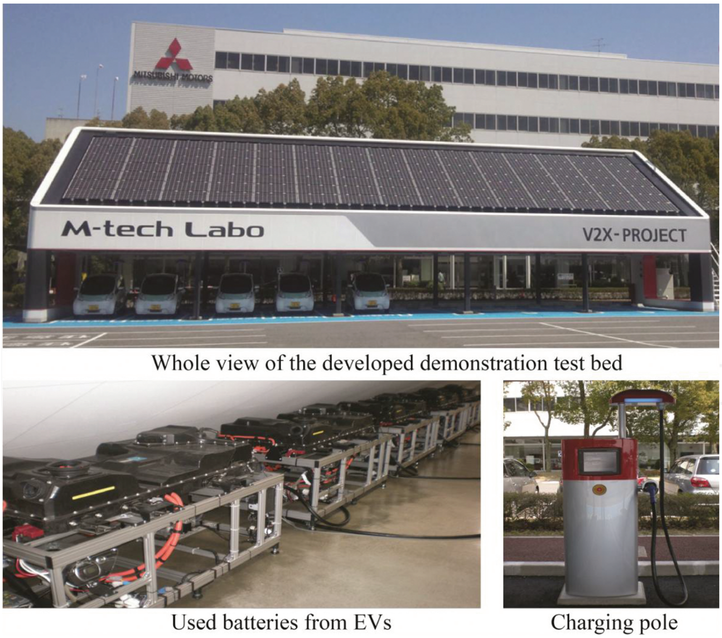

Figure 9. Overview of the developed system involving PV, EVs, and used EV batteries.

Components	Properties	Value
PV panels	Type	Monocrystalline
	Capacity	20 kW
	Direction, angle	South, 30°
	PCS capacity	AC 200 V, 100 A
EVs	Type	i-Miev G
	Number	5
	Battery capacity	16 kWh
	Charging capacity	DC 370 V, 15 A
	PCS capacity	AC 200 V, 15 A
Used EV batteries	Original EV	i-Miev G
	Number	5
	Condition	1-year usage
	Battery capacity	16 kWh
	Charging capacity	DC 370 V, 15 A
	PCS capacity	AC 200 V, 15 A

Table 1. Specifications of the developed test bed.

EMS is controlling the balance of both demand and supply of the main office building and test bed. EMS also forecasts and measures the demand of the office building. In addition, VIS is also developed as an independent system which communicates with EVs and transmits the received information to EMS. **Table 1** shows the detailed specifications of the developed demonstration test bed.

The drivers submit their daily traveling plans to VIS up to one day before the scheduled departure. To facilitate this, a web-based system has been developed facilitating the drivers to input and check their traveling plan from any computers or mobile devices. If EVs are not connected to the designated charging stations of EMS, such as in motion, EVs send their data to VIS in an interval of 10 s wirelessly. In addition, VIS transmitted the received data from EVs to EMS simultaneously. EMS receives EV data from VIS and weather information from meteorological agency. Although the weather information is received basically one day before, meteorological agency will update these data automatically once there is any renewal or correction in the weather information.

Used EV batteries are utilized for peak-shift. Charging of used EV batteries is practically performed from midnight to morning (00:00–06:00). Threshold for charging and discharging of both EVs and used EV batteries is set to SOC 90% and SOC 40%, accordingly. In addition, load leveling is designed to be conducted during afternoon peak-load time starting from 12:00 until 18:00 (6 hours duration) because the total amount of potentially available electricity from EVs and used EV batteries is limited and very small compared to the total load of the office building. In addition, to diminish the effect of ambient temperature on charging and discharging behaviors of used EV batteries, the storage room of used EV batteries is controlled to have a temperature of 25 °C throughout the year at.

The load of office building is estimated as the sum of the base load and fluctuating load, especially the air conditioning demand. The air conditioning demand is calculated using historical data for several previous years and forecasted ambient temperature received from meteorological agency. The demand of office building in certain typical time, L_t, can be simply approximated as follows:

$$L_t = L_{BS} + f\left(\left[T_{OA} - T_{ST}\right]_t \left(\Delta\tau\right)\right) \tag{1}$$

where L_{BS}, f, T_{OA}, T_{ST}, and $\Delta\tau$ are the base load for 30 min interval (kWh) of the office building, functional relationship, outside ambient temperature (°C), room temperature inside the office building (°C), and time shift (h), respectively.

The available electricity from EVs, P_{EV}, which are in motion and not plugged in to the charging poles can be estimated as the correlation of SOC and the remaining distance (both are received from VIS), and can be represented as follows:

$$P_{EV,t} = \left(SOC_{EV,t} \times C_{EV} - d_t \times \eta_{EV}\right) - SOC_{\min} \times C_{EV} \tag{2}$$

where $SOC_{EV,t}$, C_{EV}, d_t, η_{EV}, and SOC_{min} are SOC of each EV (%), EV battery capacity (kWh), remaining travel distance to the designated charging station (km), power consumption of EV (kWh km^{-1}), and minimum SOC threshold for discharging (%), respectively.

To calculate the peak-cut threshold, a day load duration curve is initially created using the historical data of the averaged office building load for the same month in the last year. A peak-cut threshold, P_{thr}, can be approximated using Equation (3). **Figure 10** shows the illustration of a day load duration curve.

$$\begin{aligned} &for\ L_n > P_{thr} \\ &\Sigma L_n = n\ P_{thr} + \Sigma P_{ev,m} + \Sigma P_{bat,m} + P_{pv} \end{aligned} \tag{3}$$

where P_{bat}, n, and m are available power from used EV battery (kWh), number of load higher than peak-cut threshold, and number of EVs and used EV batteries, respectively.

In general, a load duration curve lines up all the loads in a descending order. Therefore, in this demonstration test, a day load duration curve is created by sorting all 30 min duration of office building loads from the largest to the smallest loads. Therefore, the plotted area represents the total electricity consumed by the office building for a day (starting from 00:00 to 24:00). Furthermore, the generated electricity from PV panels is directly delivered to the building without being managed by EMS to be stored in the battery. In addition, the total electricity which can be obtained from connected EVs, used EV batteries, and PV panels is plotted on the top of a day load duration curve for the corresponding day while its bottom is kept to be straight at the same value of load. Therefore, the created straight line is a peak-cut threshold which is used in load leveling.

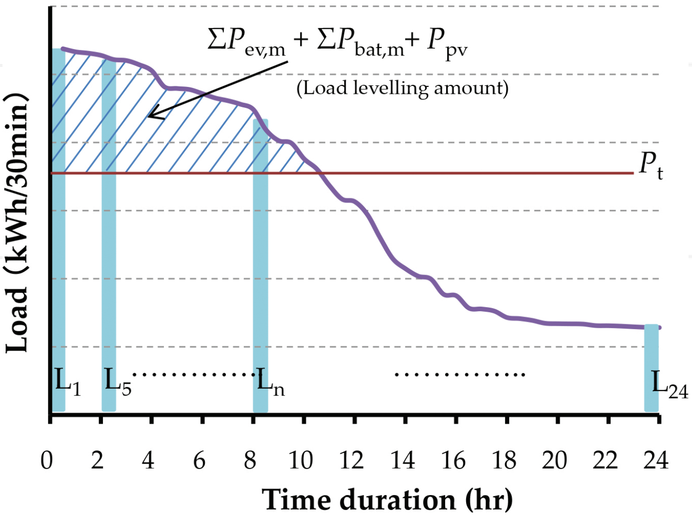

Figure 10. Typical load duration curve and the calculated peak-cut threshold.

8. Results of load leveling test

A result of load leveling demonstration test of one representative weekday is shown in **Figure 11**. It consists of the total grid load (net electricity purchased from the grid), building load (the total load consumed by the office building), electricity generated by PV panels, and total charging and discharging from and to EVs and used EV batteries. Charging and discharging of EV and used EV batteries are represented as dotted blocks in positive and negative sides, respectively. The total grid load during after-noon peak-load time (load leveling test from 13:00 to 16:00) is significantly lower than the building load. This is because of the power generated by PV panels and peak-cut threshold which order the EVs and used EV batteries to discharge their electricity.

Charging and discharging of EVs and used EV batteries in negative sides mainly occur due to charging of used EV batteries during the night time and EVs charging during morning time (before the peak-load time) and during lunch break time. As used EV batteries are charged during night time, the grid load during this time is higher than the building load. EVs generally arrive at the office building at around 08:00 and they are connected to the designated charging stations of EMS. From this moment, charging and discharging behaviors are fully controlled by EMS. Because the building load is still lower than the calculated peak-cut threshold, EVs charging can be conducted until the building load reaches nearly the peak-cut threshold to increase the discharging capacity of the EVs during peak-cut. Moreover, additional charging starts again during noon break (12:00–13:00) because the building load drops drastically creating any marginal grid load.

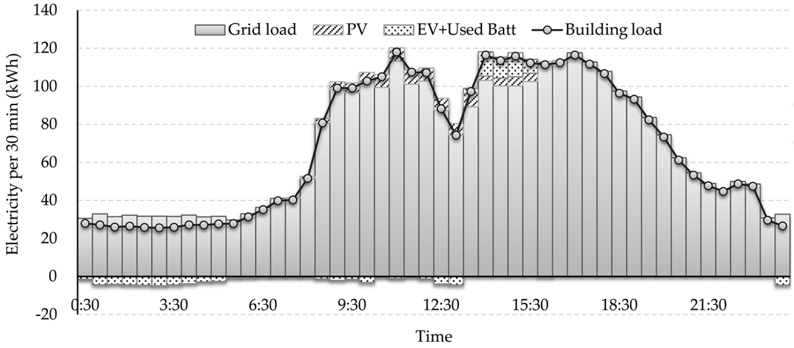

Figure 11. Results of load leveling test during weekdays.

From **Figure 10**, the peak-load occurs twice, i.e., before noon and afternoon, respectively. However, before noon peak-load is lower than the one in afternoon time. The generated electricity by PV is always consumed directly without being charged, hence peak-cut for the before-noon peak-load is conducted only by PV. In addition, the afternoon peak-load starts usually from 13:00 after the end of lunch break time. During this time, the building increases significantly and when it reaches approximately the calculated peak-cut threshold, EMS sends immediately the control command to EVs and used EV batteries to discharge their electricity according to the required amount for load leveling. Hence, the purchased grid load can be kept to lower than the contracted power capacity.

However, due to the limitation of available number of EVs and used EV batteries, load leveling only can be performed in a relatively short duration of time. It is estimated that as the number of EVs and used EV batteries taking part in this ancillary service program increases, more significant effect of load leveling can be achieved. In addition, a longer duration of load leveling and lower value of peak-cut threshold can be obtained accordingly.

Figure 12 shows the total amount of load leveling in a day by each PV panels, EVs, and used EV battery for 8 months of duration of demonstration test. Furthermore, **Figure 13** shows the averaged total load leveling by each PV panels, EVs, and used EV battery in different months. The used EV batteries have the largest and most stable load leveling share compared to EVs and PV. On the other hand, the generated electricity from PV is quite fluctuating because it is influenced strongly by the weather condition, especially solar intensity. Furthermore, the share of EVs in load leveling is also strongly influenced by their main usage as vehicle because it will affect significantly their SOC (available electricity for load leveling).

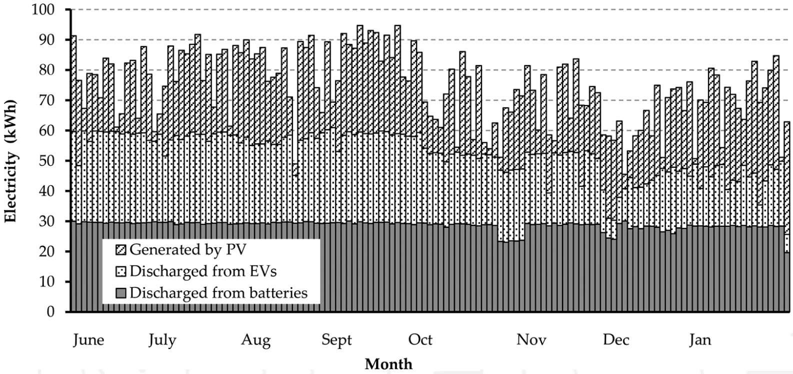

Figure 12. The amount of load leveling in a day by each component (PV, EVs, and used EV batteries).

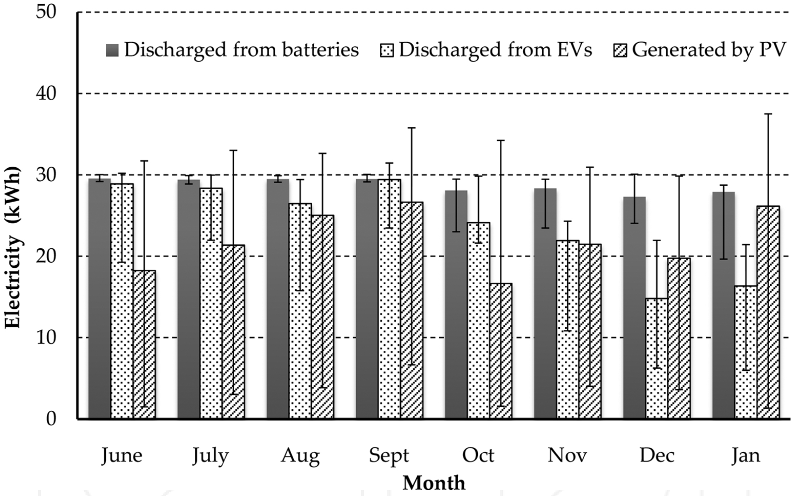

Figure 13. Averaged total load leveling by each component (PV, EVs, and used EV batteries).

The uncertainties are brought mainly by three factors: EVs, PV, and building load. These factors result in divergence between the predicted and real values. In this demonstration test, because the capacity of office building load is significantly larger than the total electricity which can be provided by PV panels, EVs, and used EV batteries, it is assumed that the strongest factor influencing this uncertainty is the building load, especially demands for air conditioning. Moreover, PV also gives an additional influence to this uncertainty due to its fluctuation.

As the results of conducted demonstration test, the predicted grid load showed a relatively high similarity with the real grid load. However, the difference between the predicted building load and its real load is relatively large due to the above-mentioned uncertainties.

The divergences in office building load and generated electricity from PV panels can be lowered by controlling the charging and discharging amounts from both EVs and used EV batteries. In addition, in this demonstration test, the uncertainty related to EV availability and its capacity do not show any significant impact. It is because the drivers of EVs are basically the employees who are working in the office building and almost the commuting routes are constant every day. It is considered that although there is an uncertainty on EVs' availability and their capacity, the divergence between the predicted and real grid loads could be reduced as long as the capacity of the used EV batteries which are owned by EMS are able to cover those fluctuating factors.

9. Some findings and suggestions

There are some important findings and suggestions which can be derived from the above theoretical study and demonstration test which are related to the employment of EVs and their used batteries to support the electricity in a small-scale EMS.

a. To calculate an optimum peak-cut threshold, an accurate forecast of both demand and supply is required. The demand forecast is influenced strongly by two main factors (especially the fluctuating load): weather condition and human behavior inside the building. To achieve more accurate weather forecast, timely update of weather information from meteorological agency and utilization of historical meteorological data are considered very important. In addition, regarding the forecasting of the human behavior, a construction of database and knowledge of specific behavior patterns of the office building is demanded. In case that the measurement of behavior patterns is relatively difficult to be performed, the method of guiding the behavior of the residence by establishing some regulations or policies might be taken.

b. Objective and accurate metering system to measure the amount of charged and discharged electricity to and from EVs is crucially demanded to enhance the trust and transparency. It can be performed by independent third party which is trusted by both EV owners and EMS/aggregator, especially in an aggregator-based contract scheme. The measurement can also include the participating duration, including stand-by time.

c. The increase in EVs number taking part in this ancillary service results in larger available capacity for load leveling (peak-cut). Unfortunately, this phenomenon is also potential to cause higher risk of larger fluctuation in case that EMS cannot forecast accurately the number of EVs. Installation of larger amount of stationary battery (used EV batteries) is considered potential to buffer and absorb this fluctuation through charging and discharging controls.

d. If some EVs which are participating in the ancillary service stop suddenly their service and demand an emergence charging due to some factors, such as traveling distance which will be traveled, EMS also must be able to coordinate this kind of sudden charging demand for EVs. The uncoordinated charging can result in creation of a new peak-load.

e. Compared to peak-load during summer, peak-load during winter is generally lower. However, peak-load during winter occurs mainly during evening time, around 17:00. This is because the heating demand inside the office building increases following the decrease in ambient temperature. It is important to note that the basic working hour also ends in this time, therefore there is any possibility that some EVs are demanding an additional charging before leaving the office. As a result, a new peak-load can occur during this time if the demand for EV charging is high. EMS must be able to also predict this kind of emergency and uncoordinated charging, hence a new peak-load can be prevented.

f. Additional number of EVs and total capacity of used EV batteries will be required when the amount of electricity generated by REs, including PV and wind, increase due to larger amount of fluctuating electricity in the supply side.

10. Conclusion

This chapter discussed the enhanced utilization of EVs and their used batteries to participate in ancillary service to support the electricity, especially in a small-scale EMS. In addition, experimental study based on the real data collected from the demonstration test bed has also been described. The study showed that it is feasible to utilize EVs and used EV batteries in supporting small-scale EMS. Furthermore, load leveling which determines initially the peak-cut threshold and, then controls both charging and discharging behaviors of EVs and used EV batteries based on peak-cut threshold is considered as a valid technique. As a result, the purchased electricity from the grid can be kept to be lower than the contracted power capacity.

Accurate forecast of both load and supply is considered as one of the important issues in this utilization, in addition to the availability forecast of EVs and their batteries. The supply includes the condition of electricity market, possible generated power by REs, and available electricity which can be supplied by EVs. Furthermore, highly accurate load forecast, especially the fluctuating load including human behavior and air conditioning, is also very essential to achieve an optimum target condition as it has been estimated by EMS.

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