Demand Side Management Using a Battery-Equipped Quick Charger for Electric Vehicles

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1. Back Ground

- The burden imposed on owners having to install electrical vehicle (EV) quick chargers is not light due to the increase in the demand for peak electricity as well as the cost of installing facilities.
- In addition, the increase and uncertainty of electricity demanded by charging EVs is likely to make grid operation difficult for power companies in the near future.

- It is useful to approach the matter from the standpoint of peak cuts by shifting or reducing electricity demand that is attributed to the charging of EVs.
- It is important to minimize inconvenience caused by prolonged durations to charge EVs by controlling the time they start to charge or restricting the power used by EV chargers.

We have developed a battery-equipped quick charger for EVs with demand side management (DSM)

2. Configuration

- This system consists of a quick charger including four 10 kW rectifier units and one 10 kW DC/DC converter unit, a communication unit, a controller, and a lithium-ion (Li-ion) battery system.
- The controller unit monitors energy consumption at the point of common coupling (PCC) via a communication unit and can change the number of rectifier units in operation according to consumption when an EV is charging.
- The communication unit transmits the data being measured and alarm signals to a data centre via a mobile network to supervise energy consumption.
- The quick charger has a controller that receives EV commands via a CAN bus, and the quick charger sets the current to meet the EV's command value.
- Optimal and fast charging becomes possible in response to in-vehicle battery performance and the usage environment via the CHAdeMO mechanism.

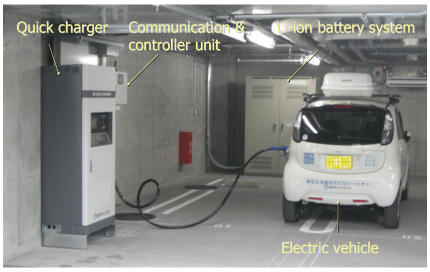

Fig. 1. Demonstration facility for field test

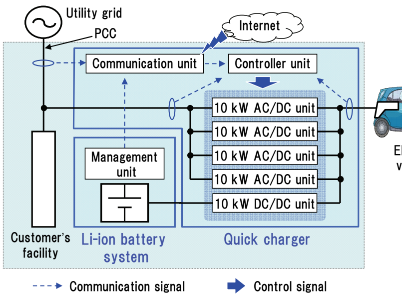

Fig. 2. System configuration for battery-equipped quick charger

Table1. Specifications

Systems	Items	Units	Specifications
Quick charger (AC input)	Phase and wire	-	3-phase, 3-wire
	Rated voltage	V	200
	Power factor	-	Over 0.95
Quick charger (DC output)	Range of output voltage	V	50 - 500
	Range of output current	A	0 - 125
	Range of output power	kW	0 - 50
	Efficiency	%	Over 90
Battery	Rated capacity	Ah	85
	Range of operational voltage	V	237.6 - 369.6
	Range of discharge current	A	0 - 300

3. Control Function

A. EV charging mode with DSM function

- When the quick charger receives a charge command from the EV, the controller determines
  - the number of available rectifier units that are obtained from Formula (1).
    (The EV charging power when using P_{Cv} as an upper limit is larger than that when using contract power as an upper limit.)
  - whether the DC/DC converter unit is available or not taking into consideration the state of charge (SOC) of the Li-ion battery.

  ➡ The controller calculates the maximum output capacity in the quick charger based on the number of available rectifier units and the DC/DC converter unit, and then the quick charger starts to charge the EV.
- If the energy consumption reaches a contracted value or an arbitrary value such as P_{Cv} at the PCC when the EV is being charged, the controller reduces the number of rectifier units in operation and increases the electricity supply derived from the Li-ion battery. When energy consumption is sufficiently low, the controller gradually increases the number of rectifier units.
- In addition, the controller manages the SOC of the Li-ion battery based on information from the management unit in the Li-ion battery system. If the SOC reaches a set threshold to stop charging, the controller stops the battery from discharging.

$$n = \frac{(P_{Cv} - P_b(t))}{P_{max\_unit}} \quad (1)$$

$$P_{Cv} = P_C + \frac{t_s \cdot Pc - \int_0^{t_s} P_d(t)dt}{30 - t_s} \le P_f \quad (2)$$

n :The number of available rectifier units
PCv :The virtual contact power [kW]
$P_b(t)$:The power consumption by the customer's building [kW]
P_{max_unit} :The maximum output power of the rectifier unit [kW]
P_c :The contract power [kW]
$P_d(t)$:The receiving power at PCC (including power consumption by the quick charger and customer's facilities) [kW]
t_s :The time the EV started to charge ($0 \le t_s \le 30$) [min]
P_f :The capacity of the electrical facilities [kW]

B. Battery charging mode

- Charging by constantly controlling the voltage and the current is carried out to charge the battery safely.
- As EV charging has priority over battery charging, the battery is only charged when the EV is not charging.
- The operational range of SOC, i.e., the set threshold for charging and stopping charging, is taken as a variable according to the time-of-use rates for electricity and the frequency of EV charging to increase economical efficiency and convenience.

4. Simulation

A. Calculation condition

- Simulation tool is MATLAB/Simulink.
- We created a power consumption pattern for an apartment building.
- A total of five EV charges would occur during the evaluation period (6h).
- The charge characteristics of a commercially available EV in this simulation based on actual measured values is adopted. (Fig. 3)
  - This EV was charged by constantly controlling current in the early stages of charge, and it was charged by constantly controlling voltage in the last stages of charge.
  - The time it took to charge the EV was only about 20 min when the capacity of the quick charger was 40–50 kW; however, it took an hour when the capacity was 10 kW.

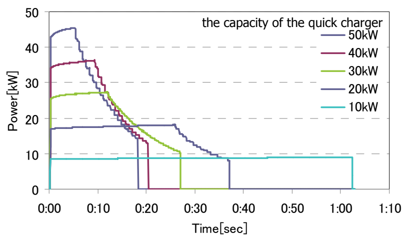

Fig. 3. The duration of EV charging when SOC of in-vehicle battery increases from 20 to 80% on a single quick charge.

- The results using three different methods listed in Table 2 are compared.

Table 2. Comparison of EV charging time

Method 1	With proposed DSM function
Method 2	With general DSM function (retaining instantaneous value of receiving power at PCC below contract value at any time.)
Method 3	With no DSM function

B. Results

- When energy consumption ΣP_d almost reached contract energy ΣP_C, the DSM function in the controller reduced the number of rectifier units in operation. As a result, ΣP_d remained under ΣP_C. (Fig. 4)
- Methods 1 and 2 satisfy the constraint that receiving energy at PCC is less than the contract energy, which is 20 kWh. However, Method 3 does not satisfy the constraint. (Fig. 5)
- Compared to 18 min for Method 3, the average charge time per single charge is long about 20 min for Method 2, and about 8 min for Method 1.

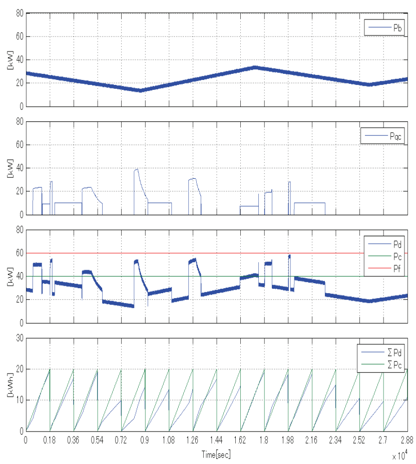

Fig. 4. Results from simulating demand. (P_b: building power, P_{qc}: quick charger, P_d: receiving power at PCC (P_b+P_{qc}), P_c: contract power, P_f: electrical facility capacity, ΣP_d: energy of P_b, and ΣP_C: contract energy)

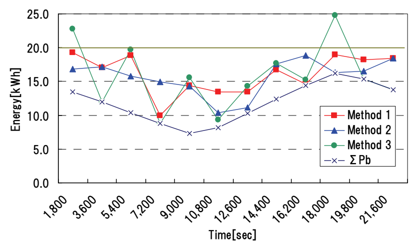

Fig. 5. Comparison of consumed energy every 30 min. (Σ Pb :the amount of energy used by the apartment building except for EV charging.)

5. Conclusion

- We developed a battery-equipped quick charger for EVs with DSM function.
- We confirmed in simulations that electricity demand remained within the range of the contracted value and EV charging time was only increased by a few minutes compared to that without the DSM function.
- We installed this system in a parking lot under an apartment building, and started the field test in July, 2012. We are planning to operate this system so that we can obtain field data for a few years. We expect the DSM function will be improved based on these field data.

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