Electric Vehicle Charge-and-Share

Campus Demonstration on Sustainable Charge, Energy Mobility & Sharing

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Abstract— **Electric vehicles are possible candidate as flexible charging demand from variable renewable energy sources such as solar and wind power generations, and as distributed V2G (Vehicle-to-Grid) energy storage providing energy management services for house/office/apartment owners and ancillary services for TSOs (Transmission System Operator) and DSOs (Distribution System Operator). In this paper, possibilities of multiple services by the electric vehicles are evaluated by using data of electric vehicle demonstration projects. Some services are actually implemented to the electric vehicles and charging infrastructure in the university campus. Overview of the campus demonstration project, Charge-and-Share, is explained in this paper.**

Keywords-Electric Vehicle; Smart Charging; Vehicle-ro-Grid; Renewables Integration; HIL

I. INTRODUCTION

Capability of V2G would activate flexible energy management for the house/office/apartment/factory. All the EV models and some charging system are normally equipping with discharging function in Japan. Pioneering ancillary service demonstration projects based on the V2G have been established in European countries and United States [1], [2], [3]. Network codes for the electric vehicle and supply equipment interconnecting into the power systems is to be provisioned [4], [5]. The V2G capable electric vehicle will act as mobile energy storage for everything that needs the power and energy. Renewable powered re-charging of the electric vehicles is an important solution for de-carbonization of both transportation and energy sector [6], [7], [8], and supply and demand matching in the power system [9].

In this paper, potential of smart charging and V2G is evaluated based on data analysis to the smart house and building projects with the electric vehicles. Hosting capacities of renewables and electric vehicles into a distribution feeder, where massive integration is assumed, are quantified through the power systems simulations. The author is conducting a demonstration project based on the power systems hardware-in-the-loop (HIL) simulation facility and the actual electric vehicle and charging facility in the campus. Multiple services such as residential and office building energy management, grid-scale ancillary services, and the renewable powered re-charging is to be implemented. The system concept of the project is described in this paper.

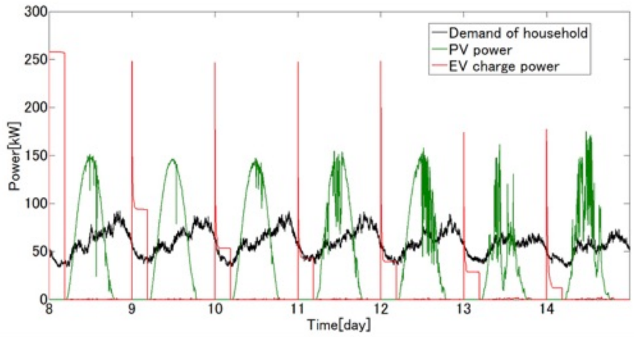
II. SIMULATION

A. Smart House

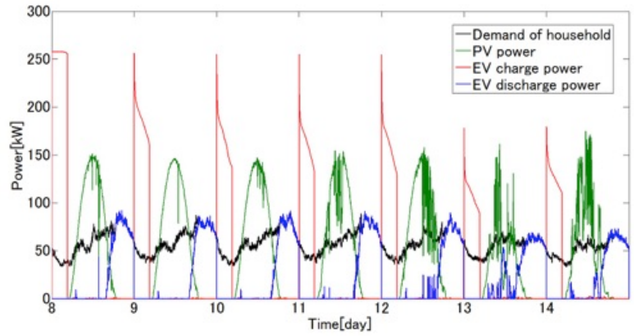
Potential of household energy management (V2H : Vehicle-to-Home), solar powered charging (S2V : Solar-to-Vehicle), and grid ancillary service (V2G) is evaluated on data of a smart houses equipping the rooftop solar power generation and the plug-in hybrid electric vehicle. Solar power generations, power demands, and vehicle usages are measured altogether in 67 houses. In this paper, a week simulation in summer season is executed by using these measurements. It is assumed that all the vehicles are pure electric with 30kWh battery, and can perform 6kW charging or discharging control. Power consumption for vehicle drive is estimated as 0.1kWh/km.

Fig. 1 indicates simulation results, power curves of sum of 67 houses. In the base case, the electric vehicles are charged up during the nighttime with discount electricity price (13.45JPY/kWh) from 24pm to 7am against the daytime price (24.16JPY/kWh). In the V2H case, the electric vehicles are once discharged during evening peak time of household power demand if they are pugged-in, then re-charged during nighttime. In the S2V case, the electric vehicles are charged preferentially by solar surplus power. Solar surplus is defined as 50kW reverse power flows from 67 houses, in this paper. For the V2G case, ancillary service signals are emulated considering a utility level thermal power generator and the solar power generations. Electric vehicle aggregator bits with 250kW charging or discharging capability, and the ancillary service signals are equally dispatched to 67 vehicles.

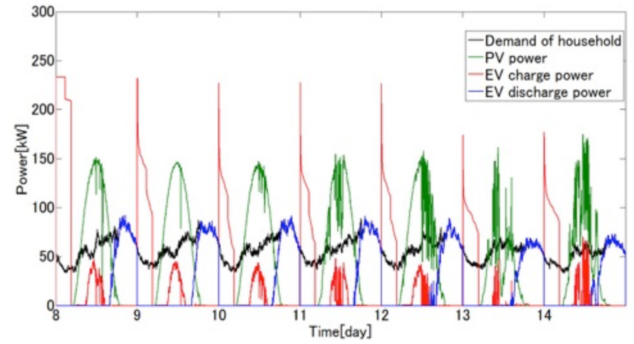
Numerical evaluations in each case are summarized in Table. I. The V2H can reduce about 28% of electricity costs. The S2V contributes self-consumption of rooftop solar generations. The electricity costs increase because of high FIT price (33.00JPY/kWh), however, it would be very effective for post FIT situation. The V2G create an additional value for contributing the ancillary services. If the price incentive same order as the electricity price (10.00JPY/kWh) is considered, the electricity costs could be offset by the incentives.



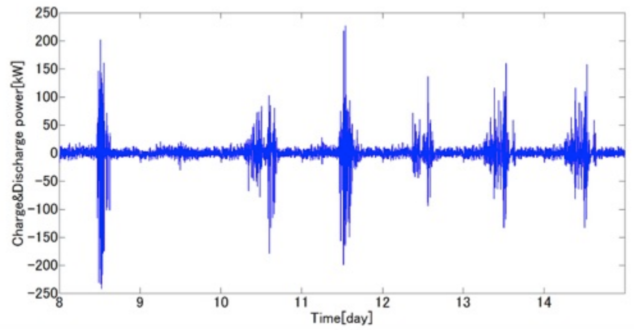
(a) Base



(b) V2H



(c) S2V



(d) V2G

Figure 1. Power curves of Base/V2H/S2V/V2G cases

TABLE I. EVALUATION OF BASE/V2H/S2V/V2G CASES

	Electricity Cost [Yen/Week]	PV Self Consumption [kWh/Week]	Ancillary Service [kWh/Week]
Base	182,410	57	
V2H	130,626	53	
S2V	152,622	673	
V2G		56	16,975 (UP : 8,518) (Down : 8,457)

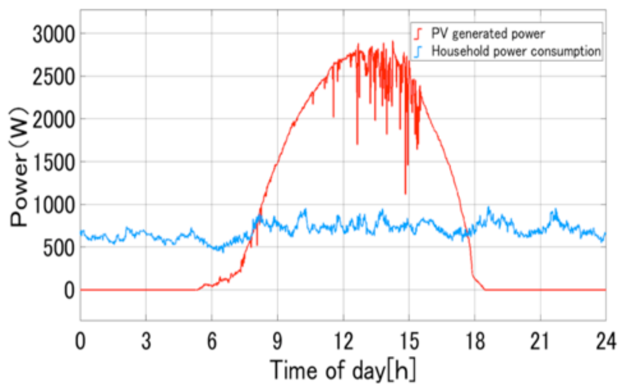
B. *Smart Building*

The V2B (Vehicle-to-Building) system has been established in the office building and apartment building in Japan. Company owned electric vehicles and sharing electric vehicles for apartment residents could be discharged for building energy managements. Reduction of contract power and monthly electricity cost by the V2B control was confirmed by a simulation on the measurements of an apartment building with a sharing electric vehicle. The proposed V2B control was also confirmed to give no inconvenient to vehicle usage.

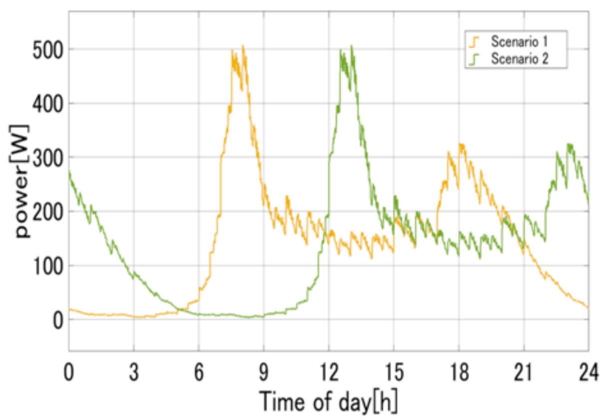
C. *Distrribution Feeder*

Managing timing of charging the electric vehicle in the house and office, power flow loading on the distribution transformer and voltage profile on the distribution feeder can be optimized. Fig. 2 shows the averaged power consumption and solar power generation per house, and averaged charging power of an electric vehicle at the residence and the office, estimated by the traffic survey. In Fig. 2 (b), scenario 1 is uncontrolled, and scenario 2 is timer charging of 3.5 hours delay.

It is obvious that the timer charging is effective for absorbing solar power generation in the office around noon, and also effective for avoiding evening peak in the house. This simple charging control gains the hosting capacity of solar power and electric vehicle to the distribution feeder by 8%. When the V2G power discharging from the electric vehicle is allowed, more flexible "aggregated storage operation" can be achieved [10].



(a) Power consumption and solar power generation



(c) Electric vehicle charging power

Figure 2. Power curves of solar, load, EV per house

III. Demonstration

A. V2G System

Configuration of the V2G system [11] is shown in Fig. 3. The EVs and EVSEs (Electric Vehicle Supply Equipment) are connected via VPN between campuses. The EVSE transforms DC 330V to single-phase AC 200V, and seamlessly control charging and and/or V2G power. The rapid prototype controller integrates three communication links between the components, and determines the power set point taking the detected grid frequency, the battery SOC, and the remote signals from the EV aggregator into account. Standardized communication protocols are used for integrating the components.

Step responses of the system are evaluated under the stepwise frequency change generated by the power amplifier. Fig. 4. shows the instantaneous values of AC voltage and AC current, the grid frequency, active power output, and the battery SOC. The active power at charge is defined as positive value. The active power was controlled in response to the detected frequency change with a communication dead time and a delay of the power conversion.

In Fig. 5, the V2G system is interconnected with the power system, in which the grid frequency fluctuates as a result of the supply and demand imbalance of the actual TEPCO (Tokyo Electric Power Company) power system. Just after standing up the system, the EV was charged up to 50% readying for the emergency departure. After the EV continued to supply the charge and discharge cycles for the frequency response, the EV was charged up to the destination SOC (90%). Total settling time of the system was within one second including time lags caused by the frequency detection, communication, and response of the power conversion and control. It was enough to follow the frequency change. The seamless mode switch was also realized by the system.

B. Vehicle Grid Integration HIL

The V2G system is cooperated with the power and communication HIL facility. The power system digital simulator generates real-time control signals from the power system model, in which large-scale renewable energy sources, multiple EVs, and conventional generators are modified. The V2H/V2B/S2V/V2G control strategies are implemented to the vehicle grid integration HIL facility.

Current laboratory setup is described in Fig. 6. A flexible power amplifier (AMETEK MX15-1pi) synchronizing the power system real-time simulator (Opal-RT OP5600) can supply instantaneous voltage at the optional location in the power system and/or distribution feeder model. Two V2G capable battery energy storage systems (Mitubishi i-MiEV and DENSO system) and a rapid prototyping inverter system (TriphaseNV PM15) are used for the targeting devices of the power and communication HIL.

Advanced ancillary services suitable for the electric vehicle, such as FFR (Fast Frequency Response) and SIR (Synthetic Inertia Response), are designed by use of the vehicle grid integration HIL facility [12]. Smart inverter control for the electric vehicle, such as reactive power control, is also designed for mitigating local voltage and power flow impact in providing global ancillary services to the power system [13].

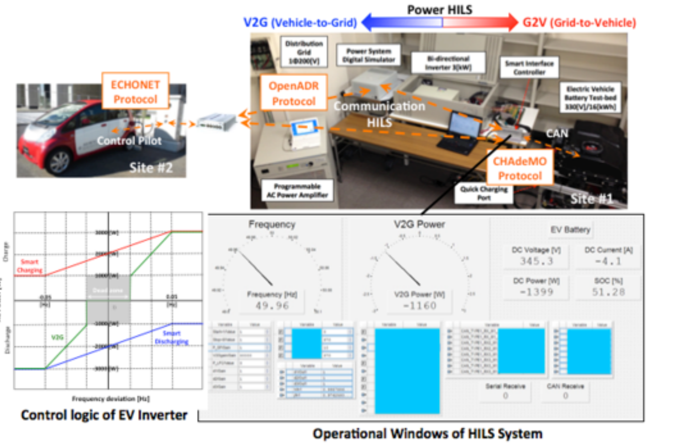


Figure 3. Configuration of V2G system

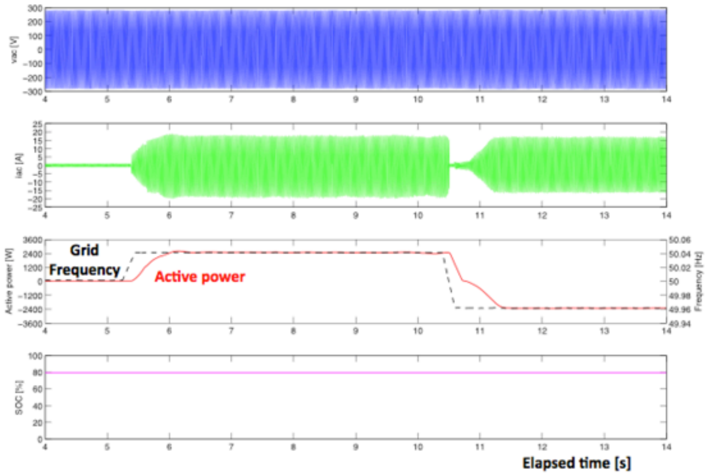


Figure 4. Configuration of V2G system [11]

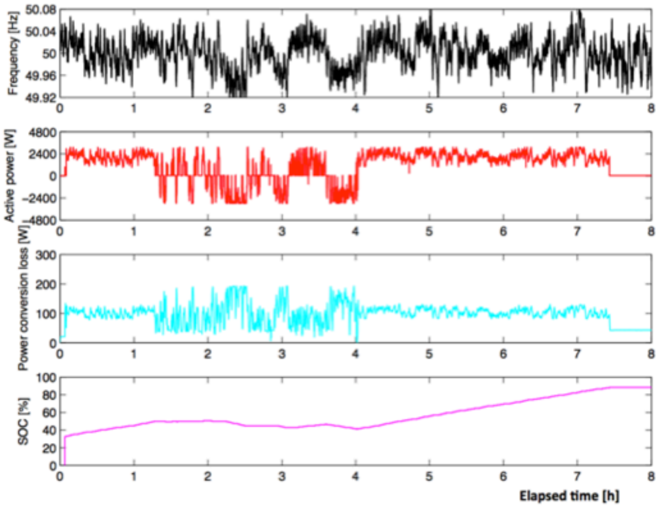


Figure 5. V2G control for the TEPCO power system [11]

C. Charge-and-Share Project

Three electric vehicles are joined to the vehicle grid integration HIL facility from August 2017. Unveiling event was held during the open campus on 5th September, as shown in Fig. 7. White vehicle is van type (NISSAN e-NV200 van) equipping 24kWh battery system. Black vehicle is high spec wagon type (NISSAN e-NV200 wagon) with power outlet function up to 1500W from the 24kWh

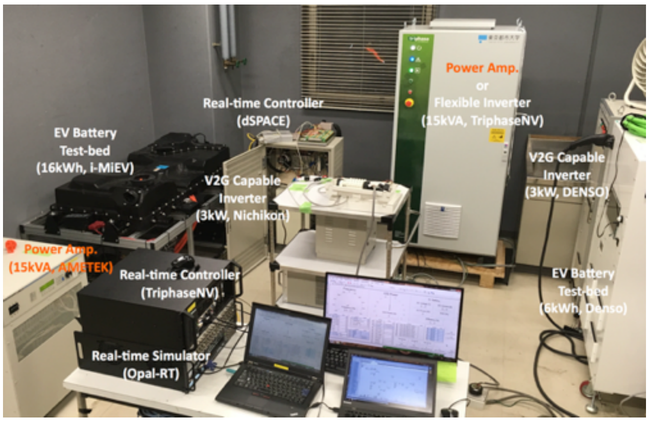


Figure 6. Vehicle grid integration HIL facility

Figure 7. Electric vehicle campus demonstration

Figure 8. Electric vehicle Charge-and-Share project

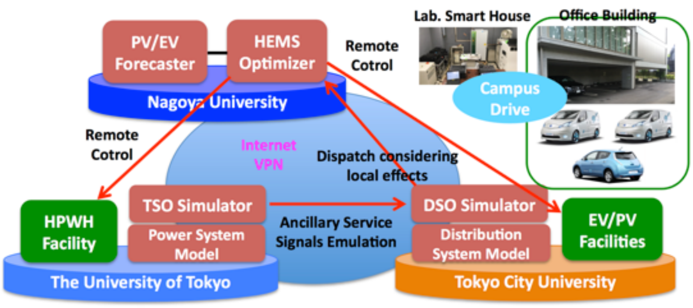


Figure 9. United HIL approach between the universities

battery system. Third silver vehicle is standard sedan type (NISSAN Leaf) with 30kWh battery system. All the vehicles are V2H/V2B/V2G capable, and grid-tied power conversion system will be installed into the garage of the office building and the laboratory smart house test bed.

First stage of the campus demonstration is evaluation of detailed power and energy consumption and regenerative in driving. This information is useful for estimating how much energy is available for the energy management and ancillary services. The electric vehicles are actually driven between the campuses via public roads. Second stage is design and implementation of renewable powered charging to the electric vehicles. There is a 40kW solar power generation on the office building, and a rooftop solar power generation can be emulated by the HIL facility. Renewable powered charging is demonstrated based on the actual measurements of the building/household solar power generations and the wind power generation at the remote site. Third stage is integration of the power system ancillary services with the renewable charging and the energy management strategies. The electric vehicles could supply power and energy for the office building and the smart house, short cycles of charge and discharge for the power system, and the reactive power compensation for the distribution system, at the same time. Concept image of the Charge-and-Share project is summarized in Fig. 8.

It is important for collaborating the control strategies, optimization schemes, and test facilities proposed by the universities. The authors are developing the united HIL as shown in Fig. 9. Grid-scale ancillary service signals are generated by the TSO simulator in the University of Tokyo, and local impact on the distribution feeder is simulated on the DSO simulator in Tokyo City University. Information of the electric vehicles, renewable generations, and house/building loads is transferred to the HEMS (Home Energy Management System) optimizer [12] located on Nagoya University. The ancillary service signals are dispatched to the electric vehicle test facilities via the HEMS optimizer and the DSO dispatcher (resource aggregator) proposed by Osaka Prefecture University [13].

IV. CONCLUSION

In this paper, the V2G applications for the smart house, smart building, smart distribution feeder are evaluated through the simulations by use of actual measurements on the smart grid demonstration projects. Flexible electric vehicle control has potential to gain the hosting capacities of the renewable generations and the electric vehicles themselves. Hosting capacities in islanded Microgrid with massive renewables and electric vehicles integration are also evaluated by the simulation of supply and demand imbalance.

The vehicle grid integration HIL facility has been conducted by coordinating the V2G system, actual electric vehicles, and the power system real-time simulator. The electric vehicle Charge-and-Share project is being established for demonstrating the renewable powered charging, the campus energy management, the grid-scale ancillary services, and their synthetics. The concept and system structure of the united HIL is designed by considering TSO/DSO/Aggregator/HEMS hierarchy and the resources of each university. Collaborative researches are performed on the TCU-HIL facility.

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