Charging/Discharging Behaviors and Integration of Electric Vehicle to Small-Scale Energy Management System

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Abstract: Integration of electric vehicle (EV) to support a small-scale energy management system (EMS) was demonstrated and studied. Initially, charging and discharging behaviours of electric vehicle in different seasons were evaluated to clarify the impact of surrounding temperature to charging and discharging rates. It was found that charging and discharging during summer results in higher rates than ones during winter. In addition, the integration of EVs to small-scale EMS (office) for peak-load shifting showed a very positive effect. Discharging of EVs during noon's peak load can cut and shift the load. Therefore, higher contracted capacity of electricity can be avoided leading to lower total electricity cost.

1 INTRODUCTION

A massive adoption of electric vehicle (EV) replacing the conventional internal combustion engine vehicle (ICEV) is potential to reduce both greenhouse gases emission and fossil fuel consumption (Oda et al., 2016). Therefore, better environmental impacts can be achieved. Rapid development of EV was accelerated by some factors including rising oil and gas prices, enhancement in battery technology, and policies related to environment and transportation (Aziz et al., 2015a; Oda et al., 2017). However, EV has some barriers in its deployment such as high initial cost, long charging time, and limited cruising range. Although the operating cost of EV is relatively lower than conventional ICEV, the production cost of EV is significantly higher (Thiel et al., 2010). Therefore, a value-added utilization of EV is crucially required to improve the economic performance of EV. Hence, sustainable deployment of EV can be achieved. However, a massive deployment of EV can give a significant impact to the grid, especially in case that uncontrolled charging and discharging take place massively. To minimize the impact of this problem, as well as increase the economic performance of EV, the concept of vehicle to grid (V2G) has been studied (Kempton and Letendre, 1997).

EV utilization in supporting the grid has been evaluated by some researchers previously (Kempton and Kubo, 2000; Tomic and Kempton, 2007; White and Zhang, 2011; Aziz et al., 2014; Aziz et al., 2015b). The integration of EV to grid (V2G) can be realized because of the character of EV in both charging and discharging behaviours. As these can be controlled, scheduling and rate control become possible.

The parked and connected EVs can be considered as a potential battery which is capable to absorb, store and deliver back the electricity from and to the grid following the given schedule and control value. The realization of V2G can be achieved when minimally three essential requirements are fully satisfied: (1) electricity connection between EV and grid, (2) communication facilitating control flows between EV and operator, and (3) metering system providing fair measurement (Drude et al. 2014). In V2G system, certain grid operator or energy management system (EMS) can send a request for electricity to a number of parked and plugged EVs to discharge or absorb the electricity to and from the grid.

V2G leads to possibility of several ancillary services to grid such as load levelling, frequency regulation, spinning reserve, and storage (Kempton and Tomic, 2005; Gao et al., 2014). The distributed EVs in large number and area are potential as massive energy storage that can be used to balance responsively the fluctuating supply such as PV and wind. Furthermore, because EVs are mobile, they can be utilized as energy carrier carrying the electricity from and to different places and time because of some factors including price difference and emergency condition. EV utilization in V2G is considered

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feasible because the estimated profit is higher than the current market price of EV batteries although considering the wear of battery.

This paper focuses mainly on two issues: 1) evaluation on charging and discharging behaviour of EVs, and 2) impact of peak-load cutting and shifting in a small-scale EMS based on demonstration test.

2 VEHICLE TO GRID

2.1 V2G in Community Energy Management System

A community EMS (CEMS) has been proposed in Japan with the main aim of integrating the energy utilization, covering both demand and supply sides, therefore, more efficient energy utilization and reduction of CO_2 emission can be realized. The initiatives to propose and adopt CEMS came from the willingness to harmonize energy services, minimize environmental impacts, and maximize economic benefit. CEMS manages both demand and supply of energy, especially electricity, across the whole community. It is responsible in maintaining the balance and harmonization in the community, hence, the comfort, security, and safety of the members are improved. In addition, environmental parameters are also considered in parallel with the living quality.

Therefore, in CEMS, both information and energy are flowing simultaneously across the community. CEMS receives and manages the information and then delivers it to the community members according to their function. CEMS must be sufficiently robust and secure because it deals with personal and authentication information from the community.

Figure 1 represents a schematic structure of CEMS including electricity and information flows, especially its relation with the EV utilization inside CEMS. CEMS collects and manages the information from smaller EMS such as building EMS (BEMS), house EMS (HEMS), and factory EMS (FEMS). In addition, CEMS also has a communication with the outside of community and also upper energy supply such as electric utilities. CEMS predicts and maintains both energy supply and demand based on available previous historical data for certain time and forecasted weather information. Furthermore, CEMS also calculates and optimizes the energy balance with the aim of achieving the lowest energy cost throughout its community. In addition, in case of emergency such as disaster, CEMS evaluates and controls the energy conditions and communicates to its lower EMSs and negotiates with other CEMSs or electric utilities to cover its energy demand and recover the conditions.

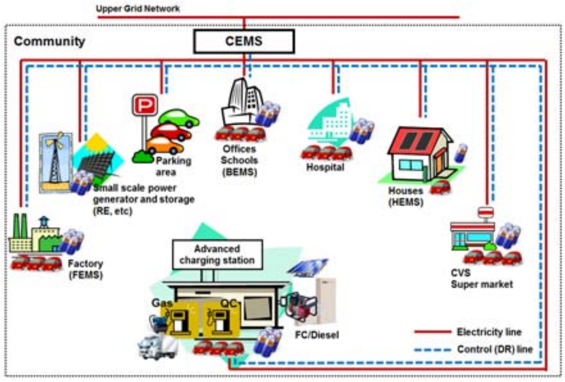

Figure 1: Utilization of EVs to support CEMS.

2.2 EV Utilization System

Utilization of EVs to support the grid, including ancillary services and storage, is possible because of EVs characteristics. In energy storage utilization, charging of EVs can be scheduled when the price of electricity drops because of electricity surplus in the grid. In addition, when the electricity price increases, electricity can be discharged and delivered back to the grid, leading to economic margin for the owner. The ancillary services from EV to grid includes frequency regulation (both up and down) and spinning reserve. Ancillary services are important to maintain the quality of the electricity. As the responses of EV in both charging and discharging are very fast, the ancillary service by EV is considered potential.

Figure 2 represents the schematic utilization of EVs for grid support. In general, there are two schemes in this utilization: direct and aggregator-based schemes. The collection of real time data in a certain interval from EVs includes battery state of charge (SOC), EVs position and predicted arrival time. This data collection is performed by a vehicle information system (VIS). In the reality, VIS can be owned and operated directly by EMS, aggregator or independent service operator.

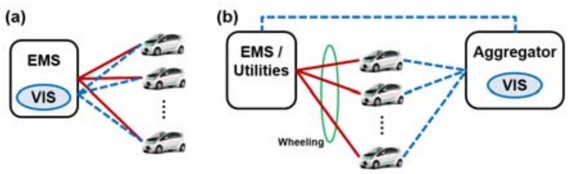

Figure 2: Schemes in utilization of EV supporting the grid: (a) direct scheme, (b) aggregator-based scheme.

In direct scheme, EV owners have the service contract directly with electricity-related entities. In this scheme, both the electricity and information are handled privately. This scheme is well suited for a relatively small-scale EMS and in where EVs are parked and connected in relatively long time (such as office). Its main advantage is the potential to maximize the profit of the involved entities. Furthermore, both charging and discharging controls are easier as EVs are directly connected and fully controlled by EMS. The current study focuses on this type of utilization scheme.

On the other hand, in aggregator-based contract, EV owners have service contracts with the aggregator. The information including its position and battery SOC are handled by aggregator via VIS. Aggregator negotiates for electricity business with the electricity-related entities (EMS or electricity utilities). This kind of utilization scheme is prevalent for relatively large-scale EMS or electricity utilities. EVs may be distributed in different location, such as charging stations and parking areas. The electricity to and from EVs may be transferred via power wheeling system through the available grids. Aggregator offers some possible ancillary services to the EV owners. In turn, EV owners can choose them and receive their profit payment from aggregator.

Load levelling correlates strongly with the management of both demand and supply of electricity. Its aim is lowering the total power consumption in peak hours by shifting the load from peak to off-peak hours. Load levelling can be performed through peak-load shifting and peak-load cutting. The former is defined as moving the electricity load during peak time to off-peak time. It could be achieved through utilization of stationary battery or other storages. The latter deals with the effort to reduce the electricity purchased from the grid by generating or purchasing the electricity. In reality, it can be performed through harvesting the energy especially during peak hours, such as RE, or by purchasing the electricity from other entities including EVs. In this case, EVs are considered as energy storage and carrier storing and transporting the electricity from different time and place. Hence, the economic performance of EV can be increased by joining this kind of ancillary program.

3 CHARGING AND DISCHARGING BEHAVIOURS

EVs largely adopt li-ion batteries to store the electricity as power source because of high energy density, stable electrochemical properties, longer lifetime, and low environmental impacts (Aziz et al., 2016). Temperature is considered as one factors influencing charging and discharging behaviours of li-ion batteries. Generally, lower temperature leads to poor charging and discharging performance because of electrolyte limitation (Xiao et al., 2004) and changes in electrolyte/electrode interface properties including viscosity, density, electrolyte components, dielectric strength, and ion diffusion capability (Jansen et al., 2007). Liao et al. (2012) found that as the temperature decreases, the charge transfer resistance increases significantly, higher than bulk resistance and solid-state interface resistance.

Unfortunately, lack of study deals with the effort to clarify the charging behaviours in different temperature or season. In this study, to clarify the effect of temperature (ambient temperature), to the charging behaviour of EV, charging in different seasons: winter and summer, were conducted initially.

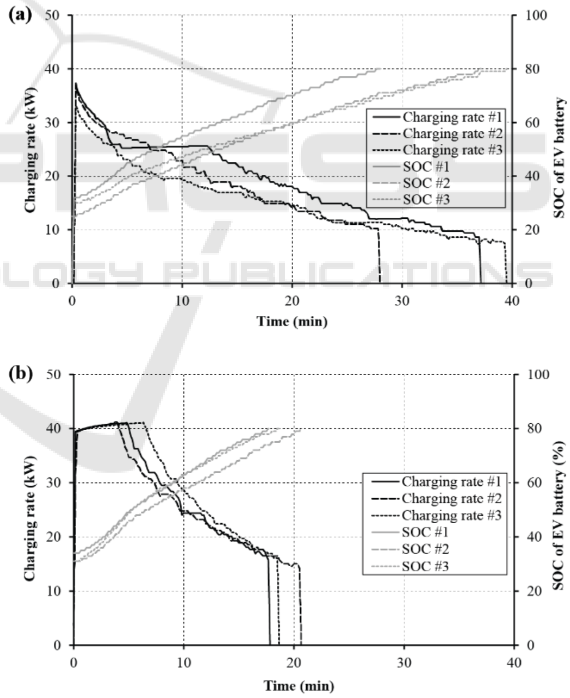

Figure 3: Charging performances of EV in different seasons: (a) winter, (b) summer.

Figure 3 shows the relation among charging rate, charging time, and SOC of EV battery both in winter (a) and summer (b). Generally, although the rated capacity of the charger is 50 kW, the charging power absorbed by EV battery is relatively lower, especially in winter. Compared to charging in winter, charging in summer leads to higher charging rate and shorter charging time. Numerically, to reach SOC of 80%, the required charging times in winter and summer were 35 and 20 min, respectively. In summer, higher charging rate (about 40 kW) could be achieved up to SOC of 50%. It decreased gradually following the increase of SOC and it showed the charging rate of 16 kW when SOC reached 80%. On the other hand, in winter, the charging rate reached about 35 kW instantaneously in very short time and decreased following the increase of SOC. The charging rate when SOC reached 80% was about 10 kW.

4 V2G DEMONSTRATION IN SMALL-SCALE EMS

The schematic diagram of EV integration test to support the electricity in a small-scale EMS is presented in Figure 4. EMS basically controls all the electricity demand and supply. It requests, manages, and integrates some information: electricity load, weather information from meteorological agency, EV information from VIS, electricity condition from CEMS and utilities. The meteorological agency sends periodically the weather information. It is used by EMS to calculate the next coming load and the possibly generated electricity from RE. Building load is classified into base and fluctuating loads. The former is the minimum demand consumed by the system to operate for 24 hours continuously. Therefore, it is generally constant throughout the time and almost not affected by the weather condition. In addition, the latter depends strongly to the behaviours of the residents. Human behaviour is influenced by the weather condition including temperature and humidity. In addition, the generable power from RE, such as wind and solar, is predicted also by EMS based on the received weather information.

EMS also receives information from VIS including EV position, battery SOC, and estimated arrival time. VIS collects the information from EV routinely. The collected data is utilized to coordinate both charging and discharging of EV and to keep the balance of electricity distribution and avoid any peak-load in EMS. In addition, VIS also can provide additional services to the driver regarding the availability of ancillary service programs offered by EMS or aggregator. Therefore, EMS also requests from electric utility the electricity condition and price information. These will be used to calculate the demand as well as the charging and discharging behaviours of both EVs and used EV batteries.

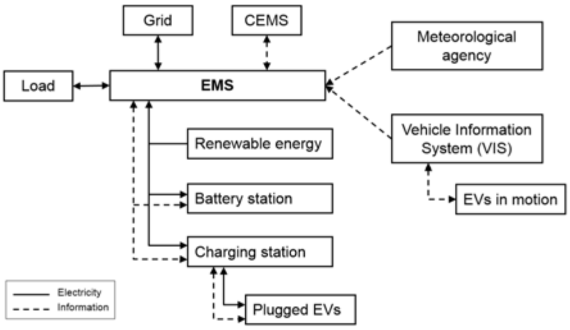

Figure 4: Schematic diagram of developed V2G in small-scale EMS.

4.1 Developed V2G Concept

Figure 5 represents the concept of peak-load cutting and shifting (load levelling) developed for a small-scale EMS. Four main subsequent steps were proposed: (1) forecasting of load and power from RE, (2) forecasting the amount of load levelling, (3) correction of calculated value, and (4) charging and discharging controls of EVs. Forecasting of load and power from RE is conducted for 24 hours-ahead.

During forecasting of load and generable power from RE, EMS initially requests a weather information from meteorological agency for calculating the generable electricity from RE including PV and wind. In this study, the generated electricity from RE is completely used for peak-load cutting and will be consumed entirely with no storage. Therefore, the weather information is also utilized to predict the fluctuating load mainly due to human behaviour inside the building, especially related to air conditioning and lighting. The outputs from this first step are forecasted RE generation and load curves for the next 24 hours ahead.

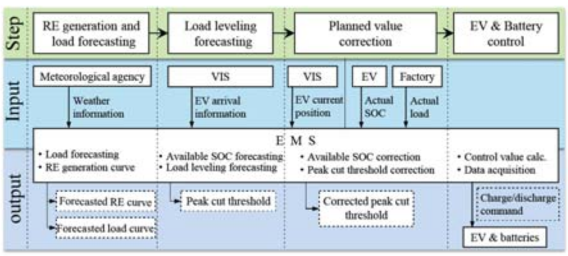

Figure 5: Load-levelling concept used in the V2G demonstration.

Once the load and RE generation have been forecasted, EMS calculates the possible load levelling which can be achieved in the next 24 hours. For this purpose, EMS communicates with VIS to estimate the number of EVs and their SOC states which are available to join the program. VIS initially receives the travelling schedule from the drivers and, subsequently, VIS transfers this information to EMS including EV's ID, planned departure time and estimated arrival time. Moreover, the registration of travelling schedule by the driver should be done up to 24 hours before the departure. As the available resources for peak-load cutting and shifting and load curves are estimated, EMS can calculate the peak-load cutting threshold for the next day. It is defined as the maximum amount of electricity purchased from the grid by EMS. It is theoretically calculated based on some factors including electricity price, contracted capacity, available power generation, and storage. When the electricity consumed by the building increases and the purchased electricity from the grid reaches the peak-load cutting threshold, EMS sends the command to EVs and used batteries to discharge their electricity. Hence, the electricity purchased from the grid is same to of lower than the calculated peak-load cutting threshold. In the real application, it may avoid a higher price of electricity during peak time.

When EVs are in motion, the information of EVs is transmitted to VIS. VIS sends the data to EMS which is used to recalculate the available electricity from EV. EMS also recalculates the building load based on the real weather and the real load of building. Next, EMS modifies its energy management plan, especially the peak-load cutting threshold.

When EVs arrive and are connected to the chargers, they communicate directly with EMS. Hence, all the information is updated including the available electricity from EVs. From this moment, EVs are ready to take part in the ancillary service program offered by EMS. EVs are fully controlled by EMS, especially their charging and discharging behaviours. Finally, EMS calculates and sends the control command to each EVs and used batteries to keep its previously calculated peak-load cutting threshold.

4.2 Demonstration Test

The demonstration test facility was constructed in the factory area of Mitsubishi Motors Corp., Okazaki, Japan. It was connected and utilized to support the electricity of the main office building. As RE generator, 20 kW PV panels were installed on the roof top of test bed. Five EVs (battery capacity of 16 kWh), Mitsubishi i-Miev G, were taking part in the program and the drivers were also the employee. Hence, EVs were mostly parked and plugged to the charging poles during working hours. Therefore, five used batteries, used for about 1 year from the same type of EV, were also installed and directly owned by EMS. EMS are managing all the demand and supply sides of the test bed. On the other hand, VIS was also developed as a standalone system to communicate with EVs and transfer the information to EMS.

Used batteries were practically used for peak-load shifting. They were charged during the night time (off-peak hours) when the price of electricity was cheaper. In this study, this charging was performed from 00:00 to 06:00. The SOC thresholds during charging and discharging of both EV and used battery were fixed at 90% and 40%, respectively. In addition, as the total capacity amount of EVs and used batteries was very small than the total load of the office, peak-load cutting was designed to start from 12:00 until 18:00 (targeting mainly on the afternoon peak).

Figure 6 represents the results of load levelling test in a representative weekday consisting of total grid load, building load, generated power from PV, and charged/discharged electricity to and from EVs and used EV batteries. The grid load is the net electricity from the grid. Light green blocks in positive and negative sides represent discharge and charged electricity amount from and to EVs and used batteries, respectively. The main objective of peak-load cutting and shifting is to reduce the grid load, especially during peak hours, to reduce the total electricity cost of the building.

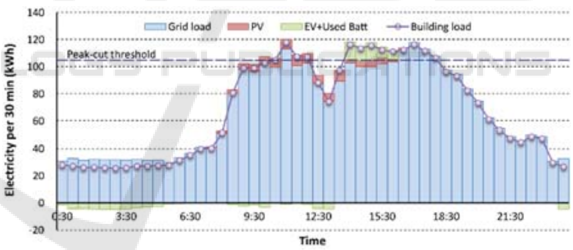

Figure 6: Schematic diagram of developed V2G in small-scale EMS.

PV generated the electricity during a day and it was directly consumed without being stored. The used EV batteries were charged during the night with a lower electricity price, starting from 00:00 to 06:00. As the result, the grid load during the night slightly increased. In the morning, around 08:00, EVs reached the office and they were plugged in designated charging poles. From this moment, charging and discharging behaviours were fully controlled by EMS. Because the building load was smaller than the calculated peak-load cutting threshold, charging for EVs was performed until the building load reaches nearly the peak-load cutting threshold. Additional charging started again during noon break (12:00 to 13:00) because the building load dropped drastically.

Peak-load takes place twice in a weekday: before and afternoon. Peak at the morning is lower than one in afternoon. The afternoon peak usually starts from 13:00 following the end of noon break. As the peak-load is higher than the calculated peak-load cutting threshold, EMS sends the control command to both EVs and used batteries to discharge their electricity. As the results, the grid load can be reduced. However, because the total capacity of EVs and used batteries is very small compared to the total building load, peak-load cutting can only be performed in a relatively short duration . If the number of EVs participating in the load levelling program increases, the effect of load levelling becomes more significant. Therefore, longer peak-load cutting and lower peak-load cutting threshold can be achieved.

5 CONCLUSIONS

Integration of EV to small-scale EMS is studied and demonstrated in this study. Charging and discharging behaviours of EV were initially clarified. It was found that charging and discharging rates during summer is higher than ones during winter. The demonstration test was performed to measure the application of EVs for peak-load cutting and shifting. It was clarified that the utilization of EVs for peak-load cutting and shifting in small-scale EMS is very feasible.

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REFERENCES

Aziz, M., Oda, T., Mitani, T., Watanabe, Y., Kashiwagi, T., 2015a. Utilization of electric vehicles and their used batteries for peak-load shifting. *Energies*, 8(5):3720-3738.

Aziz, M., Oda, T., Morihara, A., Murakami, T., Momose, N., 2014. Utilization of EVs and their used batteries in factory load leveling. In *Proceedings of 2014 IEEE PES Innovative Smart Grid Technologies Conference (ISGT)*, doi: 10.1109/ISGT.2014.6816370.

Aziz, M., Oda, T., Kashiwagi, T., 2015b. Extended utilization of electric vehicles and their re-used batteries to support the building energy management system. *Energy Procedia*, 75:1938-1943.

Aziz, M., Oda, T., 2016. Load levelling utilizing electric vehicles and their used batteries. *Modeling and Simulation for Electric Vehicle Applications*, InTech, Rijeka. pp. 125-147.

Aziz, M., Oda, T., Ito, M., 2016. Battery-assisted charging system for simultaneous charging of electric vehicles. *Energy*, 100:82-90.

Drude, L., Pereira, L.P., Ruther, R., 2014. Photovoltaics (PV) and electric vehicle-to-grid (V2G) strategies for peak demand reduction in urban regions in Brail in a smart grid environment. *Renewable Energy*, 68:443-451.

Gao, B., Zhang, W., Tang, Y., Hu, M., Zhu, M., Zhan, H., 2014. Game-theoretic energy management for residential users with dischargeable plug-in electric vehicles. *Energies*, 7:7499-7518.

Jansen, A.N., Dees, D.W., Abraham, D.P., Amine, K., Henriksen, G.L., 2007. Low-temperature study of lithium-ion cells using a Li_ySn micro-reference electrode. *Journal of Power Sources*, 174:373-379.

Kempton, W., Kubo, T., 2000. Electric-drive vehicles for peak power in Japan. *Energy Policy*, 28:9–18.

Kempton, W., Letendre, S.E., 1997. Electric vehicles as a new power source for electric utilities. *Transportation Research Part D*, 2:157–175.

Kempton, W., Tomic, J., 2005. Vehicle-to-grid power fundamentals: Calculating capacity and net revenue. *Journal of Power Sources*, 144:268-279.

Liao, L., Zuo, P., Ma, Y., Chen, X., An, Y., Gao, Y., Yin, G., 2012. Effects of temperature on charge/discharge behaviors of $LiFePO_4$ cathode for Li-ion batteries, *Electrochimica Acta*, 60:269-273.

Oda, T., Aziz, M., Mitani, T., Watanabe, Y., Kashiwagi, T., 2016. Number of quick charging stations and their quick chargers for electric vehicles ─a case study considering the traffic density of the road type─. *Journal of Japan Society of Energy and Resources*, 37(6):7-12. (in Japanese).

Oda, T., Aziz, M., Mitani, T., Watanabe, Y., Kashiwagi, T., 2017. Actual congestion and effect of charger addition in the quick charger station —Case study based on the records of expressway—. *IEEJ Transactions on Power and Energy*, 136(2):198-204.

Thiel, C., Perujo, A., Mercier, A., 2010. Cost and CO_2 aspects of future vehicle options in Europe under new energy policy scenarios. *Energy Policy*, 38:7142-7151.

Tomic, J.; Kempton, W., 2007. Using fleets of electric-drive vehicles for grid support. *Journal of Power Sources*, 168, 459-468.

White, C.D., Zhang, K.M., 2011. Using vehicle-to-grid technology for frequency regulation and peak-load reduction. *Journal of Power Sources*, 196:3972-3980.

Xiao, L.F., Cao, Y.L., Ai, X.P., Yang, H.X., 2004. Optimization of EC-based multi-solvent electrolytes for low temperature applications of lithium-ion batteries, *Electrochimica Acta*, 49:4857-4863.