Integration of Sensor Network and Energy Management System in Home and Regional Community Environments

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Abstract: Decreasing greenhouse gas emissions is one of the urgent issues that mankind is facing to. So far energy management systems (EMS) have been installed into a factory environment and good results have been obtained. In this paper, we propose to integrate sensor network systems and EMS to adapt to a heterogeneous home environment and to expand EMS enhanced by information and communication technologies to the level of regional community. Our proposal consists of four phases. A prototype development of the sensor network-based power monitoring and controlling system is presented to prove the effects of the first and second phases. Also two study cases are presented to support the third and forth phases of the proposed system.

1. Introduction

In 2007, the Intergovernmental Panel on Climate Change (IPCC) and Mr. Al Gore won the Nobel Peace Prize for their efforts to build up and disseminate greater knowledge about man-made climate change, and to lay the foundations for the measures that are needed to counteract such change. Here, the climate change actually corresponds to global warming caused by greenhouse gas emissions. Urge action against it is needed and advance of information and communication technologies (ICT) including sensor networking will be able to contribute to it from the viewpoint of energy management. Although installation of energy management systems (EMS) into a factory environment has started around thirty years ago already [1], introduction of EMS into home and office environments has been left behind. Recently, a trial of current stream measurement in occupational and domestic environments has started using a ubiquitous sensor network called "Plug" [2]. The Plug has not only the electrical current sensing function but also a wide range of sensing modalities such as sound, light, vibration, motion, and temperature. Therefore the Plug can be applied to various situations, although it seems that how to use the Plug depends on each situation.

On the other hand, turning our eyes to the outside of home and occupational environments, a concept of system connecting small, distributed electrical power generators and consumers locally has been established, that is to say a MicroGrid. There exists considerable research to date on Microgrids with a number of major research projects underway and a number of demonstration projects commissioned internationally [3]. In the Microgrids projects, variety of power generators is considered, but consideration of variety of consumer houses still seems to be missed.

Considering the on-going studies comprehensively, it can be said that lowering greenhouse gas emissions needs from an appliance-level electric power management to a regional community-level power management. In this paper, we present an electric power management plan consisting of four phases. Based on the proposed plan, a prototype implementation of current sensing and controlling at the home-area level is presented. Effects of the plan from the economical and ecological viewpoints are also shown in this paper.

2. Power Management System with Four Phases

To realize a safe, economical, ecological and comfortable life, we propose a power management system consisting of four phases. Figure 1 shows the proposed power management system framework, which include four phases. Each phase is explained in the following subsections.

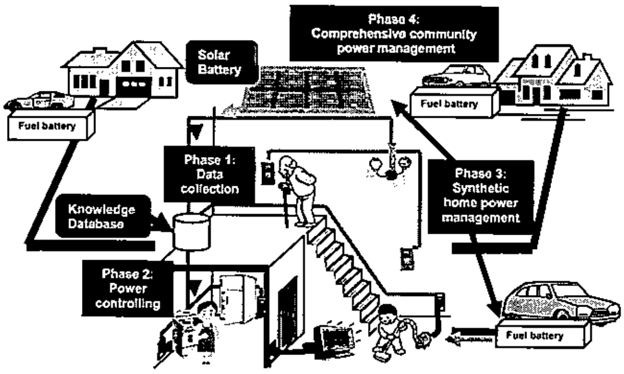


Fig. 1. Framework of power management system with four phases.

2.1.The First Phase

In this phase, power consumption data are collected from each electric appliance in a home environment. Figure 2 is a simple architecture of network to collect measured power consumption data. In Fig. 2, Master corresponds to a sink node and Slave does to a sensor node. It shows that Slave, a sensor networking module, is attached to each electrical appliance and power consumption data are collected to Master via network. The physical network can be a network based on IEEE 802.15.4 or a network of power line communication. Although analyzing the collected data depends on the type of application, one example is to extract behavior patterns of residents by monitoring appliance behaviors by making use of the knowledge database. Though the content of the knowledge database also depends on the application area, the house layout with distance is one of the elementary knowledge in the database, for instance.

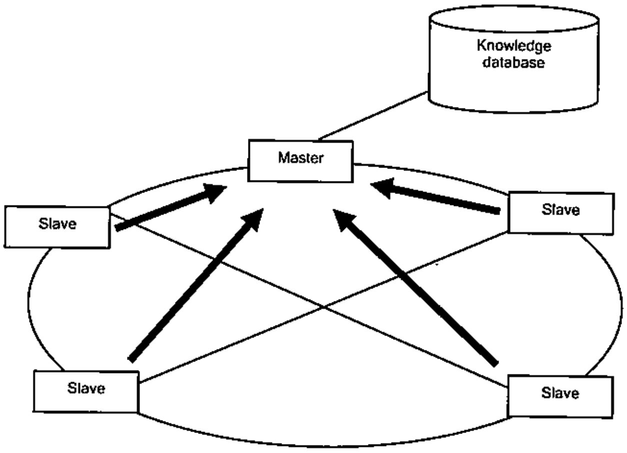
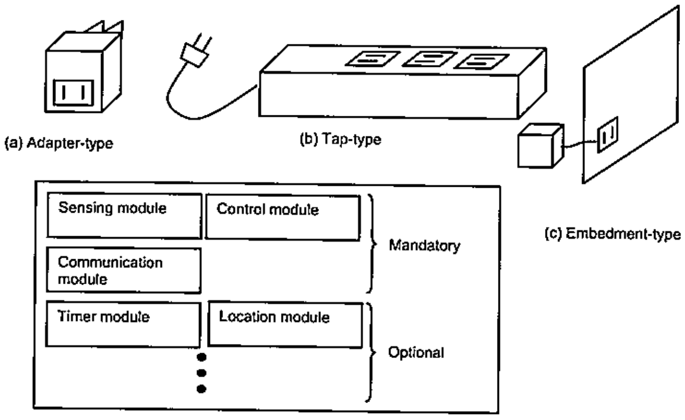


Fig. 2. Simple architecture of a sensor network to collect power consumption data.



(a) Adapter-type (b) Tap-type (c) Embedment-type

(d) Modules in Slave

Fig. 3. Three types of shape and inside modules of Slave.

Final shapes of Slave are assumed to become (a) to (c) in Fig. 3 and the modules to be included in Slave is depicted in Fig.3 (d). The modules are separated as the mandatory ones and the optional ones. The former includes sensing, control and communication modules and the latter includes timer and location modules and so on.

2.2.The Second Phase

In the second phase, power consumption of electrical appliances is controlled based on the measured data collected in the first phase. There are two methods of controlling. One is an on/off-type control method and the other is a continuous control method. In the on/off-type control method, an appliance can be turned on or off by way of sending a control command over network. Mechanically a relay circuit can be used, for example. By the continuous control, the power amount supplied to each appliance can be changed continuously. A power-control circuit based on thyristors can be used to decrease the amount of power supply. The appliances to which this method can be applied are, however, limited. The classification of appliances from the viewpoint of power controllability is needed to be stored in the knowledge database. Nevertheless, owing to such power control methods, the system can suppress the total amount of power usage even when there is an upper limitation of available power like the limitation of a breaker on a distribution board. The control circuit will be included in Slave as the control module shown in Fig. 3 (d).

2.3. The Third Phase

In the third phase, synthetic home power management will be done by connecting electrical appliances, power generators and batteries through the home network. In this phase, the system is assumed to manage the power self-generation, the power sold by a power company, the power consumption and the power storage in the batteries synthetically. The residents will be benefitted by this system in several ways. In some case, they can store the power sold by the power company in the batteries at night and use the stored power by day. Because the electricity charges in the night time are usually set to be cheaper than those in the daytime, the residents will enjoy the economical benefit. In addition, the power company can find a merit to be able to average the power consumption all the day. In another case, the system will manage the priority control of power supply from the power self-generators and the batteries at the time of some unusual event, e.g. blackout. Since the capacities of the power self-generators and the batteries are limited and the residents usually do not know the power consumption of each appliance, this system will be useful to provide the efficient way of power usage.

2.4. The Forth Phase

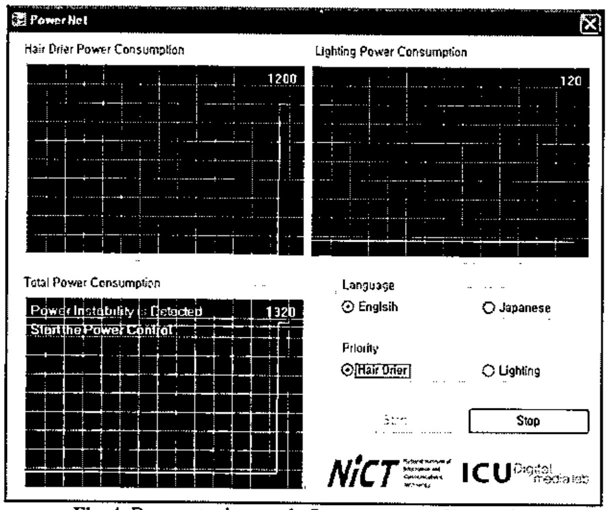
In the last or forth phase, a comprehensive community power management system that enables us to trade power reciprocally will be deployed by connecting each power management system in home. As the result, an efficient and disaster-resistant social infrastructure will be realized on the basis of super distributed power network. The mechanism in this phase is similar to that in the third phase and can be merged into the Microgrid system naturally. The most different point is that the flows of electricity should be grasped correctly when power from a home with surplus is supplied to its neighborhoods, because this is a kind of trade.

3. Prototype Implementation of the Proposed Model in First and Second Phases

In order to realize the power management system described in Section 2, we have started to implement a prototype system in the first and second phases.

As Slave, we have developed a circuit with a sensing module, a continuous control module and a communication module. As the sensing module, electric current detecting part using a shunt register has been implemented. As the continuous control module, two types of control method were used: a phase control method and a pulse control method with zero-crossing detection (just say the pulse control method hereafter). The phase control method can be applied to a resister-type power consumption appliance and the pulse control method can be applied to a simple motor-driven appliance. By comparing both methods, the phase control method can control power supply more minutely but the type of appliance to which this method can be applied is very limited. As the communication module, IEEE 802.15.4 was used this time.

To demonstrate the prototype system, we used two kinds of appliances: a light of 120W and a dryer of 1200W. The demonstration had two purposes. The first is to measure the used power correctly and the second is to control the consumed power continuously and automatically when it is detected the total power consumption is over an upper limitation. In this demonstration, the upper limitation was set as 1300W. The results are shown in Figs 4-6.



Power Instability is Detected Start the Power Control 1320

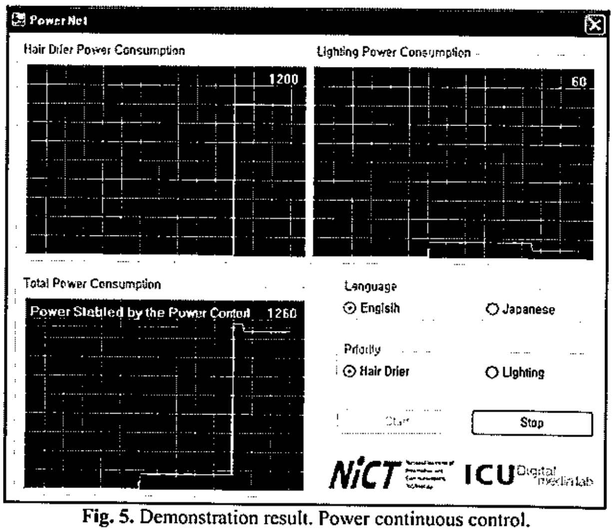
Language: ⊙ Englsih ○ Japanese

Priority: ⊙ Hair Drier ○ Lighting

Fig. 4. Demonstration result. Power consumption sensing.

In Fig. 4, the upper-right window shows the power consumption by the light and the upper-left window shows the power consumption by the dryer. It is found that the power consumption of both appliances was measured correctly and stably. The lower-left window shows the sum of power consumption by the light and the dryer. The instance of Fig. 4 is just after the over-usage beyond the upper limitation was detected and before the automatic power control began. Therefore the total power consumption is presented as 1320W.

Figure 5 shows an instance after the power supply to the light had been controlled automatically and continuously. Since the power supply to the light was cut off to 50%, the brightness of the light decreased and the value of the upper-right window changed to 60W. As the result, the total power consumption in the lower-left window had also decreased as 1260W under the upper limitation. The power consumption by the dryer remained unchanged.



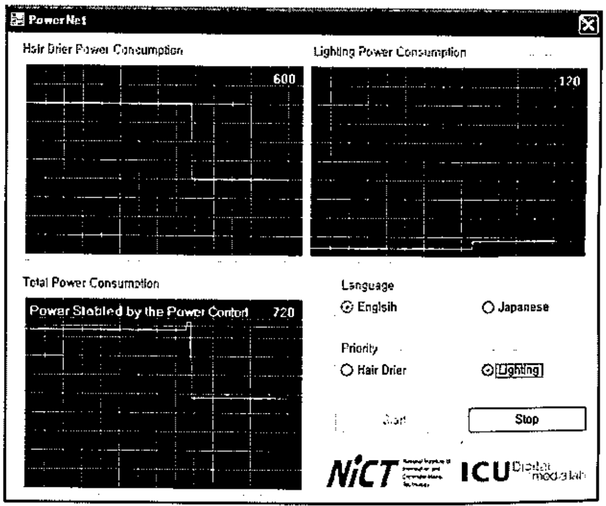
Power Stabled by the Power Control 1260

Language: ⊙ Englsih ○ Japanese

Priority: ⊙ Hair Drier ○ Lighting

Fig. 5. Demonstration result. Power continuous control.

Which appliance should be controlled can be changed from the interface window. A resident can select priority with the radio buttons in the lower-right part. Figure 6 shows an instance after the priority had changed from the dryer to the light. In this case, firstly power supply to the light was recovered and then power supply to the dryer was cut off to 50%. As the result, the power of the dryer decreased and the value of the upper-left window changed to 600W. The total power consumption in the lower-left window shows the final adjusted value, 720W.



Power Stabled by the Power Control 720

Language: ⊙ Englsih ○ Japanese

Priority: ○ Hair Drier ⊙ Lighting

Fig. 6. Demonstration result. Priority change from the dryer to the light.

4. Case Studies on the Proposed Model in Third and Forth Phases

The effects of the third and forth phases of the power management system described in Section 2, two case studies are shown in this section.

4.1. Case Study in the Third Phase

As described in the third phase in Section 2, the residents can be benefitted by storing night power in the batteries and using the stored power by day. We simulated this case by making use of the realistic figures and the simulation result is presented in Table 1.

As the assumption, we adopted a family model with a pair of parents and three children and collected real power usage data of this family model from the real existing family. It is assumed that there is a 16 kWh battery in this house and the efficiency rate of charge/discharge, A/D and D/A is 90%. This efficiency rate is said to be the worst value. The second row of Table 1 shows the total power in kWh used by the real family each month and the third row does the average power use per day. The average value is needed because the battery repeatedly charge and discharge day by day. The forth row presents the calculated results of electricity charge in yen by the proposed method. We used the existing electricity charge system of one Japanese power company and precisely calculated the daytime power charge by the power company when the power consumption exceeded the battery efficient capacity. The fifth row in Table 1 shows the real charges by the present system, that is purely daytime charges.

The sum of the forth row is 61,148 yen and that of the fifth row is 101,873 yen. It means that the family can save about 40% of electricity charge by the proposal system.

4.2. Case Study in the Forth Phase

The other study case is about the rate of transmission loss between the power plant and the end-point houses. From the statistics of fiscal 2005 and 2006 of ten major power companies in Japan, the average rate of transmission loss is about 5.2% in Japan as a whole. After a computation with a slight approximation, this loss can be regarded to correspond to 19,720 thousand tons of CO2. Since the amount of greenhouse gas emissions in 1990, that is the base year in Kyoto Protocol, is 1,237 million tons of CO2, it is found that the computed CO2 amount caused by the transmission loss corresponds to about 1.6% of the amount of greenhouse gas emissions in 1990. Although it is impossible to get rid of all of the transmission loss, the reciprocal power trade in the comprehensive community power management will be able to contribute to decreasing the transmission loss from power plants. More precise computation and simulation studies based on the real situation are needed to support the effects of the forth phase of the power management system.

5. Conclusion

In order to realize a safe, economical, ecological and comfortable life, we propose a power management system with four phases in home and regional community environments. The basis of the proposed system is constituted by the power monitoring and controlling sensor network whose mandatory modules are sensing, controlling and communication modules. A prototype implementation of the sensor network is presented. In addition, two case studies to support the third and forth phased in the proposed system have been shown.

Further studies include the extension of the sensor network prototype into a home environment and introduction of power self-generators and batteries in such a real experimental environment. With the extended test bed, some services to detect human behavior and to save the wastes of power will be tested. More precise computation and simulation studies are needed to make the proposed model more realistic.

References

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Table 1. Demonstration result. Priority change from the dryer to the light.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Total power (kWh)	328	346	391	366	343	380	442	583	341	323	375	348
Power use per day (kWh)	10.9	11.5	13.0	12.2	11.4	12.7	14.7	19.4	11.4	10.8	12.5	11.6
Charge by the proposal (yen)	4,681	4,681	4,717	4,681	4,681	4,681	5,535	8,767	4,681	4,681	4,681	4,681
Charge by the present (yen)	7,318	7,720	8,724	8,166	7,653	8,478	9,861	13,007	7,608	7,207	8,367	7,764