INCENTIVE BASED CONTROL METHOD OF CUSTOMER SIDE BATTERY ENERGY STORAGE SYSTEMS IN LOCAL ENERGY COMMUNITY

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ABSTRACT

Large number of distributed energy resources (DERs) such as photovoltaic systems (PVs) and battery energy storage systems (BESSs) have been installed in distribution systems. Then, the customers may operate BESSs for the efficient use of energy in cheaper price and self-consumption of PV electricity. Furthermore, there may be community operators who control DERs and BESSs in a local energy community. However, if the BESSs are operated to optimize their local objectives (cost minimization, etc.), the demand fluctuations of the distribution system will be complicated, and there may be problems of the distribution system operation, such as voltage fluctuation. To cope with the problem, demand response may be one of the solutions. In this paper, incentive based control method of BESSs is proposed, and the effect of the proposed method is evaluated by simulation analyses.

INTRODUCTION

Large number of distributed energy resources (DERs) such as photovoltaic systems (PVs) have been installed in distribution systems after the launch of a feed-in tariff (FIT) scheme for renewable energy in July 2012, in Japan. In addition, battery energy storage systems (BESSs) are expected to be installed in distribution systems for the efficient use of energy in cheaper price and self-consumption of PV electricity [1]. In near future, electric vehicles (EVs) will widely spread and may be used as BESSs when they are connected to the distribution systems.

The BESS is flexible energy resource because the charging and discharging time can be controlled unless the convenience of the customer is lost. Therefore, customers may operate BESSs to realize their objectives in near future, for example the cost minimization, the efficient use of energy, peak load shifting, and so on. Furthermore, community operators who aggregate a large number of DERs in the local energy communities will appear and control the DERs as a virtual power plant (VPP) to realize their objectives.

However, the DERs including BESSs may cause problems on the distribution systems, such as voltage rise, and so on [2][3]. If the customers or the community operators control the DERs to optimize their objectives, it may cause demand fluctuations in the distribution systems. Then, it may have impacts on the distribution system operation, for example the voltage fluctuation may occur in the distribution system.

To cope with the problem, demand response (DR) may be one of the solutions. The DR may be used to shift or to reduce peak demand by giving incentives during periods of peak demand, then the demand fluctuation may be suppressed.

In this paper, incentive based control method of BESSs is proposed, and the effect of the proposed method is evaluated by simulation analyses.

SIMULATION TO EVALUATE IMPACT OF BESS ON DISTRIBUTION SYSTEM

When large number of DERs and BESSs have been installed in the local energy community, it is expected that the efficient use of energy may be realized by DERs and BESSs in the community.

However, the BESSs are operated to optimize the local objectives such as cost minimization, it may cause the demand fluctuations and the voltage fluctuations in the distribution systems.

To evaluate the mutual impact between a community and a distribution system, a simulation method to evaluate the mutual impact between a community and a distribution system was proposed [4]. Using the proposed simulation method, the impact of BESSs on distribution system is evaluated.

Customer Operation of BESS

If the BESSs are operated by customers, they are operated to minimize the electricity cost of customers.

The customer creates a plan of charge and discharge of the BESS to minimize the cost of electricity in the day before operation. The charging and discharging plan is created based on the electricity price of each time period considering the predicted electric demand, hot water demand and the PV power generation. To find the optimal schedule, genetic algorithm (GA) is applied in the customer operation [5].

Distribution System Model

Figure 1 shows the distribution system model to simulate the voltage of the distribution system, considering the load ratio control transformer (LRT) at the substation and the voltage control devices on the distribution feeder such as step voltage regulator (SVR). In this model, the PVs and the BESSs are distributed equally in the distribution feeder. By this model, the voltage, current, and power flow of the distribution system can be evaluated.

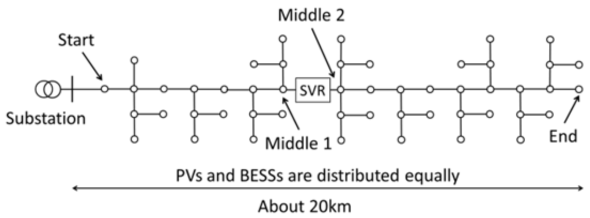

Fig. 1 Distribution system model.

Simulation Conditions

The load curve of the local energy community is shown in Fig.2. This load curve is an example of a sunny day. Figure 3 shows an example PV output pattern of the same day. These curves are used for simulation analyses described below.

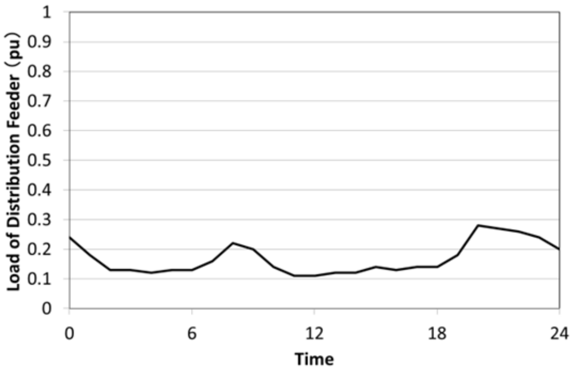

Fig. 2 Load curve of the local energy community (sunny day).

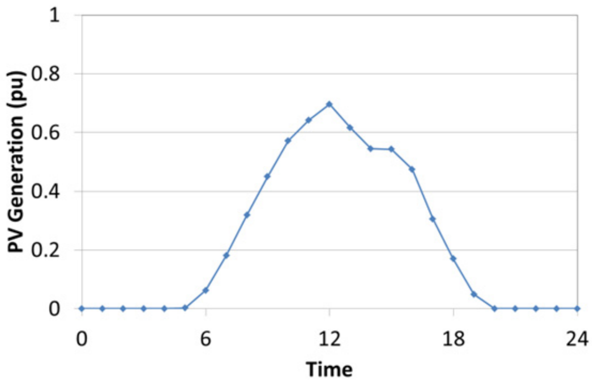

Fig. 3 PV generation curve (sunny day).

The electricity prices for customers are shown in Table 1. The electricity prices are different in each time period. The price of the midnight is cheaper than the others.
The price of the PV surplus power is set to 19 yen/kWh assuming that the price of the PV power becomes cheaper than the electric price in the near future.

Table 1 Electricity prices for customers.

Buyer	Time Period	Electricity Price (yen/kWh)
LV Customer (residential)	10-17	35.54
	7-10, 17-23	27.32
	23-7	13.10

Impact on the Distribution System

The simulation results of feeder power flow are shown in Fig. 4. In this figure, the power flow without PVs, with PVs, and with PVs and BESSs are shown, respectively. In this case, the electric price in the midnight is cheaper than the other time period, therefore charging BESSs at midnight is economical for customers. Then, the customers charge the BESSs at midnight and discharge them in the evening. As a result, the BESS charging is concentrated at midnight time and the peak load of the community is increased.
Figure 5 shows the voltage of the distribution feeder. In this case, PVs and BESSs are installed in the distribution feeder and the installation ratio is 40%. In this figure, the voltages are converted to LV considering the voltage tap of the transformers.
The voltage at the middle 2 (secondary side of SVR, as shown in Fig. 2) exceeds upper limit when the charging BESS is concentrated. To cope with the voltage rise, the peak demand should be suppressed by shifting charging load.

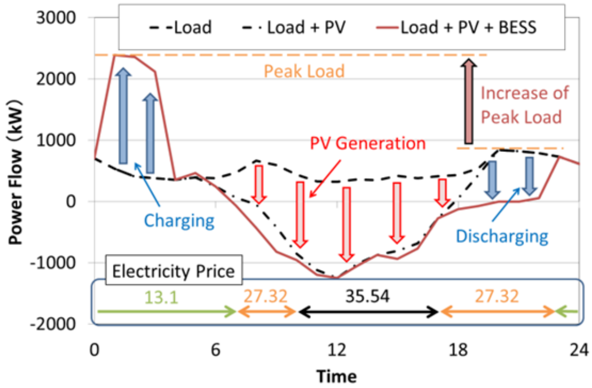

Fig. 4 Power flow of distribution feeder.

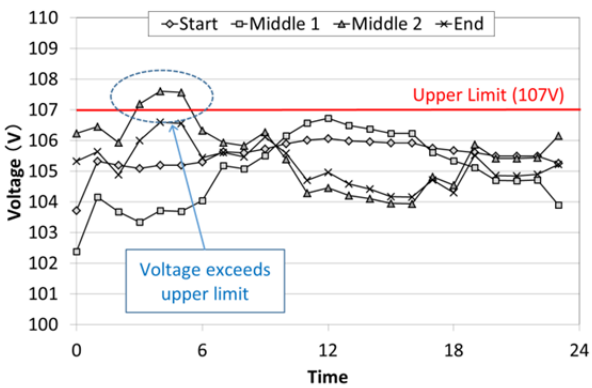

Fig. 5 Voltage of the distribution feeder (case with BESS).

INCENTIVE BASED CONTROL METHOD

This paper proposes the control method to suppress the peak load of charging BESS in the residential area using incentive based DR. The proposed method assumes that residential customers have demand side management system which can be used for automated DR.
To suppress the peak demand, the community operator gives customers same amount incentives for BESS charging. Then the electric demand of charging BESS will be shifted to the time period when the incentive is given because it is more economical for the customers (Fig.6).

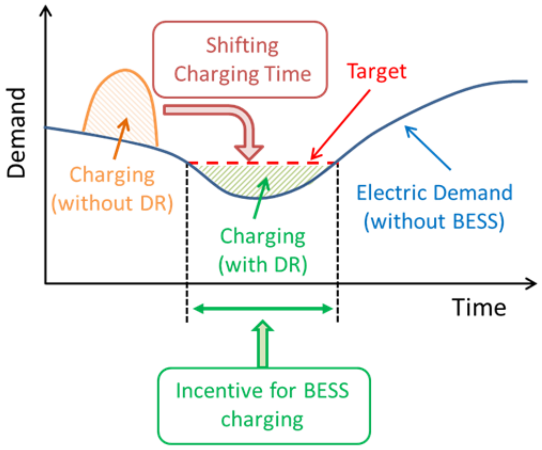

Fig. 6 Demand shifting by the proposed incentive based control method.

Procedure of the Proposed Method

Figure 7 shows the procedure of the proposed method. The community operator creates a plan of electric demand without changing the charging amount by obtaining the charging and discharging plans of the BESSs of the customers in the day before operation. Then, the community operator decides the incentives of each time period.

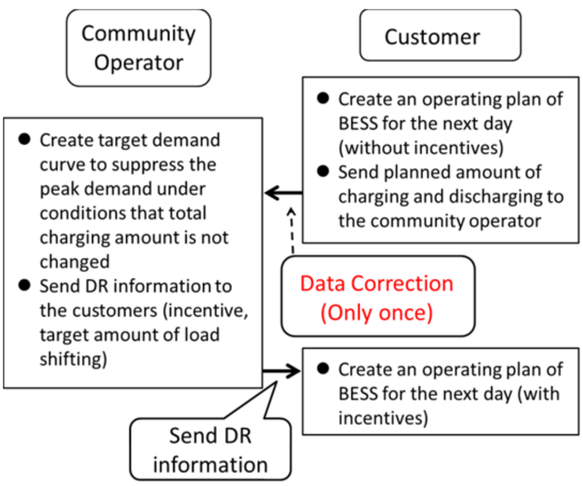

Fig. 7 Procedure of the proposed incentive based control method.

To induce appropriate amount of load shifting, the community operator provides the greatest incentive when the amount of load shifting is equal to the target amount (Fig. 8).

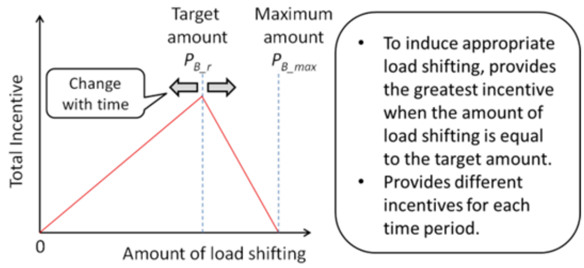

Fig. 8 Procedure of the proposed incentive based control method.

SIMULATION OF PROPOSED INCENTIVE BASED CONTROL METHOD

Simulation analyses were carried out to evaluate load levelling effect of the proposed incentive based control method.

Simulation Results (example day)

In these analyses, it is assumed that the BESS of the customer can be operated by the energy management system (EMS), and automatically responds to the incentives.
The simulation results of feeder power flow are shown in Fig.9. In this figure, the power flow with only load, with PV, and with BES operation are shown, respectively. PV installation ratio to distribution feeder capacity is 100%. And the storage capacity of the BESs is about 1.5 hours of the distribution feeder capacity.
As shown in Fig.9, the battery charging load is dispersed from midnight to early morning and peak load is reduced by the proposed method.

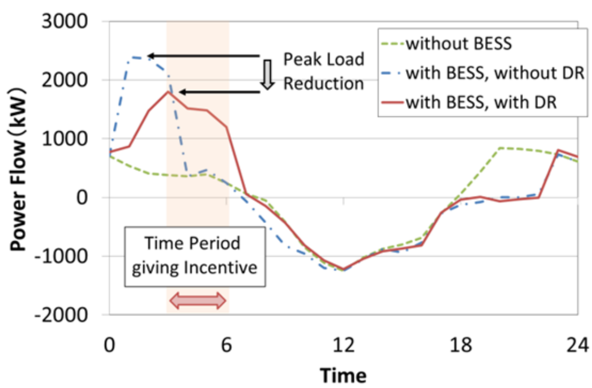

Fig. 9 Simulation results (distribution feeder power flow).

Simulation Results (annual simulation)

Annual simulations are carried out to evaluate annual load levelling effect.
Figure 10 shows simulation results of annual maximum load. It is shown that the annual maximum load is approximately 10% reduced by the proposed method.
Figure 11 shows simulation results of load duration curve for a year. It is shown that the peak load is shifted and the load of the local energy community is levelled throughout the year by the proposed method.

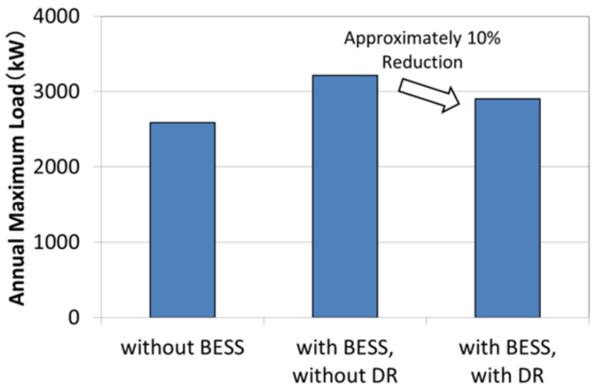

Fig. 10 Simulation results (annual maximum load).

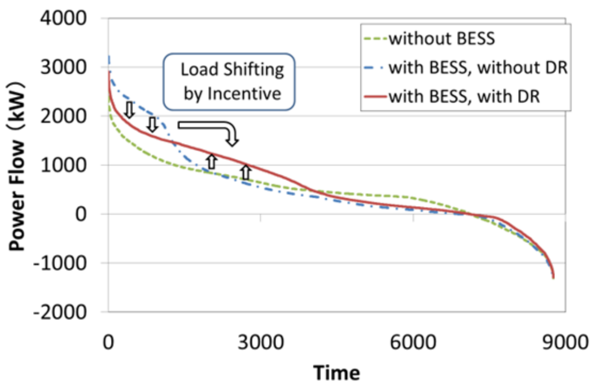

Fig. 11 Simulation results (load duration curve for a year).

CONCLUSIONS

In this paper, an incentive based control method of BESSs is proposed. By the proposed method, the charging of the customer's BESS is shifted and the load levelling of the distribution system is achieved. To induce appropriate amount of load shifting, the community operator provides the greatest incentive when the amount of load shifting is equal to the target amount in the proposed method.
The effect of the proposed method is evaluated by simulation analyses. It was shown that the battery charging load is dispersed and shifted from midnight to early morning and the load of the local energy community is levelled throughout the year by the proposed method.

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