Agent-based electrical power management model for houses equipped with storage battery and photovoltaic units

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***Abstract*— Smart grid systems have been actively discussed to realize a sustainable and a low-carbon society that efficiently consumes electric power and to introduce photovoltaic power generation, i.e., renewable energy or electric vehicles. In this study, we focus on the smart meter system based on an agent model to manage electric power use in residential homes with which solar panels and a storage battery are equipped. We evaluated the system for one month during weather changing patterns.**

Keywords-component; agent model, smart meter, electrical power management

I. INTRODUCTION

In recent years, smart grids are attracting attention worldwide. Various developments are anticipated in living environments by introducing efficient control of electric power, renewable energy, or electric vehicles. The role played by information technology in smart grids is especially crucial. Since one concept of smart grids is to construct advanced power networks by fusing existing power networks and communication facilities, we must appropriately control all the devices in the power network with information technology. However, such control of power networks in smart grids is not easy. For example, although the green energy produced from sunlight, wind, or waves would be focused on as well as thermal power, hydropower, and nuclear power, which are the main generation methods, systems have to be developed that correspond to the decentralization and uncertainty of electric generation. In addition, there are many problems in controlling the electricity in each home when we trade the electricity generated at home and operate electric vehicles.

In this study, we develop an agent-based model to manage the electric power in homes equipped with photovoltaic power generation and a storage battery. To practically reproduce a real situation, we applied the electrical power consumption data and the photovoltaic power generation of Japanese homes. We assume that each agent has a charge/discharge strategy to control the power from the storage battery. We evaluate the impact of photovoltaic power generation and the battery by a simulation experiment.

II. ELECTRICAL MANAGEMENT WITH SMART GRID

A. Smart grid

The smart grid attracts attention as a next-generation advanced power network (see Figure 1). The characteristic of the smart grid is to adjust automatically the electric power supply and demand by the computer's operation function and communication function. Moreover, energy saving, cost reduction and reliability are also expected.

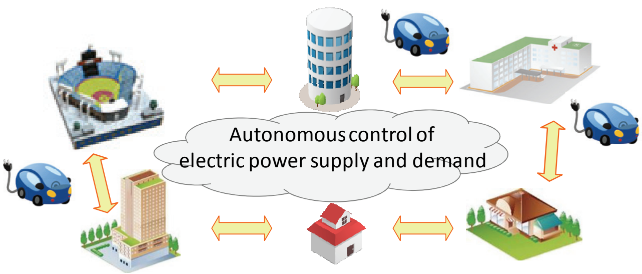

Figure 1. Image of smart grid

Smart grids are attracting attention as a next-generation advanced power network (Fig. 1). Their characteristics include automatic adjustment of the electric power supply and demand based on the computer's operation and communication functions. Moreover, energy savings, cost reduction, and reliability are also expected.

With the smart grid, a computer controls everything from the power station in the power network to meters in the house. Because the solar power gathered from roof panels is a green or renewable energy, we are interested in it to save money and reduce emissions. However, drawbacks exist; the production of electricity depends on the weather and is only available in the daytime. Moreover, advanced management of home energy is required to trade surplus electricity.

We concentrate on a storage battery to solve the above problems of photovoltaic power generation. In a smart grid, homes or electric vehicles are equipped with storage batteries that are expected to play an important role in the future. Because the time periods during which solar panels can generate electricity are limited by the weather or daylight, we must introduce a storage battery to save surplus electric power for later discharge. This study manages the electrical power for a house equipped with a storage battery and a photovoltaic unit.

B. Agent-based electrical power management

In electric power management with smart grids, an effective approach is one that models the characteristics of each device as an agent because we must autonomously control various apparatuses. Such agents can be strategically used for advanced autonomous control by acting as a substitute for the device as a power network. Moreover, in a smart grid, since we assume the installation in each home of a high-performance electric power meter called a smart meter, we can install and use a software agent as a smart meter. Therefore, we developed an agent-based management model for residences to utilize photovoltaic power generation and a storage battery.

III. AGENT-BASED ELECTRICAL POWER MANAGEMENT MODEL FOR THE HOUSE

A. Electricity consumption pattern of the house

The electricity consumption patterns are applied from actual data [1] to realize a simulation that resembles reality. There are two types of power consumption patterns for a residence. One peaks in the morning and at night and is flat in the daytime and the other increases in the daytime and peaks in the morning and the evening. The differences in these types reflect whether the residents are staying at home in the daytime or using such appliances as air conditioners. In this study, we set two kinds of power consumption patterns converted as a single-family house in August, which is generally the hottest month in Japan (Fig. 2).

B. Photovoltaic power generation pattern

The residence in this study is equipped with photovoltaic units. Although solar energy production peaks in the daytime, since the house doesn't consume much power, a huge electric power surplus arises (Fig. 3). Such situations are exactly our study's main purpose: to efficiently manage such surplus electric power with a storage battery. Since photovoltaic power generation is affected by the weather, the daylight hours, and the location, clearly defining electricity production is difficult. We assume that in sunny weather due to various influences, the solar panels will generate approximately 60-70% of their rating output, which is 3.5 kW. This is the same level as the daily power consumption for one family, if it efficiently generates electricity in the daytime during sunny weather.

Moreover, since photovoltaic power generation production is affected by the weather conditions, we consider the weather one key factor. The probability of sunny days,

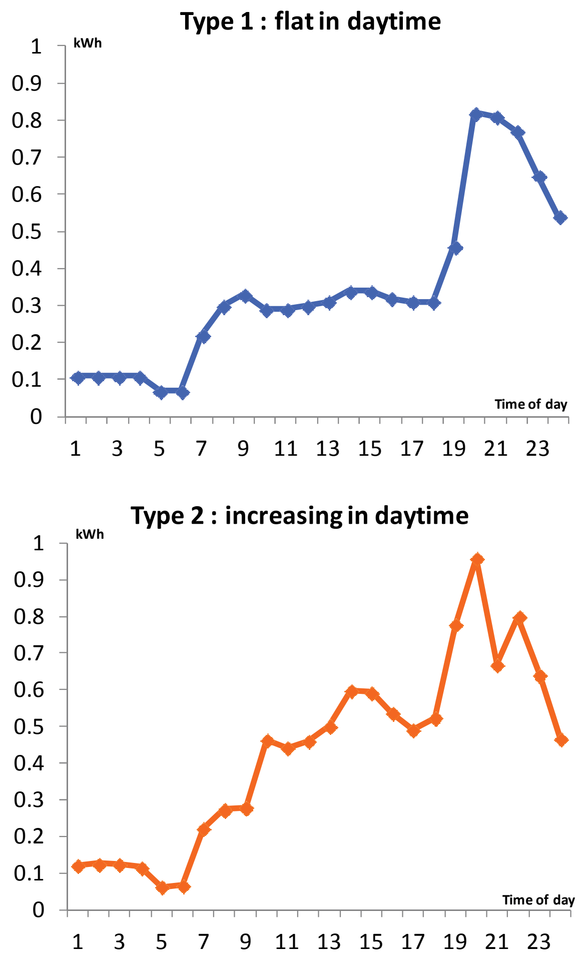

Figure 2. Electricity consumption patterns

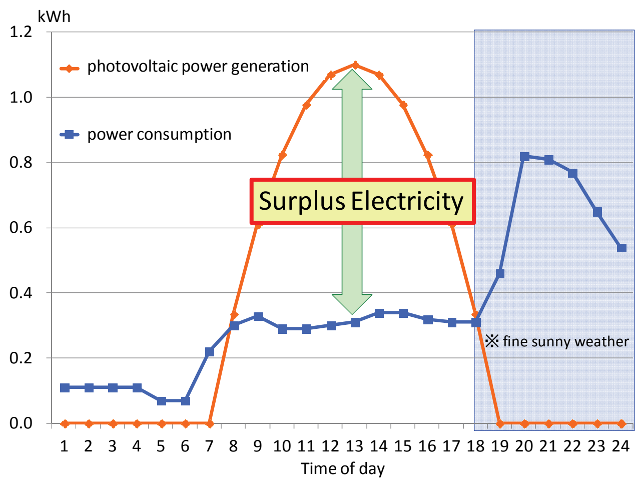

Figure 3. Production of photovoltaic power generation in fine weather

clouds, or rain is based on the August results for the past five years in Nagoya city. In addition, electricity production in cloudy weather is about 30-60% of sunny weather and about 0-10% on rainy days.

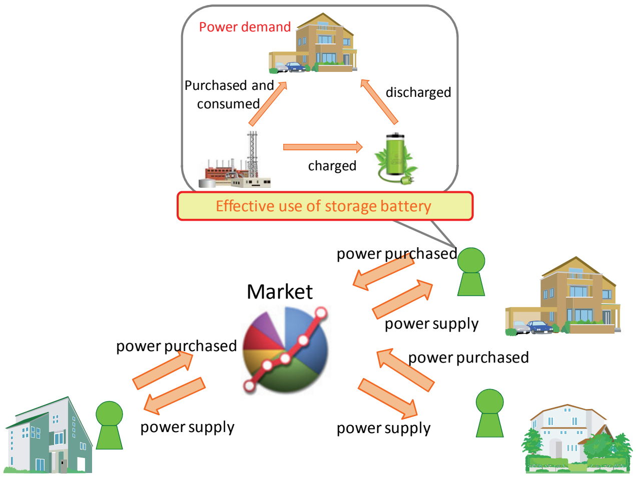

Figure 4. Image of agent-based electrical power management model

C. *Agent-based electrical power management model*

In this section, we explain the agent-based electrical power management model for a house whose power consumption is equipped with a storage battery and photovoltaic units. We assume that an agent, who controls the electricity demand in each house (Fig. 4), can take three actions to satisfy the domestic electricity demand: purchasing electricity from the power company, utilizing solar power, or utilizing the power from the storage battery. The agent performs a minimization strategy by reducing the purchase of electricity. Therefore, each agent must coordinate the volume of surplus electric power with the uncertainty of the photovoltaic source in the daytime and the capacity of the storage battery. However, selling surplus electricity remains future work because this preliminary study's main objective is to manage the surplus electricity with a battery.

The above agent's strategy can be defined as a minimization problem with the constraints of the following formula group:

$$arg\ min. \sum_t \left(d(t) - r(t) + b^+(t) - b^-(t)\right)$$

subject to $\quad b^+(t) \le e - e_0 + \sum_{j=1}^{t-1}\left(b^+(j) - b^-(j)\right)$

$$b^-(t) \le \alpha\left(e_0 + \sum_{j=1}^{t-1}\left(b^+(j) - b^-(j)\right)\right)$$

$$0 \le r(t) \le d(t) + b^+(t)$$

$$0 \le b^-(t) \le d(t) - r(t),$$

where $d(t)$ is the electrical demand (in time period t), $r(\cdot)$ is the electricity generated by the photovoltaic units, $b^+(\cdot)$ is the amount charged to a storage battery, $b^-(\cdot)$ is the amount discharged from a storage battery, e is the capacity of the storage battery, e_0 is the initial value of the charged amount in the storage battery (remaining power from the previous day), and α is the energy conversion efficiency.

IV. ASSESSMENT EXPERIMENT

A. *Setup of experiment*

This experiment simulates electric power management by supposing a community of 100 residences. According to the time course, we show the changes in the following parameters: electricity demand, the amount of purchased energy, the amount of photovoltaic power generation, the charged amount, the discharged amount, and the storage battery capacity. The value of each parameter in the result graph is the total of the 100 residences. This experiment's program was described by JAVA and operated with Windows XP Professional on a computer with Core2Quad 3.00 GHz memory .25 GB. "lp solve" was used for the optimization problem.

B. *Results of an experiment*

Figure 5 shows the results of a three-day simulation carried out under situations where the diffusion rate of the photovoltaic power generation was 10%. The weather conditions changed every day. The first day was sunny, the second was rainy, and the last was cloudy. Since power was sufficiently generated by the solar panels in the daytime on the first day, electricity was stored in the afternoon. The power stored in the battery was discharged after 19:00 because the peak load of the electricity demand had leveled off. Based on photovoltaic power generation and battery utilization, we purchased less power (differences between demand, i.e., blue lines and energy purchases, i.e., red lines) from 10:00 to 22:00. The second day was rainy, so little photovoltaic power generation was performed and most energy had to be purchased. Because photovoltaic power generation is not possible on rainy days, discharging electricity from a battery during peak hours is expected in such situations. That is a future task to improve our agent model. The production of electricity by sunlight decreases during cloudy weather, so a peak load cut at night was not seen on the third day. However, we reduced the amount of purchased energy in the daytime. Fig. 6 shows the simulation results when the diffusion rate of the photovoltaic power generation raises even more. The basic tendency is the same as Fig. 5, but less power continued to be purchased because the stored electricity increased. We must develop an advanced strategy with a learning function because all the stored power is consumed within a day, even though an enormous electricity surplus existed on the first sunny day and the next day is rainy.

Figure 7 shows the results of the 24-hour simulation carried out when the diffusion rate of the photovoltaic power generation is 10%. In this experiment, because sunny weather is assumed, the photovoltaic power generation was performed well in the daytime, and the charged and the stored power increased with the surplus electricity. Moreover, a state began during which a battery simultaneously

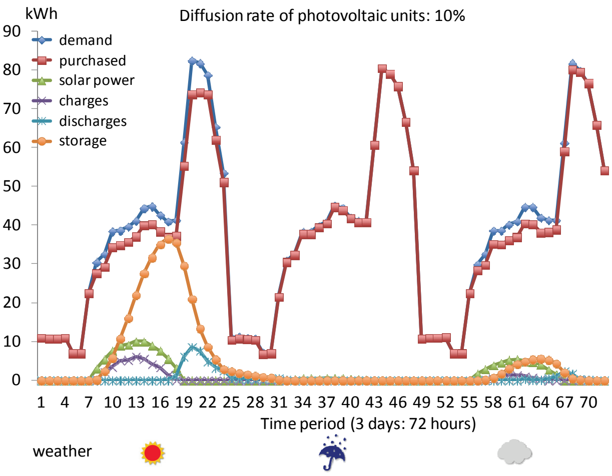

Figure 5. Result of 100 households, three days, diffusion rate of 10%

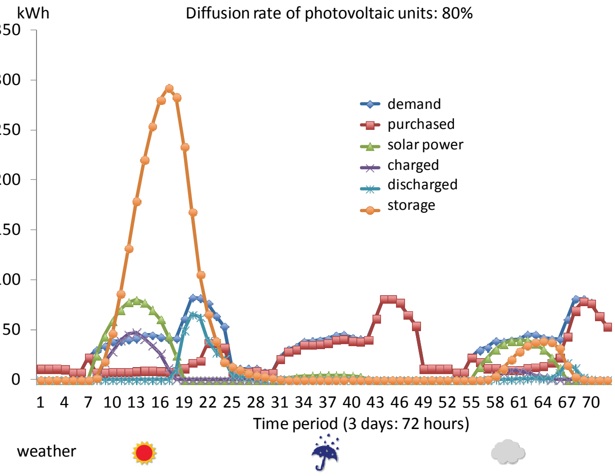

Figure 6. Result of 100 households, three days, diffusion rate of 80%

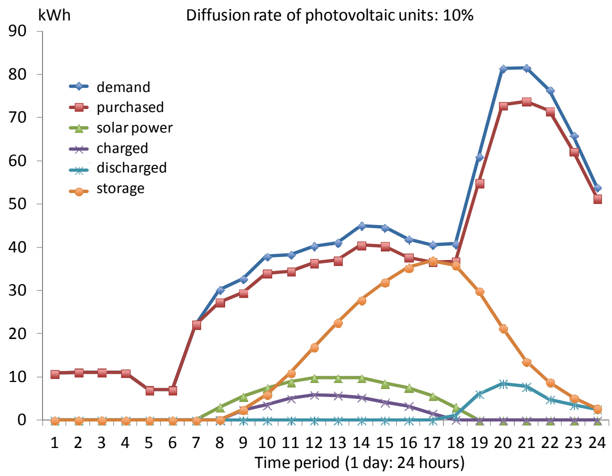

Figure 7. Result of 100 households, one day, diffusion rate of 10%

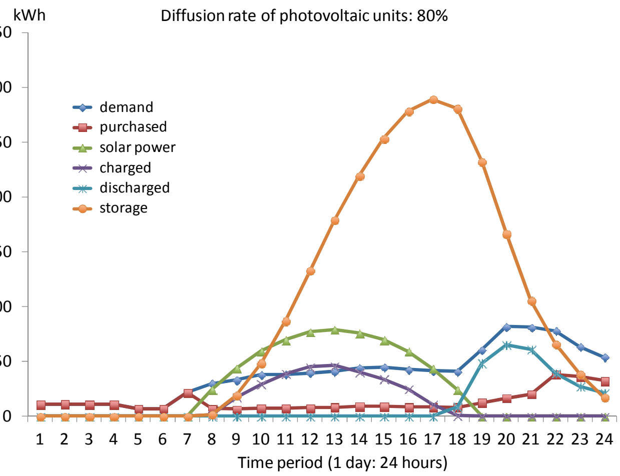

Figure 8. Result of 100 households, one day, diffusion rate of 80%

discharged during a night peak. Due to management, the amount of purchased power was reduced because the agent appropriately employed the battery storage based on the power demand or generation with solar panels. Fig. 8 shows the simulation results when the diffusion rate of the photovoltaic power generation continues to rise. The amount of photovoltaic power generation is increased and less power is purchased by effectively utilizing the enormous accumulation of electricity.

Figure 9 shows the simulation result for one month when the weather is randomly decided and the diffusion rate of the photovoltaic power generation is 50%. Our agent-based electrical management explained in the experiment (Figs. 5-8) was effective for houses equipped with photovoltaic power generation and a battery. However, even if we can effectively control energy consumption very day, daily power purchase fluctuates (Fig. 9) because photovoltaic power generation greatly depends on the weather. This is because the agent's strategy consumes the stored electricity within a day. Since the uncertainty of solar power is critical,

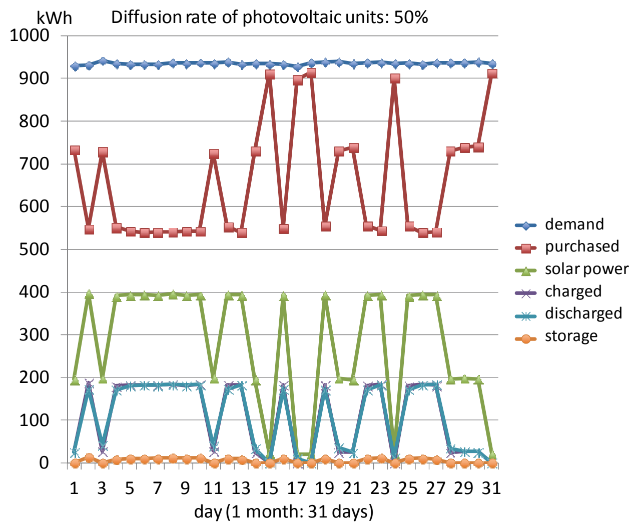

Figure 9. Result of 100 households, one month, diffusion rate of 50%

we must improve our management model to obtain stable results in which an agent acts based on a longer-term view by carrying over the surplus electricity from sunny days for rainy days.

V. CONCLUSION

In this paper, we developed an agent-based electrical power management model in a smart grid. Focusing on houses equipped with photovoltaic units and a storage battery, the agent in our model effectively controls surplus electric power in the daytime from photovoltaic power generation. The amount of the electricity consumption pattern and the photovoltaic power generation are set from data that closely resemble actual use in Japanese houses. The strategy of each agent is defined to purchase less electricity. The simulation results confirmed that the surplus electric power of photovoltaic units is efficiently utilizable with a storage battery and the total amount of the purchased electric power is reduced.

As the future tasks, our model needs to be refined and extended to manage a long-term view with a more advanced strategy. We must develop an agent model that can adequately supplement the uncertainty of photovoltaic power generation.

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