COOPERATIVE CONTROL OF DISTRIBUTION SYSTEM WITH CUSTOMER EQUIPMENT TO UTILIZE SURPLUS ELECTRIC POWER OF PHOTOVOLTAIC SYSTEMS

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ABSTRACT

When large capacity distributed generation including photovoltaic (PV) systems are installed in power systems, reverse power flow from PV systems may cause problem of surplus electric power. To reduce the reverse power flow without the reduction of PV power generation, energy management of customer equipment such as electric water heater is one of the solutions. Therefore, cooperative control of distribution system with customer equipment was proposed. In this study, the effectiveness of the proposed control method was evaluated by simulation analyses.

INTRODUCTION

Large capacity of distributed generation including photovoltaic (PV) systems will be installed in future power systems. According to Japan's energy outlook, the target capacity of PV systems for 2030 is about 50 GW, which is greater than 25% of the peak load. In addition, most of the PV systems are expected to be installed in distribution systems.

When the large volume PV systems are installed in power systems, the reverse power flow from PV systems may cause problems. One problem is the voltage rise at the distribution line [1][2]. According to the Electric Utilities Industry Law in Japan, the required voltage range is defined as 101 V ± 6 V. When PV systems generate a large amount of power, the distribution line voltage becomes higher than the proper voltage range. To cope with the voltage rise, control devices such as step voltage regulators (SVR) and static var compensators (SVC) can be used to control the distribution line voltage [3][4][5]. Another problem is the surplus electric power in the power system. In light load period, the electric power supply may become larger than the demand in the power system. Therefore, the generated power from the PV systems may be surplus electric power, and PV systems may have to reduce their output power.

To reduce the surplus electric power without the reduction of PV power generation, energy management of customer equipment may be one of the solutions. If the operation pattern of customer equipment can be controlled, the customer equipment can be operated when the output of PV systems becomes large and the reverse power flow from PV systems can be reduced. Therefore, cooperative control of distribution system was proposed. In this study, the effectiveness of the proposed control method by use of heat pump water heaters (HPWHs) was evaluated by simulation analyses.

DISTRIBUTION SYSTEM TO COPE WITH LARGE VOLUME OF PV SYSTEMS

When large volume PV systems are installed in a power system, some problems may occur in the power system. One problem is the voltage rise at the distribution line, and another problem is the surplus electric power. To cope with these problems, new technology of power system control is expected. Therefore, a future distribution system "Autonomous Demand Area Power System" and cooperative control method of the Autonomous Demand Area Power System were proposed.

Autonomous Demand Area Power System

To cope with the problems of the increased use of PV systems, a research project "Triple I (Intelligent, Interactive and Integrated) Power Systems (TIPS)" has been carried out [6]. The objectives of TIPS are to maintain the power quality, safety, stability and reliability of the power systems and to reduce CO2 emission through the use of information and communication technology and advanced power system operation and control techniques.

The Autonomous Demand Area Power System (ADAPS), which is a part of TIPS, is proposed as a future distribution system to cope with the large volume of DG through the use of a communication network and advanced power electronics [5]. To maintain the voltage of the ADAPS, techniques using advanced power electronics and communication technologies have been developed and demonstrated.

The Supply and Demand Interface (SDI) has been proposed and developed as a component of the ADAPS for the effective operation and control of customer equipment. The SDI is a device that is installed at each customer site, and its major functions are communication, monitoring and controlling. The SDI monitors and controls customer equipment such as DG systems, batteries and loads. The SDI also exchanges information with the central control system, which operates the entire distribution line through the communication network.

Cooperative Control of Distribution System with Customer Equipment

The cooperative control of distribution system with customer equipment is proposed as one of the solutions to reduce the surplus electric power [7]. The operation patterns of customer equipment are controlled in proportion to the output of PV systems, and the surplus electric power can be utilized. Outline of the proposed control is shown in Fig. 1.

First, the control system estimates profiles of PV generation and load for the following day by the weather forecast and historical data. If the estimated PV generation is large and there will be surplus electric power, the control system determines the maximum reverse power flow at customer sites to keep the power flow at substation in the target range. Then, the control system sends the maximum reverse power flow at customer site to the SDIs. The SDIs determine the operation pattern and control the customer equipment.

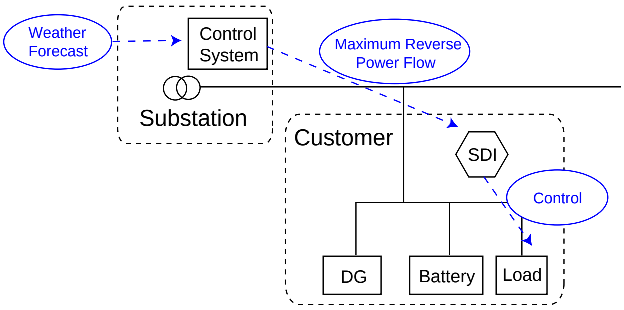

Fig.1 Outline of cooperative control of distribution system with customer equipment.

SIMULATION ANALYSES

Simulation analyses of proposed operation were carried out to evaluate the effectiveness of the proposed cooperative control method to reduce the capacity of control equipment in the distribution system.

Simulation Conditions

Simulation analyses were carried out using a distribution system model, which consists of a distribution feeder model and 1248 customers to simulate a typical residential area distribution line.

The load pattern of a residential area is shown in Fig. 2. In this study, the load pattern of spring was used because the load of spring is the lightest and the surplus electric power will be remarkable in spring.

To calculate the output of PV systems, solar radiation data in May of 2009 in Tokyo were used. Daily outputs of PV systems, which are used for simulation analyses, are shown in Fig. 3. Some days were excluded because of data missing.

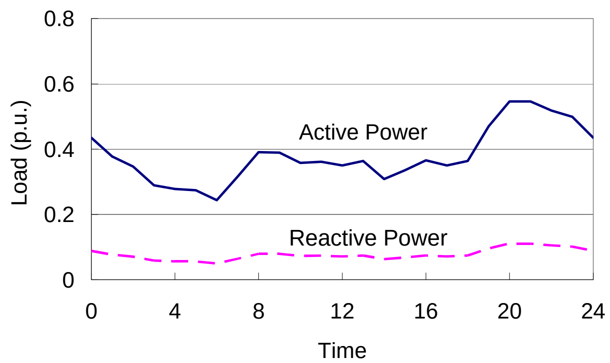

Fig.2 Load pattern of residential area.

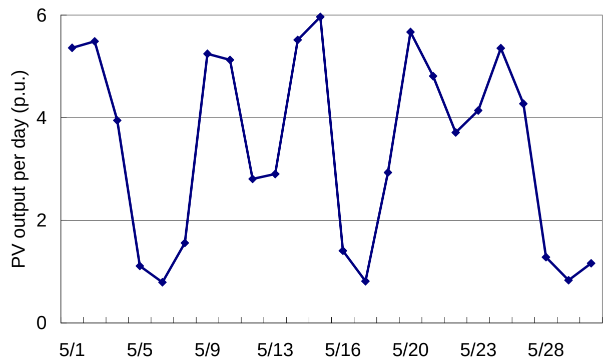

Fig.3 Daily output of PV systems (in May).

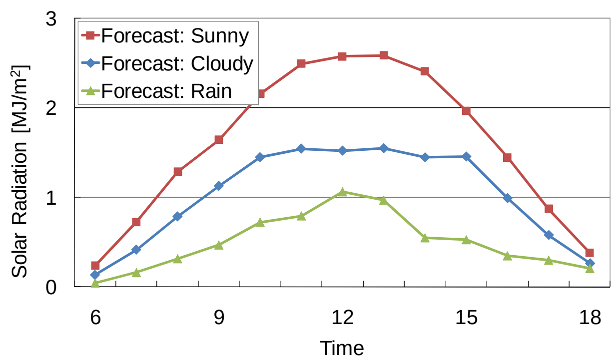

Fig.4 Average solar radiation (by Weather Forecast).

Weather forecast and historical solar radiation data were used for estimation of PV output. Output of PV system is calculated by use of average solar radiation of same season. The average solar radiation by weather forecast is shown in Fig. 4.

Heat Pump Water Heaters (HPWHs) for Controllable Customer Equipment

For the customer equipment used in the cooperative control method, it is important that the energy consumption is large and that the benefit to the user is independent of the operation time. In this study, heat pump water heaters (HPWHs) are selected as controllable loads because of the large energy consumption and flexibility of operating time. The percentage of energy used for hot water supply is about 30% of the typical household energy consumption in Japan. The HPWHs are usually operated at midnight because the price of electricity is low. But most of the hot water is used in the evening. Therefore, if the HPWH is operated during the daytime when the output power of the PV system becomes large, the inconvenience to the customers may not be so large.

The electric power consumption of HPWH depends on the efficiency. In this study, the rated power of HPWH is set at 1 kW and the maximum operation time of the HPWH is set at 3 hours.

Procedure of Cooperative Control

Though the surplus electric power should be controlled in whole power system, the HPWHs are operated to control the power flow at the substation within the proper range because simulation analyses are carried out with a distribution system model.

The procedure of the cooperative control in the simulation analyses is described as follows. First, the control system estimates profiles of PV generation for the following day using weather forecast. Second, the control system estimates the power flow at the substation. In this study, the reverse power flow at the substation is treated as the surplus electric power, and the load profiles are treated as known values. If the occurrence of the surplus electric power is estimated, the control system determines the operation schedule of the HPWHs to prevent surplus electric power, and sends the operation schedule to Supply and Demand Interface (SDI) on the customer site. The HPWHs on the customer sites are divided into two groups for improvement in efficiency [7]. The following day, the HPWHs are operated by the operation schedule.

Simulation Results

Simulation analyses for one month on an hour basis were carried out. As a part of the simulation results, the planned power flow on the previous day and the power flow on the following day are shown in Fig. 5 and Fig. 6, respectively. These figures show the results for 10 days from the simulation period.

If the surplus electric power is expected, the operation schedule of the HPWH is changed to daytime. Simulation results of surplus electric power per day based on the PV capacity is shown in Fig. 7. The surplus electric power is reduced by the proposed control with HPWHs. However, the power flow on the following day may be different from the predicted one because there are prediction errors. Therefore, a part of the surplus electric power remains even if the HPWHs are controlled by the proposed method.

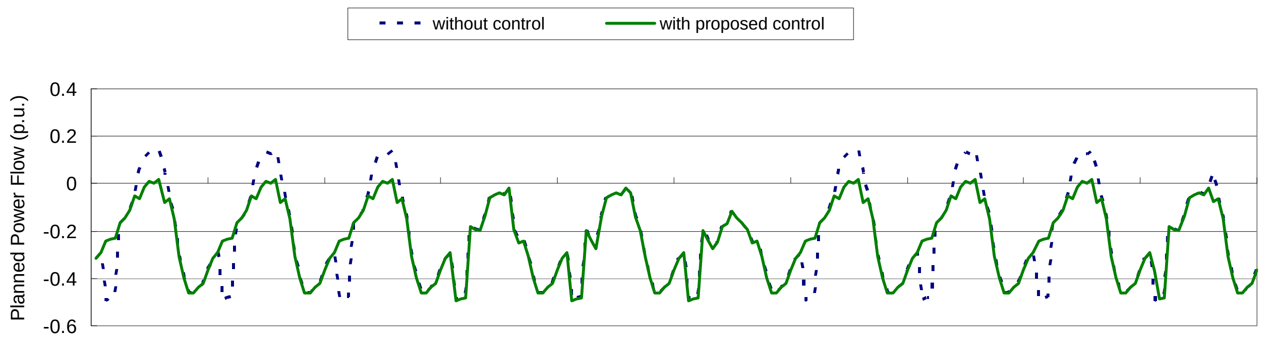

Fig.5 Simulation results (Planned power flow at substation on the previous day).

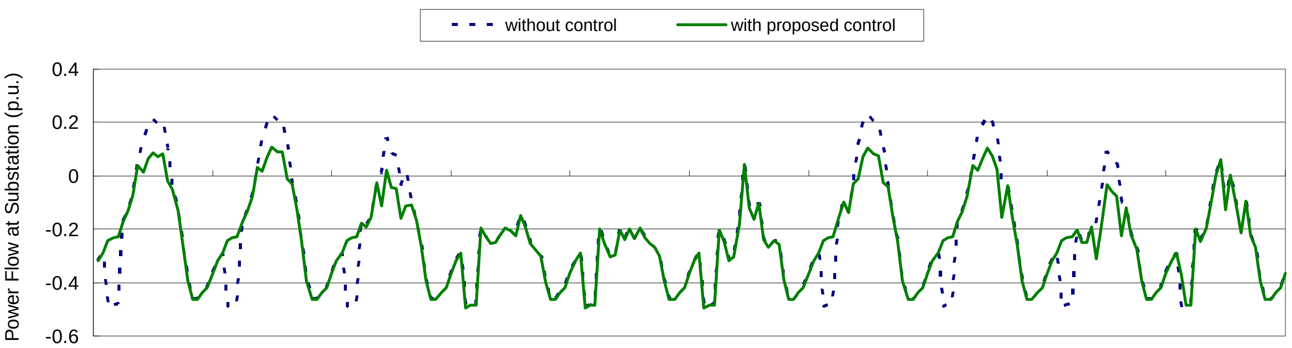

Fig.6 Simulation results (Power flow at substation on the following day).

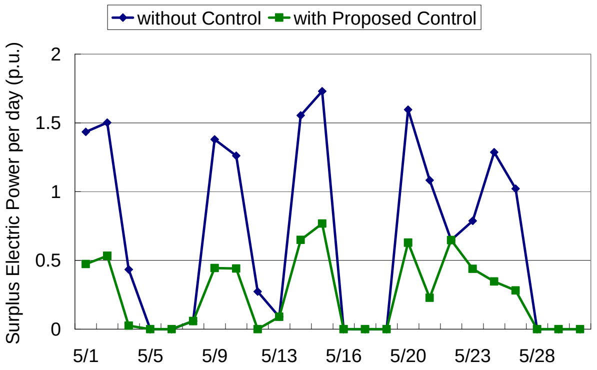

Fig.7 Simulation results (Surplus electric power per day).

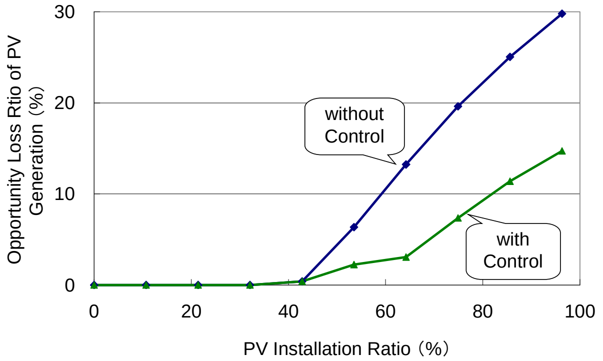

Fig.8 Simulation results (Opportunity loss ratio of PV generation).

The surplus electric power may be resolved by reduction of the PV output because the other measures such as batteries are expensive. Figure 8 shows the opportunity loss ratio of PV generation assuming that the PV output is reduced to adjust the surplus electric power. The opportunity loss ratio of PV generation is reduced by use of the proposed cooperative control with HPWHs. When the PV penetration ratio is 75 % of the distribution line capacity, the opportunity loss ratio is reduced from 20 % to 7 % by the proposed control of HPWHs.

CONCLUSIONS

Cooperative control method using customer equipment such as HPWH was proposed to cope with the problems of large capacity PV systems in the distribution system. In this paper, simulation analyses were carried out to evaluate the effectiveness of the proposed method. It was shown by the simulation results that the surplus electric power was reduced by the proposed control using HPWHs.

Considerations using various types of demand models are future studies.

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