Distributed Power Usage Control and Estimation of Total Demand

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*Abstract –*In this paper we describe a proposal of distributed power control system and a demand estimation model for suppressing total power usage. The main components of the system are smart power outlets (SPOs) which can suppress the total power usage under the contract or saving target power and also can avoid excess circuit current to prevent a breaker trip by using mutual communication. The method to suppress the total power is by stochastic way incorporating standby rate, which is calculated by using an estimation model of total power demand. We implemented SPOs with defining communication format, and verified that the method is effective as a distributed power usage control system.

I.   INTRODUCTION

Technically, it is already possible to manage power usage automatically. The major targets of desirable automation are suppressing power usage under the contract power or saving target power, and limitting all the circuit currents sufficiently under values causing circuit breaker trip. Automatic demand side magement is a desired technology for releasing people from burden of handling appliances with caring importance of them. However it is not an easy task for softwares, too[1].

Various researches and products such as HEMS, BEMS and OpenADR exist [2-5]. Their main method is to handle power usage devices by a single controller or a structured controllers classified as a centralized control system[6]. It is required for a successful operation of centralized control to collect detailed information about the devices and usage conditions [7]. Otherwise, users feel frustration to the controller and would ignore the system. Contrarily, distributed control is a practical selection for flexibility and degree of freedom. Fig.1 shows a comparison of merits and demerits of centralized and distributed systems.

However, it is not easy to attain a system's target by a distributed system[8]. We propose a practical, almost satisfactory distributed control system by using mutual wireless communication, and show an implementation of it. For a successful application of the system, we need a good estimation of the total power demand even under a controlled situation. We show a basic estimation method in this paper.

Fig.2 shows a power distribution structure with our distributed control components in a typical household. We have to restrict the circuit current under breaker's limit value, and to suppress the total power usage. Currently, we are realizing our system by using smart power outlets (SPOs) inserted between electric appliances and wall outlets, although we expect all the appliances have functions such as that we propose, in the future.
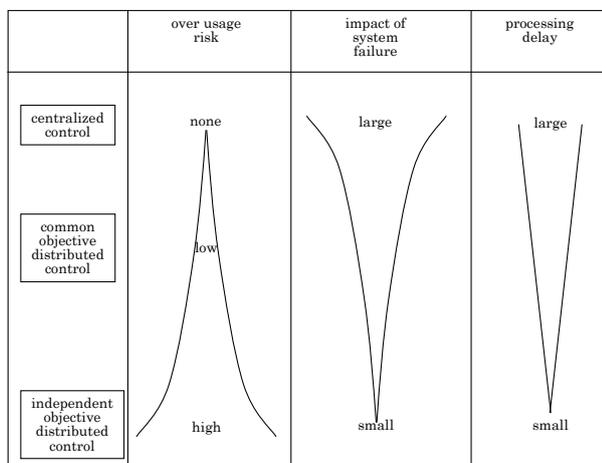

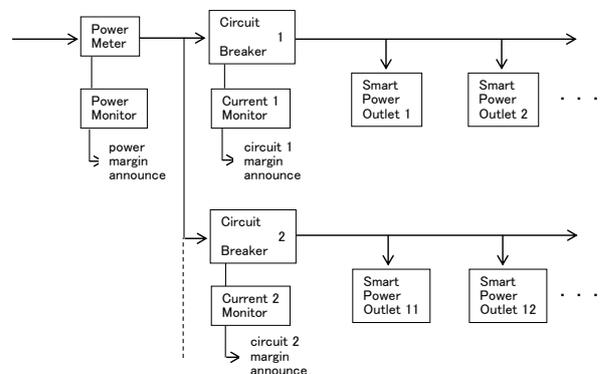Fig. 1. Centralized control vs distributed control.

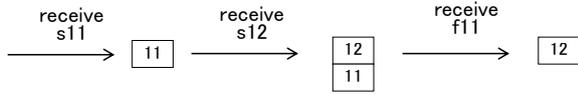Fig. 2. Power distribution in an ordinary house.

Fig. 3. Stack data structure for keeping usage order.

II. LIMITING CIRCUIT CURRENT

For restricting each circuit current under its limit value, every circuit monitor broadcasts its current margin, i.e. available current, to all SPOs connected to the circuit at one second intervals. Each SPO detects the activation of its connected appliance, and determines whether to continue supplying power to the appliance or to disconnect it by considering whether the margin is less than the power expected by the appliance or not. The expected power is to be preset in the SPO, or determined by the temporal connection and estimation by asuming a resistive appliance such as a heater [9].

There may be cases when more than one SPO start supplying power in a short time. Countermeasure to such over use condition is to stop supply by the SPO which is the last activated SPO by judging from the start order stack kept in all SPOs (Fig. 3) [10]. If the SPO is on the top of the stack, it means that the SPO must stop power supply to the connected applliance. To update the stack, every SPO has to send a start and a finish message to all SPOs on the circuit.

Also, there may be cases when all SPOs judge that it is not the last one because update messages from other SPO reaches with some transmission delays. In such cases, all the SPOs should erase the last entry of their stack after two consecutive current excess message, and judge whether the last one is itself or not, again.

III. SUPPRESSING TOTAL POWER USAGE

For suppressing the total power usage under a target value (contract power or saving target power), each SPO has to wait supplying power depending on the total power
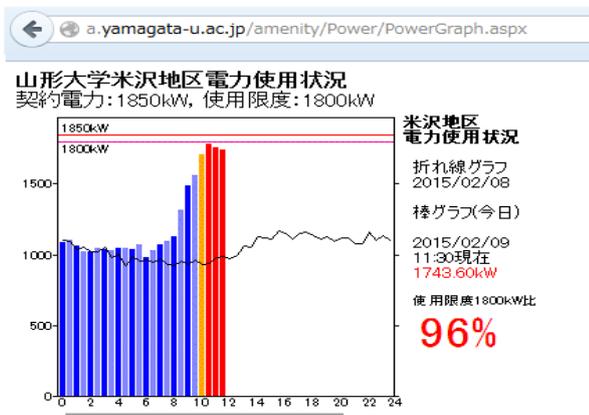

Fig. 4. A home page for showing total power usage.

usage. Fig. 4 is an example of our university's information page which shows the total power usage.

As it would be difficult to set priority or some systematic parameters to each appliance, our proposal is to set standby rate to be applied to all the appliances except emergency or absolutely necessary ones.

As an ordinary power meter for a business premise outputs an average power usage at 30 minute intervals, the standby rate should be determined to be used for the following 30 minutes.

IV. ESTIMATION OF TOTAL DEMAND

Let's determine the standby rate by estimating the total demand. If we denote the power usage at time interval t as U_t, the power usage increase (demand) at time interval t is expected as $V_t = U_t - U_{t-1}$ with linear extrapolation. If $U_t + V_t$ exceeds the target power L, we have to set standby rate w_t satisfying

$$U_t + (1 - w_t)V_t \le L. \tag{1}$$

To avoid exceeding the target power, L should be set lower than it. From equation (1), w_t can be calculated as

$$w_t = 1 - (L - U_t)/V_t. \tag{2}$$

If it is negative, w_t is to be set 0, which means no need of standby. Each SPO generates a random number in the rage of 0 to 1 when its connecting appliance starts, and it must wait supplying power to the appliance if the generated number is under w_t (Fig. 5).

Once the standby rate is larger than 0 (Fig. 6), the demand v_{t+1} for the next 30 minutes must be recalculated incorporating the effect of former w_t. If the real usage is U_{t+1} at time interval $t+1$ and $U_{t+1} \le L$, then the expected usage increase can be estimated by

$$V_{t+1} = \frac{U_t + V_t}{L}U_{t+1} - U_{t+1}. \tag{3}$$

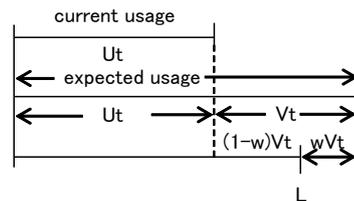Thereafter, w_{t+1} can be calculated similar to equation (2).

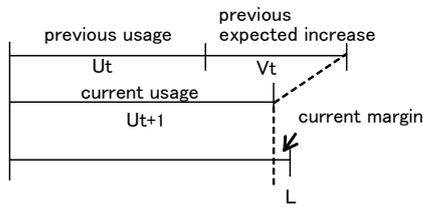*Fig. 5. Initial standby rate w for excess demand.*

Fig. 6. Situation after standby rate activation.

If $U_{t+1} > L$, $w_{t+1} = 1$ is the only thing we can do.

V. SYSTEM AND COMPONENTS

The system consists of three types of components. The first one is a total power monitor which extracts power usage from the XML data contained in Fig. 4 and send it to all the SPOs. The second one is a circuit monitor which measures the circuit current, calculate margin current, and send it to all the SPOs connected to the circuit. The third one is a SPO which measures the current to the connected appliance, switchs a relay connecting the appliance, sends infrared commands to the appliance (not used in this work), receives messages from the power monitor and the circuit monitor, and also from other SPOs. All communications are done through ZigBee (Fig. 7 and 8).
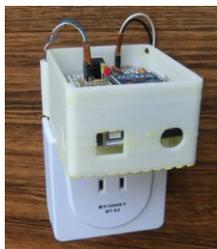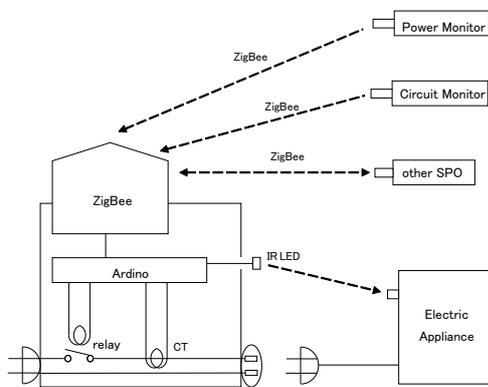

Fig. 7. A smart power outlet.

Fig. 8. Configuration of the smart power outlet.

Followings are message formats for four types of communication.

(1) s1/   SPO 1 appliance ON
(2) f1/   SPO 1 appliance OFF
(3) x1000/   power usage 1000kW
(4) b10/   circuit margin 10A

The messages "s" and "f" are for updating usage order stack in each SPO. The message "x" is for annuoncing total power usage from the total power monitor. The message "b" is for announcing circuit current margin for each circuit from corresponding circuit current monitor.

Fig. 9 shows the control flowchart of each SPO. It analyzes incomming messages and calculates the standby rate w (A), detects switching off of the connected appliance and processes finish function (B), detects switching on and processes start function including standby decision with random number generation (C), and processes the case of excess circuit current (D). Fig. 10 is the detailed flowchart of the part D, which assumes that the circuit breaker delayes for several tens of seconds before it trips in cases of small excess current.

We verified the operation of supply stop when the circuit margin gets negative, and when the total demand goes over the saving target power. Fig.11 shows an example of updating the standby rate, when the current usage is 1500kW and the expected usage 2500kW excessing
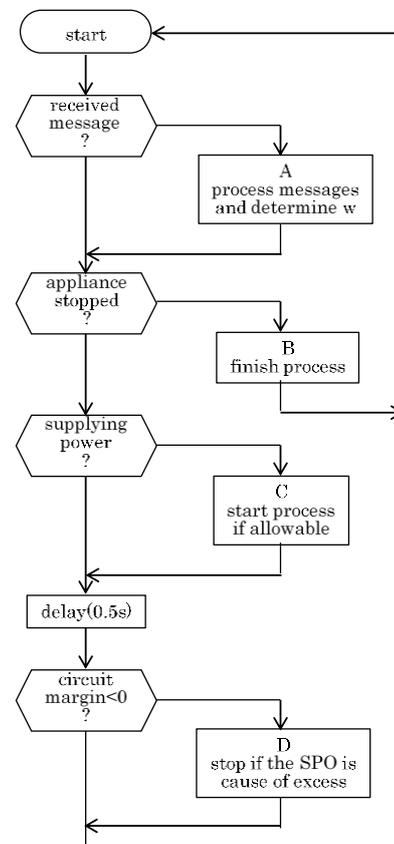

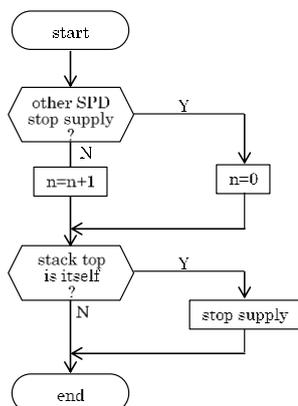*Fig. 9. Flowchart showing the algorithm of SPO.*

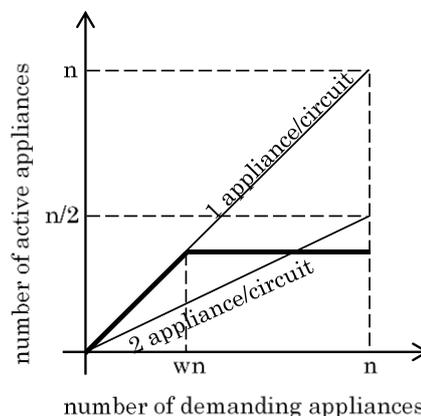Fig. 10. Detailed flowchart of the block D in Fig.9.

Fig. 12. Relation of total demand suppression
and circuit's activation limit of appliances.

2000kW contract power, resultanting standby rate to be 0.5.

VI. DISCUSSION

Our control system deals with two restrictions of circuit limit and total limit. The circuit limit precedes the other and affects the calculation of the standby rate. Fig. 12 shows a simple situation where n is the total number of appliances, w is the standby rate, power consumption of all appliances are equal, and only one appliance can be activated within each circuit's current limit. In such situation, the thick line indicates resuting number of appliances activated, which equals to the power usage, controlled by the standby rate w..

Our strategy is to standby when demands excess the limit, there is anothe strategy to reject usage, by which it is safer to restrict power usage and easier to estimate total demand, although it would be inconvienient for users.
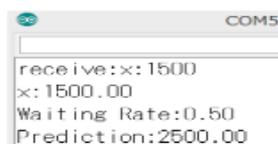

Fig. 11. Example of updating the stanby rate.

VII. CONCLUSION

We showed a practical realization of suppressing total power usage and restricting circuit current under the limit by using distributed power control scheme incorporating smart power outlets. Basic estimation of power demand and calculation of standby rate needed for the suppression are shown. Future work is expectred to test the system in a larger scale with a practical estimation of user activity.

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