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Innovative Solar Power Utilization System Using Electric Vehicles

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ABSTRACT

In order to prevent global warming, the formation of a zero-emission society is critical. As a solution, a "PV & EV system" has been proposed, which is a novel energy system that is integrated with photovoltaic power generation, storage, transporting and local consumption as a single home using electric vehicles. Herein, the authors have studied the effect of introducing the system, which combines PV, EV, and power consumption in various types of homes. As the results, CO_2 emissions of the system were reduced by more than 75 % compared with the conventional home energy system. This effect is brought by a new EV-specific functional value not found in other types of vehicles such as FCV and PHV.

Keywords: electric vehicle, photovoltaic power system, heat pump, CO_2 emissions

1. INTRODUCTION

In order to prevent global warming, the formation of a zero-emission society is critical. Various energy systems have been proposed to expand renewable energy. However, in these systems, the energy losses in a supply process of renewable energy have not been considered though it is important to make effective use of renewable energy. The authors have proposed a novel system which is called "Advanced PV & EV system". The purpose of this system is to maximize the energy efficiency from the generation of renewable energy to its consumption [1].

In this paper, the authors propose "a home grid system" which is the minimum integrated unit of energy supply and consumption that is integrated with photovoltaic power generation, storage, transporting and local consumption as a single home using electric vehicles. Additionally, the effects on introducing of "the home grid system" were studied in the different types of houses.

2. PROPOSED SYSTEM

The proposed advanced system has the following big features.

1. PV power is charged to the EV battery as direct current (DC) because generated PV power is DC.
2. In the energy supply and demand management, electric power and heat are integrated and are controlled.
3. PV power is stored to EV battery and hot water storage tank which are possible to connect with PV.

Figure 1 shows an example of a residential configuration in which a home is connected to two private vehicles, one for commuting and the other for daily or leisure activities.

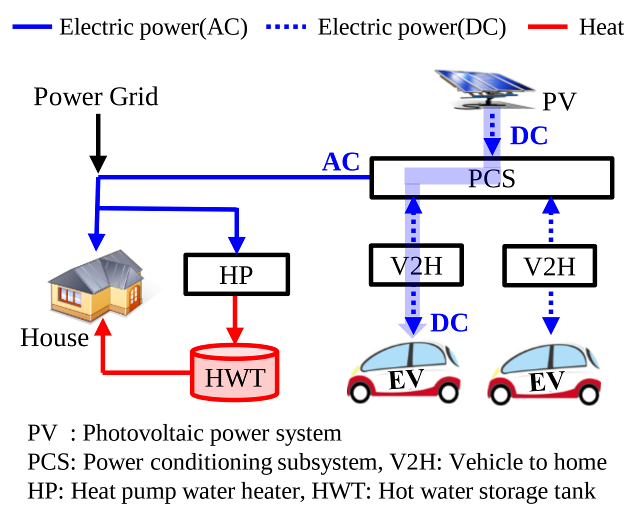

Fig. 1 Apparatus configuration of a home grid system

As an energy source, PVs using the parking area are installed at the workplace and at home. In this house, the energy consumption is only electricity and heat. The EVs are charged from the PV while parked at workplace or at home. The PV power generated at workplace is charged into EV battery and consumed at workplace. The PV power generated at home is charged into EV battery and consumed at home. While EVs do not park at the home or the PV generates more power than consumption of the home and charge to EVs, the power is supplied to the HP water heater and converted into the heat of hot water and is stored.

3. STUDY METHOD AND CONDITIONS

The effects of the system with PV installation place and different types of houses were studied by using a numerical simulation. In this study, the energy balance of the PV power generation, the power consumption of each device, as well as the energy storage of the EV battery and the hot water storage tank were calculated. As the results, CO_2 emissions, efficiencies and economy have been evaluated.

3.1 System integration simulator

Figure 2 shows the flow chart of the simulator for the integrated system. Energy consumptions that are the aim of calculation are the given conditions. PV capacities, EV battery capacities, and heat storage tank capacities of each house are calculation conditions. Based on these conditions, the supply and demand balance of the system is calculated.

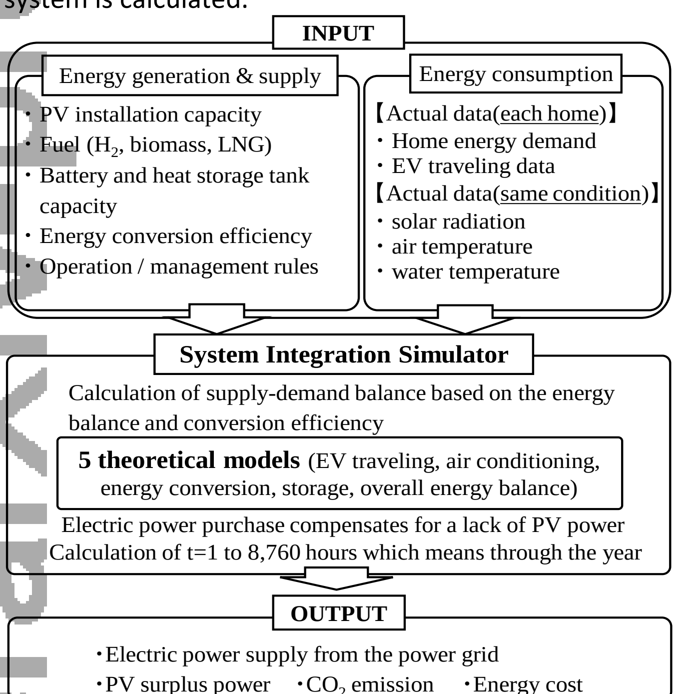

Fig. 2 Flow chart of the system integration simulator

The following five theoretical models that are verified experimentally are used for the simulator.

I. EV traveling model [2]
II. EV air conditioning model [2]
III. Heat pump consumption model [2]
IV. Energy balance model of each equipment
V. Overall energy balance of the system

The accuracy of the theoretical models is shown in Figure 3. As a result, the measured trends are in good agreement with the calculated trends.

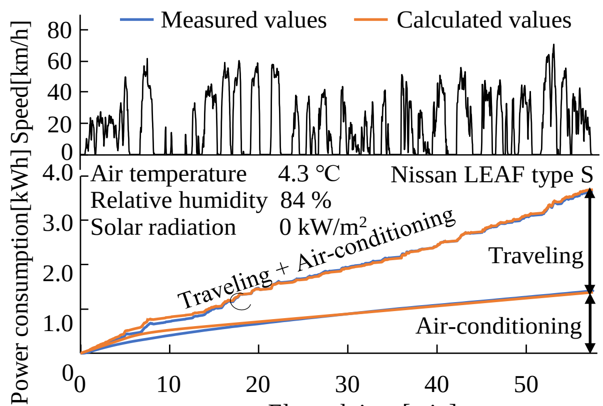

Fig. 3 Accuracy of the power consumption model of EV

3.2 Study cases

<u>3.2.1 PV Installation places</u>

The following two cases were evaluated.

(1) PV mounted on the roofs of each EV: PV power is consumed only in EV (traveling and air-conditioning).

(2) PV installed in parking areas: As shown in Figure 1, PV power is consumed by EV and workplace demand or home demand.

<u>3.2.2 Different types of houses in the home grid system</u>

The following four cases were evaluated as shown in Table 1. The energy sources and the amount of energy consumption are different in each house.

①Conventional single house: two persons are living in this house and two gasoline engine vehicles are used for commuting and daily use. Gus fuel is used for hot water supply and kitchen. Kerosene is used for room heating.

②All-electrified single house: four persons are living in this house and two gasoline engine vehicles are used for commuting and daily use. Energy source of hot water supply, kitchen and room heating is all electric power.

③14-stories high quality house: two persons are living on the sixth floor of this house and one gasoline engine vehicle is used for daily use. Gas fuel is used for hot water supply and kitchen. Air-conditioner is used for room heating.

④2-stories apartment: one person is living on the second floor of an apartment and one gasoline engine vehicle is used for commuting. Gas fuel is used for hot water supply and kitchen. Air-conditioner is used for room heating.

3.3 Study conditions

3.3.1 Same conditions

Table 2 shows the performances and specifications of each equipment that are used for calculation when the introduction of the home grid system is assumed. The equipment is commercially available except for V2H and energy management controller. Eco-Cute is used for HP water heater. For the time-series data such as air and water temperatures, the actual data for 2016 as shown in Figure 4 are used. Table 2 and Figure 4 are common in all case studies.

3.3.2 PV and EV conditions

In the home grid system, the parking area of PV was assumed to be 12.5 m^2 (installation capacity: 2.4 kW) at the workplace. And the PV installation capacities of each house were determined by the PV surplus rate (= surplus PV Power (kWh) / Generated PV power (kWh)) in the entire system. In addition, generated PV power is supplied to energy demand without reverse power flow to the conventional power grid. As shown in Table 3, the battery capacity of the EV was determined to enough capacity to enable the longest traveling range in 1 year.

Examples of Case① and Case② traveling results data of daily use cars are shown in Figure 5.

Table 1 Information for different type of houses

	①Conventional single house	②All-electrified single house	③14-stories high quality house	④2-stories Apartment
Number of residents	2	4	2	1
Number of owned vehicles	2	2	1	1
Electricity [kWh/year]	4,430	8,350	4,770	1,790
Gasoline [ℓ/year]	1,230	1,270	640	160
LPG [kg/year]	360	0	340	160
Kerosene [ℓ/year]	160	0	0	0

Table 2 Performances of each equipment

【Photovoltaic power generation】	
Maximum power	240 W
Output per unit area	190 W/m^2
【EV】	
Power consumption rate	9.1 km/kWh
Available capacity of battery	20 ~ 100 %
【Heat pump water heater】	
Heating capacity	6.0 kW
Storage tank capacity	460 ℓ
Boiling-up temperature	65 ℃
Hot water supply temperature	42 ~ 43 ℃

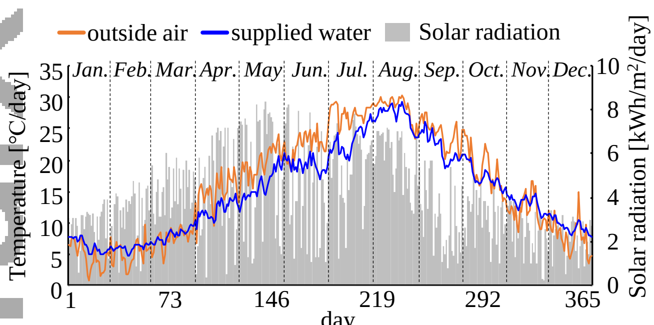

Fig. 4 The actual measurement values of temperature and solar radiation

Table 3 EV battery storages of each house

	Conventional house	All-electrified house	14-stories house	2-stories apartment
Commuting car[kWh]	16	16	-	40
Daily use car [kWh]	40	62	40	-

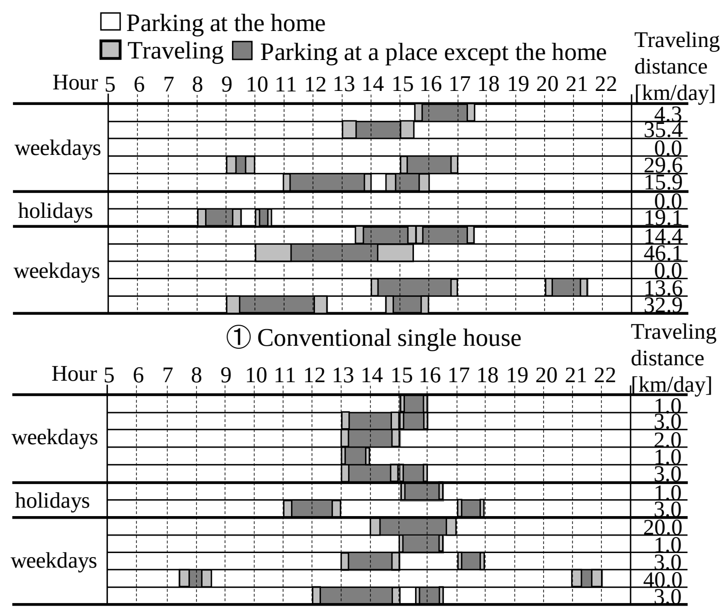

Fig. 5 Example of traveling timetable (Daily use cars)

4. RESULTS

4.1 Effect of PV installation place

Figure 6 shows a comparison between the PV surplus rate of the system in which PV is mounted on the roofs of EV and that of the system in which PV is installed in a parking area. From Figure 6, the PV surplus rate of PV mounted on the roofs of EV is much larger than that of PV installed in a parking area. This reason is as follows. A common EV in Japan is moved only less than 5% of year time. Therefore, EV battery cannot use the stored PV power. As a result, a large surpluses power is generated. Therefore, it is important to have many consumption destinations of battery like the home grid system.

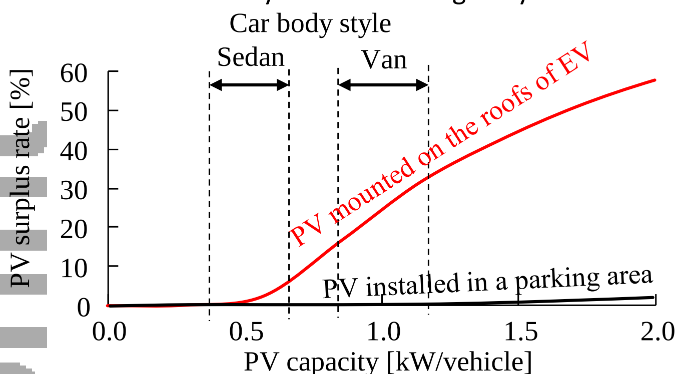

Fig. 6 PV surplus rate by PV installation places

4.2 Effect of the home grid applied on different types of houses

Figure 7 shows a comparison between CO_2 reduction rate of four Case from ① to ④.

In Figure 7, the installed PV capacity is the total capacity of the workplace and the home. From Figure 7, CO_2 reduction rate increases as the quantity of power grid supply decreases because the total PV capacity increases. And the PV surplus rate increases accordingly. When the PV surplus upper limit rate is 5%, CO_2 emissions can be reduced by more than 75 % in the home grid applied on different types of houses. This is the effect of installing PV, EV and HP water heater.

Furthermore, when the PV surplus upper limit rate is increased to 10 %, CO_2 reduction rate can be reduced by more than 85 %. However, since the PV capacity increases by about 15 %, it is necessary to consider the balance of CO_2 reduction rate and economic efficiency.

Additionally, the amount of PV capacity does not include workplace PV because of commuting without using the vehicle in case ③.

From these results, CO_2 emissions from home can be reduced of over 95% by the following future studies.

・Expansion of the use of further PV efficiency in the single home grid.

・Expansion of the use of PV efficiency by adding the cooperation of home grids and commercial facility grids.

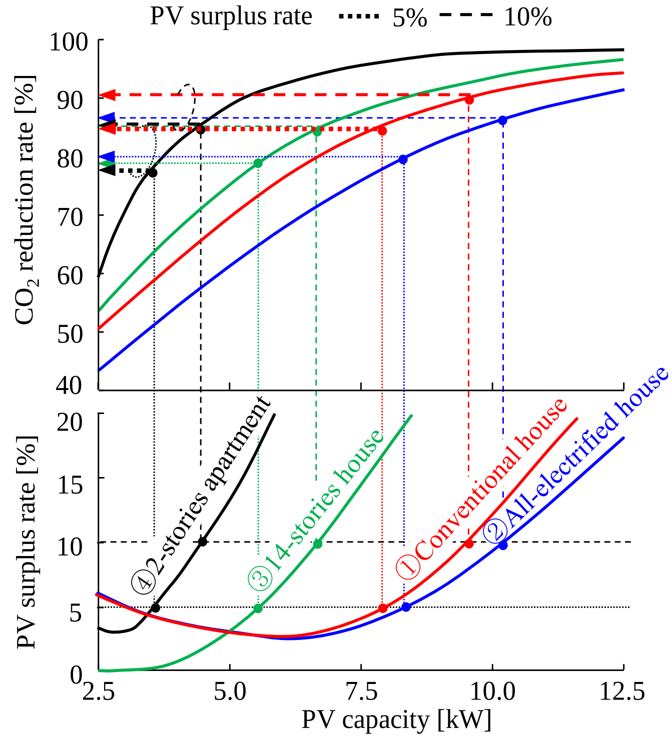

Fig. 7 CO_2 reduction effects of the home grid

5. CONCLUSION

In this paper, the authors propose "a home grid system" which is the minimum integrated unit of energy supply and consumption that is integrated with photovoltaic power generation, storage, transporting and local consumption as a single home using electric vehicles. Additionally, the effects on introducing of "the home grid system" were studied in the different types of houses. As the results,

PV installed in a parking area is better than PV on the EV roofs, because the surplus rate of PV on the EV roofs is much larger than that of PV installed in a parking area.

When the PV surplus upper limit rate is 5%, CO_2 emissions can be reduced by more than 75 % in the home grid applied on different types of houses. This is the effect of installing PV, EV and HP water heater.

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