HEMS Data Utilization Solutions Using Autonomous Adaptive Control

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Abstract

One of the means through which the transition to a sustainable low-carbon society is expected to be realized is the smart grid, which facilitates more efficient and stable energy use. Achieving this goal will require technology capable of effectively controlling multiple geographically separated systems. This technology also needs to be able to cope with any sudden environmental change. At NEC, we have been working on a control method for use in real world applications which utilizes autonomous adaptive control based on the biological adaptive mechanism to the environment. In this particular application, we are seeking to establish an energy management system (EMS) that doesn't force users to consciously make efforts to save energy; instead, we have applied this technology to the power control on the demand side and employed flexible equipment control as required. Tests have shown that our home energy management system (HEMS) can autonomously control the power to achieve intended target values by adjusting lighting and air-conditioning in response to environmental fluctuations.

Keywords

energy management system, HEMS, power saving, adaptive control

1. Introduction

In order to achieve a sustainable low-carbon society, more efficient and stable utilization of energy is required. One of the keys to realizing this is the "smart grid." Unlike conventional control systems which generate power at the supply side according to the required amount of power on the demand side, the smart grid is expected to facilitate efficient control of supply and demand throughout the entire system based on an information and communication infrastructure.

We believe that in the future the power grid control system will be decentralized. On the supply side energy will be sourced primarily from renewables using a distributed control system while power is actively suppressed on the demand side using a system that doesn't compromise convenience. We also believe that the entire control system should take the form of a local production/local consumption supply/demand balance control system based on a distribution network that can accommodate power in both directions (**Fig. 1**).

To make this possible, new control technology needs to be developed. The smart grid is comprised of many different systems dispersed geographically and ranging from the supply to the demand of power. In such a complex and constantly evolving environment, real-time optimal control using a centralized synchronous optimization method is difficult to achieve. To solve this problem, research into control that combines centralized control and distributed control is underway.

At NEC, we are examining the application of autonomous adaptive control based on biological adaptive

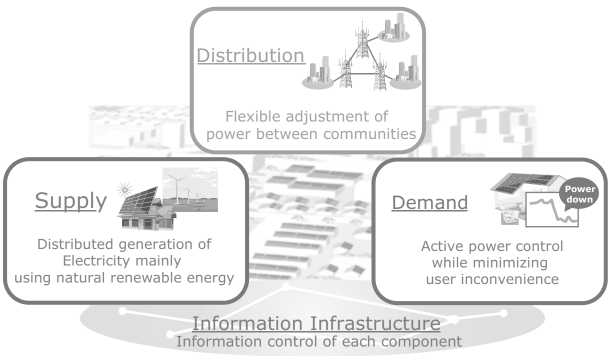

Fig. 1 Conceptual illustration of the smart grid.

mechanisms to the environment[1), 2)] as a means of achieving the smart grid. Autonomous adaptive control assumes applications to various social infrastructures in the real world, which is complicated and prone to fluctuations. It attempts to achieve optimization of the system as a whole by exchanging information locally and asynchronously based on indices that represent the efficiency of constituent subsystems. This makes the system robust enough to cope with any sudden environmental change, assuring stability of supply. Using this control method, we believe that we can develop a smart grid that enhances the efficiency of power usage by using supply/demand control of local production and local consumption.

First, we applied autonomous adaptive control technology to controlling power consumption on the demand side. By using flexible equipment control according to situations, our goal is to create an energy management system (EMS) that enables users to save electricity without having to make a conscious effort (**Fig. 2**). This means achieving the ability to actively control the amount of electric power used and the cost by suppressing the amount of total generated power to the intended target value.

Suppressing electric power can have a negative impact on the comfort of users. To minimize this, our goal is to save electricity without affecting users by optimizing the allotment of electric power between different appliances according to actual usage conditions.

This paper discusses the results of the tests carried out on NEC's home energy management system (HEMS) to verify the feasibility of the application of autonomous adaptive control technology on the demand side. To evaluate the ability of the autonomous adaptive control technology to suppress total generated power and track environmental fluctuations, tests were conducted in a house specifically designed for this purpose in Los Alamos County, New Mexico in the U.S. The results confirmed that power could be suppressed at the intended target value by flexibly controlling the lights and air-conditioning according to changes in the environment.

2. Autonomous Adaptive Control

Drawing its inspiration from biological adaptive mechanisms, autonomous adaptive control is a control method that continually adapts and adjusts to changing environmental conditions to keep the entire system running in a state close to be optimal. It takes advantage of repeating distributed computing using local efficiency indices (**Fig. 3**).

This system operates using indices based on the control targets (efficiency, comfort, safety, etc.) of the subsystems that make up the overall system, rather than on settings for specific environments. Consequently, the system does not require any complex control rules.

Using locally distributed computing between peripheral subsystems based on those indices, this method is able to bring the entire system to a state that approaches the optimum condition. Moreover, thanks to its ability to adapt to local fluctuations by recalculating as required, it has outstanding readiness. What's more, since the computing system is lightweight, it has scalability, allowing more subsystems to be incorporated as necessary.

3. Application of Autonomous Adaptive Control Technology to HEMS

When autonomous adaptive control is applied to HEMS, the power supply to appliances can be precisely controlled in situations where power is restricted - such as demand response - so as to minimize any potential deterioration in comfort levels. The autonomous adaptive control sees each device as a subsystem and bases control operations on comfort indices, assuming those

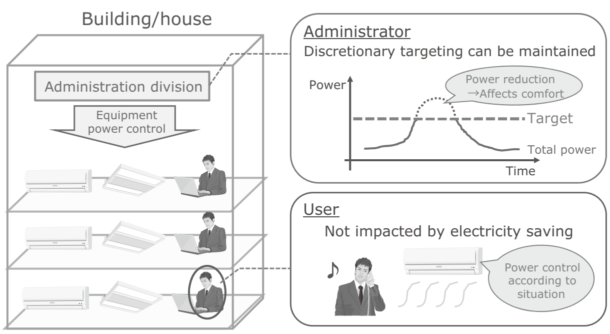

Fig. 2 Targeted energy management systems on the demand side.

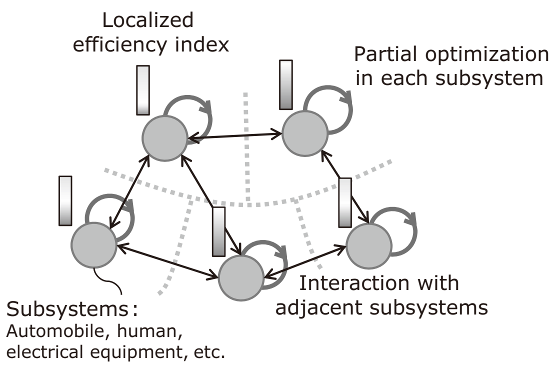

Fig. 3 Overview of autonomous adaptive control operation.

indices represent the goal that the system is attempting to achieve. For example, one of those indices has been defined as the deviation between the user's desired value and the actual temperature.

By inputting the power consumption, selected value, and actual measured room temperature into the autonomous adaptive control system, the appliances can operate in such a way that any deterioration in comfort is barely noticeable or not noticeable at all. At the same time, overall power consumption is maintained at the target value in sync with any environmental fluctuations (the selected values of air-conditioning and LED lighting are automatically adjusted).

Because control operations are derived from the target end state, there is no need to consider the input/output characteristics of air-conditioning units, which makes it easy to apply the system to a variety of uses in the home. Autonomous adaptive control can also be scaled according to the number of appliances being controlled; in fact, we're confident that the mechanisms that control a HEMS can be scaled up to control a full EMS that covers communities and cities.

4. HEMS Testing and Validation

We controlled appliances in the test house using autonomous adaptive control. The following points were evaluated during testing:

- Whether or not the power consumption of the entire house could be suppressed to the intended target value
- Whether or not the system can maintain control and suppress power consumption as required, while responding to environmental fluctuations (such as changes to appliance setting values, as well as their priority levels)

(1) Test configuration

In this test, the items controlled included all household electrical appliances compatible with the characteristics of the autonomous adaptive control system

- **Air conditioners (8 units)**

  The models tested were designed for home use. The operation mode was set to heating, and the air flow to the weakest setting. The temperature setting was adjusted between 18 and 32°C.

- **LED lights (10 units)**

  The dimmer setting was set to fixed, and the brightness setting was adjusted from level 1 to level 10.

Other home electrical appliances (an LCD television, refrigerator, hot water server, etc.) were not used as control subjects.

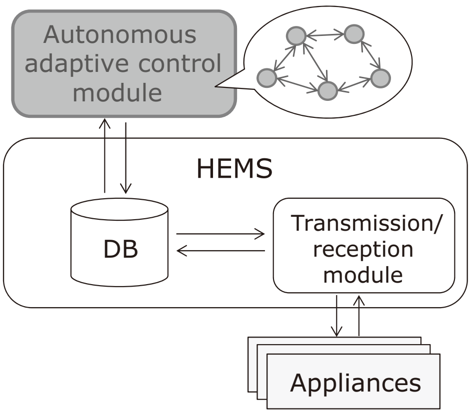

Fig. 4 System configuration in the test.

(2) System configuration

The control system combined the autonomous adaptive control module with the HEMS of the house (**Fig. 4**).

The HEMS executed the acquisition of information from the household electrical appliances and the control commands to those appliances. The data retention and control commands were performed via the database (DB). The autonomous adaptive control module input and output the data from the monitored devices via the DB. Although the implementation was centralized, virtual devices were generated within the module and computing was performed there in a distributed manner.

(3) Evaluation scenario

The validation evaluation was conducted by following the scenario below.

1) Initial settings

The brightness settings for the LED lights were set at levels 5, 6, 7, 8, and 9 for every two units respectively, while the temperature settings for the air conditioners were set at 22, 23, 24, and 25°C for every two units. The degrees of priority were set to the same settings for all units.

2) Target power consumption settings

The power consumption target values for the whole house were set at 5,000 W and 3,500 W incrementally.

3) Changes in appliance priority settings

One of the air conditioners and one of the LED lights were set to a higher priority than the others.

4) Cancellation of the priority settings

The priority settings were canceled so that all the settings the same.

5) Cancellation of target power consumption settings

5. Results

Now, let's examine the test results according to the power transition graph for the whole house and the graph for each appliance's selected values.

Fig. 5 shows the value transition of each appliance.

It is clear from this graph that the power of each appliance was controlled according to the settings of the target values, and the total power was near the target value. It is also clear that, even when the priority of the appliance was changed, the total value maintained the designated target value. The results indicate that power usage throughout the house could be effectively controlled and stabilized at the intended target value.

Fig. 6 and **Fig. 7** show the transitions of the selected values of each appliance.

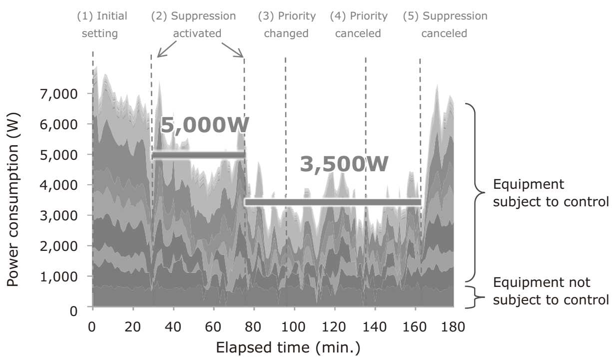

Fig. 5 Transition of the power consumption of the appliance.

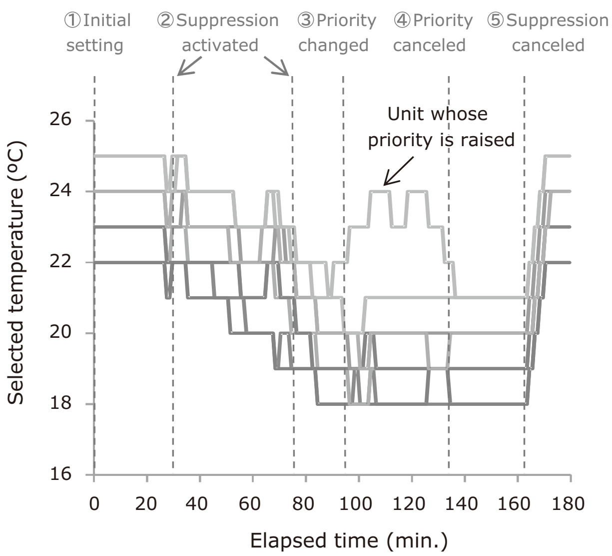

Fig. 6 Transition of the selected temperature of air conditioners.

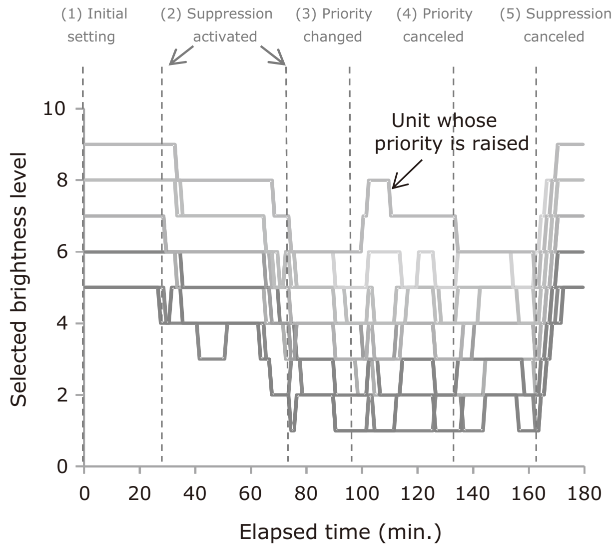

Fig. 7 Transition of the selected brightness of LED lights.

From initial setting until power suppression was initiated, all the appliances operated at the desired values. Next, it is clear that the selected values for both the air conditioners and LED lights could be uniformly controlled after power suppression had been initiated. The selected values for both the air conditioners and LED lights were set to use as little power as possible. It is also clear that, after the degrees of priority were set midway through the test, only the selected values of those units whose degrees of priority had been raised were adjusted to higher levels. In other words, control operations were performed so that the selected values of the units with higher degrees of priority approached the desired selected values. These results indicate that the autonomous control system was able to adapt to the changes in conditions that accompanied the adjustments made to the selected values and degrees of priority of the units.

6. Conclusion

To help make possible an EMS which would be able to reduce power consumption without noticeable adverse effects on user comfort, we tested our autonomous adaptive control system on the air conditioners and LED lights in the house specifically configured for testing, and then we evaluated how effectively the system was able to suppress overall power consumption and how well it tracked environmental fluctuations.

The tests confirmed that power could be maintained around the intended target values. We confirmed that control was also possible when the selected values for each appliance were changed as well as when changes in priority were input by the resident. In other words, the system made it possible to actively reduce power consumption using the equipment configuration of the HEMS while adapting to changes in settings and environmental conditions.

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