Study of Priority-based Power Assignment Scheme for Smart Home Energy Management System

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Abstract: A home energy management system (HEMS) plays a vital role in realizing the efficient and versatile control of consuming power among home appliances (HAs) in smart homes. In this paper, we present a system model of smart homes, which consists of smart meters (SMs), HAs, and HEMS. We also analyze the function of HEMS in computing the power assignment of HAs based on the appliance priority. Simulation results reveal that the stability criteria of HEMS can be guaranteed even though the existing of limited power supply and time delay.

1. Introduction

A home energy management system (HEMS) plays a vital role in realizing the efficient and versatile control of consuming power among home appliances (HAs) in smart homes. Smart home is an integration of home automation equipment, home securities, home communication and other attractive features based on advanced technologies, such as combined automation, combined networks and communication technologies [1], [2]. Smart home is a concept that assists control of numerous different systems in a household (e.g. air conditioning, heating, security, and lighting) is acknowledged under the term smart home [3]. The objective of moving towards to the smart home is enhancing safe, energy efficiency, comfortable, economical and environment-friendly unique life style for each individual. In this way, we have to face the worst situation of energy shortage due to increasing number of consumer electronics and their attractive functions according to the development of smart home [4]. The reliability, efficiency and stability of the smart home is expected to be significantly improved via home energy management system (HEMS) and smart meter (SM) is the most essential part of the energy system [5]. The high power required by HAs (like white goods, audio/video devices, communication equipment and air conditioning systems), makes our homes one of the most critical areas for the impact of power consumption.The future home should be smart enough to maintain its stability all the times. So, we need to introduce a HEMS model that plays a vital role in obtaining reduction in maximum consuming power by the HAs. HEMS is a complete system that includes all the important elements to achieve reduction of power consumption [6]. A HEMS is a networked system which is responsible for monitoring and managing the working operation of in-home appliances, according to the specific set of criteria. The introduction and availability of SM technologies have introduced a paradigm shift in the analysis of power system. The real time management of instantaneous consuming power of the HAs through SM is a key factor of HEMS. SMs are gradually adopted due to multiple benefits like the extraction of useful information from SM readings can lead to intelligent decision making in power consumption analysis [7]. as more and more HAs and consumer electronics are used, the overall power consumption in smart houses (1) inclines to grow and (2) leads an increase in the risk of power blackout. This is the reason that to reduce the power consumption at home, we need a check and balance system for instantaneous consuming power of HAs. In order to reduce maximum consuming power, it is first important to know how power is consumed. Therefore, power consumption monitoring is needed. The real time monitoring of instantaneous consuming power of the HAs can be successfully achieved by SM [8]. Secondly, it is necessary to manage and control the HAs to apply power reduction strategies.

In our proposed scenario of smart home energy management system the HAs considered to have different priority levels. The higher priority HAs can take more power as compare to the lower
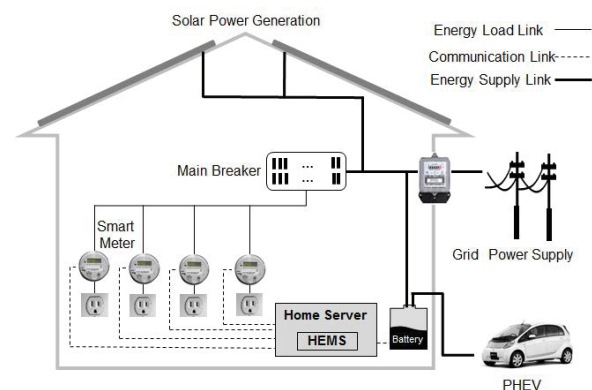
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Fig. 1   A sustainable house with source and loads.

priority HAs from the available power. Though the ON/OFF status of the HAs, we need to reassign a part of consuming power from lower priority HAs to the Higher priority HAs. In this paper, we study the power assignment scheme for the HAs based on their priorities so that the total power is shared. In overall scenario, the use of SMs will help us in measuring instantaneous consuming power levels of the HAs and send this information to HEMS. HEMS receives the ON/OFF status from the HAs and instantaneous consuming power levels from SMs, along with priority calculates the target power level for each HA. It is shown that the dynamics of the behavior of HAs with change in value of system parameters introduce critical system events like overshoot. Simulation results are discussed for the better understanding of how proposed HEMS model for smart home work with priority.

The rest of this paper is organized as follows. Research background and motivation that are related to this paper summarized in Section 2. In Section 3 and 4, we described the system modeling and simulation results respectively. Finally, we conclude our research and future works in Section 5.

2. Research Background and Motivation

2.1 Research Background

2.1.1 Home Energy Management System (HEMS)

As stated in [9], HEMS consists of a group of functions that facilitate remote monitoring, controlling, planning and repairing of operations and provide information on the status of installed devices and the network. In particular, the HEMS have following four functions:

Auto configuration : Auto-configuration is the most important function for user of home network services because many homes have a wrong configuration.

Easy monitoring : Comfort and easy access to real-time information in energy consumption help the user in paying attention to energy saving.

Remote controlling : On-line access to a customer's usage pattern and device status enables HAs to be controlled remotely.

Smart planning : automatic peak load management provides smart planning for reducing energy consumption.

2.1.2 Smart Meter (SM)

SM has following functionalities to help owner in following ways:

1) Outage Management
2) Automatic meter reading
3) Pre-payment
4) Active load control
5) Sub metering
6) Revenue Protection

SM is a subject that attracts much more attention. Smart metering is obtaining many benefits in a lot of aspects. Many benefits are available, especially on improving the energy efficiency. The smart metering is the combination of power system, telecommunication and several technologies. SM has countless benefits like it can enhance reliability, remotely read interval meeting, with the meter capable of daily reads, quality of supply and outage detection to improve consumer supply services, ability to control

connection and disconnection remotely and apply supply capacity limits to manage emergency situations and quicker restoration. In future electricity distribution grids, SM would play an important role in monitoring the performance and the energy usage characteristics of the load. Collection of energy consumption data from all consumers on a regular basis allows managing electricity demand more efficiently and also to advise the consumers about the cost efficient ways to use their HAs. In addition, integration of SMs helps utility companies in detecting unauthorized consumption and electricity theft in view of improving the distribution efficiency and power quality [10].

2.2 Research Motivation

The need for electricity has been growing rapidly in recent years as a result of addition of HAs at home to make life comfortable for the user. These technological advances allow the shortage of electricity. Additionally, the electricity consumed varies significantly over time. The future smart home is a self-motivated home with continual real-time communication between HAs, HEMS and SM. Embedding intelligence in the form of home energy management system in smart homes to meet the challenges of improved reliability, security, efficiency and system dynamics is a challenging task. Electricity is the basic need for daily life and its failure will probably paralyze the individual home to the whole city depending on the scale of the failure. The severe accidents by large scale failure have been recognized and many efforts have been done for preventing such a failure [11], [12], and [13]. On the other hand, when total power consumption of the HAs cross the power supply limit is also a critical problem, but no research study has been done to control this situation. It causes mental stress for the home users and also damages to the HAs. HEMS often encounter unexpectedly high energy consumed level due to various reasons. The HEMS need to be continuously balance the energy available for HEMS and the consumed energy for reliable energy delivery across the HAs. As the consumed energy increased, the available energy limit for HEMS also decreased, which makes the HEMS susceptible to outage [14].

For controlling and managing the HAs, a number of HEMS were proposed and developed [15]-[16]. The previous HEMS monitors and controls the home devices, and display home energy consumption information. HEMS in [17], is explained in detail with its overall goals that must be fulfill by HEMS and also provide guidelines for the system development to reduce power consumption at home efficiently. In general, priority of the HAs is also an important study in HEMS [18], but transient behavior issues for detailed analysis are neglected in many papers. To control and maintain stability the detailed behavior analysis is very important. So, we try to consider priority issue in our system. Communication delay and communication interval between SM and HEMS are also key factors in system stability and performance criteria that we should consider as well.

3. System Model

Main breaker of the house is the breaker that the feeder wire connects to. Main breaker is designed to trip if the amperage rating exceeds the value labeled on the breaker. Main breaker is fur-

ther divided into sub-breakers. Sub-breakers are used to extend a feed for multiple branch circuits in whole area of house. From there, the sub breaker connects to outlets, lighting and other loads via individual circuit breakers.
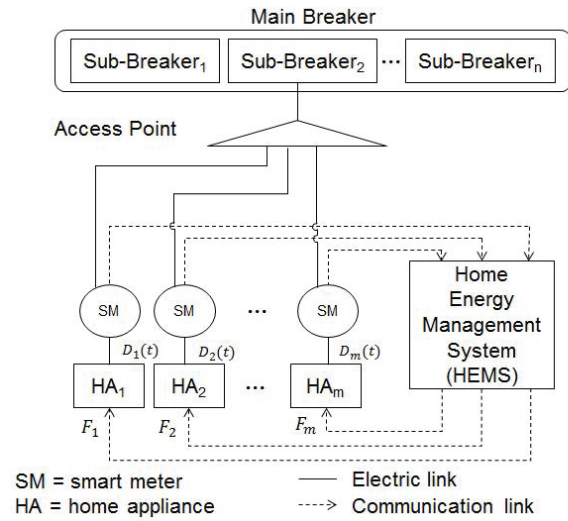

Fig. 2 System overview considered in this paper.

The aim of the proposed system is to study the power assignment scheme for smart home energy management system based on HA. The total power available for HAs is shared based on HA's priority level defined by the home user. The proposed system model consists of HAs, SMs and HEMS. An example is illustrated in Fig.2. We assume that each instantaneous consuming power $D_i(t)$ of HA is modeled by the first order state equation,

$$D_i(t) = -a_i \cdot D_i(t) + a_i \cdot F_i \qquad (1)$$

where parameter a_i decides the response speed, and F_i decides the steady state response (we will call it "target power level"). It is clear that if we assume

$$D_i(0) = D_{init_i}, \qquad (2)$$

$D_i(t)$ will be given as

$$D_i(t) = (D_{init_i} - F_i) \cdot e^{-a_i \cdot t} + F_i \qquad (3)$$

The use of SMs will help us in measuring the instantaneous consuming power levels of HAs called $D_i(t)$ and send this information to HEMS. Then the functions of HEMS are to collect ON/OFF status information from each HA and instantaneous consuming power level $D_i(t)$ from SM. After collecting information, along with HA priority, HEMS computes a target power level for each HA, F_i. Upon receiving a message from HEMS, each HA behave according to the target power level. We additionally consider that a delay $\tau[s]$ is the total time of the sending information

from the SM to the HEMS, the processing time at HEMS, and the sending information from the HEMS to the corresponding HA.

3.1 Priority

The center notion of our proposed model is a priority. We use priorities to share available power among HAs. As some HAs are more important than the other HAs at home, according to this importance criteria we give priorities to the HAs. At first, all important HAs are given high priorities and system will choose the higher priority HAs first to give power as compare to lower priority ones.

3.2 Appliance Type

In our proposed Scheme, we consider two types of HAs (1) Controllable HAs and (2) Uncontrollable HAs. The HAs which belong to Uncontrollable type of HAs, can perform the operation with only one fixed power level. The HA can be turn ON if the available power level is equal to fixed power level of the HA, otherwise HA would be turned off. On the contrary, controllable HAs can perform operation with more than one power levels. If the available power level for the controllable HA is less than the minimum consuming power level of the HA, HA would be turned off.

3.3 Communication interval

As the proposed system works with message exchanges between HAs, SMs and HEMS. For this purpose, we define an interval T_c of consecutive communications between HAs, SMs and HEMS. In Figure 3, we define two time variables, one is global time t and other is local time x in each interval.

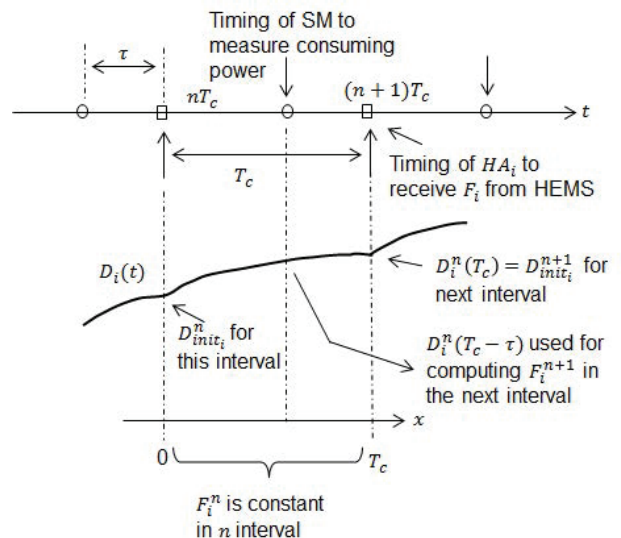An interval starting at nT_c and ending at $(n + 1)T_c$ is called "in-

Fig. 3 Time variables considered.

terval n" and all variables related to interval n are denoted with superscript (n), such as:

$$D_i^{(n)}(x) = \left(D_{init_i}^{(n)} - F_i^{(n)}\right) \cdot e^{-a_i \cdot x} + F_i^{(n)} \qquad (4)$$

Note that $D_{init_i}^{(n)}$ is the initial value $D_i^{(n)}(0)$ of the interval n, and is the same with the last value $D_i^{(n-1)}(T_c)$ of the previous interval $n-1$. T_c is a designer's parameter but $\tau \leq T_c$ is more realistic and should be considered because if $\tau > T_c$, HEMS needs to compute another information which would overlap with the other information. When the communication interval n starts, each HA receives the information of target power level $F_i^{(n)}$ from HEMS, and the last value $D_i^{(n-1)}(T_c)$ is used as $D_{init_i}^{(n)}$ for this interval. Target power level $F_i^{(n)}$ would remain constant during this interval.

3.4 Priority Based Power Sharing (PBPS) Scheme

For our proposed system, we have some assumptions, for example, we have m total no. of HAs and each HA has its given priority level (Pri_i) defined by the home user, maximum consuming power level (D_{imax}) and HA response speed (a_i). We assume that all these parameters are positive. The initial values for $D_i(0)$ and F_i are assumed zero and remaining power $R = P$, where P is the total power available for all HAs.

As HEMS is responsible for calculating the target power level F_i for the HAs based on their priorities. For this purpose HEMS will compute calculated priority (C_{pri_i}) based on ON/OFF status of the HAs and normalized priority (x_i) for re-assigning remaining power to the HAs. The target power level for each HA can be calculated as:

$$F_i^{new} = \begin{cases} D_{imax}, & \text{if } R \cdot x_i + F_i^{old} \geq D_{imax} \\ R \cdot x_i + F_i^{old}, & \text{if } R \cdot x_i + F_i^{old} < D_{imax} \end{cases} \quad (5)$$

The given Eq. (5) work with normalized priority, HEMS re-assigns the remaining power to the HAs according to normalized priority. Where remaining power R can be calculated as,

$$R = P - \sum F_i \quad (6)$$

The normalized priority for each HA can be calculated as:

$$x_i = \frac{C_{pri_i}}{\sum C_{pri_i}} \quad (7)$$

The calculated priority can be calculated as:

$$C_{pri_i} = \begin{cases} 0, & \text{if } F_i = D_{imax} \text{ OR HA is OFF} \\ Pri_i, & \text{if } F_i < D_{imax} \text{ AND HA is ON} \end{cases} \quad (8)$$

If the $\sum C_{Pri_i} = 0$, shows that all the HA_i are OFF or already reached to its maximum consuming power level. If the $\sum C_{Pri_i} > 0$, shows that the calculation of target power level continue calculation. The processing time at HEMS is the calculation time for Eq. (5), (6), (7) and (8). For each communication interval, HEMS calculates the priority of the HA and re-assign remaining power to the HAs. The simulation results shows clearly, the power assignment criteria of HEMS for each HAs.

4. Simulation Results and Discussions

When the total power consumption of HAs is more than the power supply limit, the situation is considered as a critical issue in the system design. In our proposed system, each HA has maximum consuming power level (D_{imax}), response speed (a_i) and priority (Pri_i), the remaining power is fed back to each HA that still need to reach its maximum consuming power level. As the first experiment, we will investigate the basic criteria of power sharing based on the HA priority.

In home we have many HAs, for the simplicity, we will consider only three kitchen appliances. All three HAs are attached with SMs. The first attached HA_1 is kitchen fan with $D_{1max} = 5A$, the second HA_2 is refrigerator with $D_{2max} = 8A$ and third HA_3 is the rice cooker with $D_{3max} = 10A$. The total power available for the HAs is $P = 20A$. At first, we consider the case when all three HAs are turned ON at the same time with system parameter $a_1 = 2, a_2 = 5, a_3 = 8, (i = 1, 2, 3)$ for each HA respectively. We further assume that HA_2 and HA_3 are uncontrollable HAs whether HA_1 is a controllable HA.
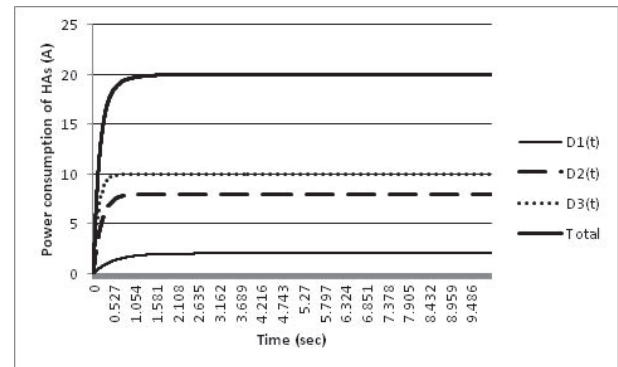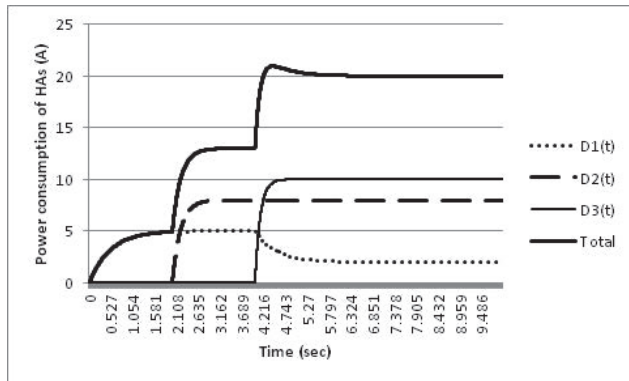

Fig. 4 Power consumption behavior of three HA_s with priorities $Pri_1 = 2$ for HA_1, $Pri_2 = 8$ for HA_2 and $Pri_3 = 10$ for HA_3.

From the Fig. 4, we can observe that by giving high priority to uncontrollable HAs $i.e.$ HA_2 and HA_3, these HAs can take more power from the total power available. The reason is that HEMS calculates the normalized priority based on the given priority levels. The assigned power from HEMS is enough for the uncontrollable HAs to reach their D_{max}. If HEMS have remaining power, it is re-assigned to the HAs that still need to reach D_{max}.

Next, we consider the case when all three HAs are turned ON at different time with same system parameter values a_i, D_{imax} and pri_i which we discuss in Fig.5. As we turn ON HA_3 later with high priority, high response speed and maximum consuming power level, the HA_1 starts decreasing its power to give more power to the high priority HA. The speed of increasing power is very high than the speed of decreasing power, overshoot occur (see Fig.5).

Fig. 5 Power consumption behavior of three HAs with different turn ON time $t = 0$ for HA_1, $t = 2$ for HA_2 and $t = 4$ for HA_3.

At last, we consider the case when all three HAs have same response speed $a_i = 5$. We noticed that the overshoot did not happen. The reason is that the speed of increasing the power level is the same for the HAs with the speed of decreasing. All other parameters are same with the Fig. 5.
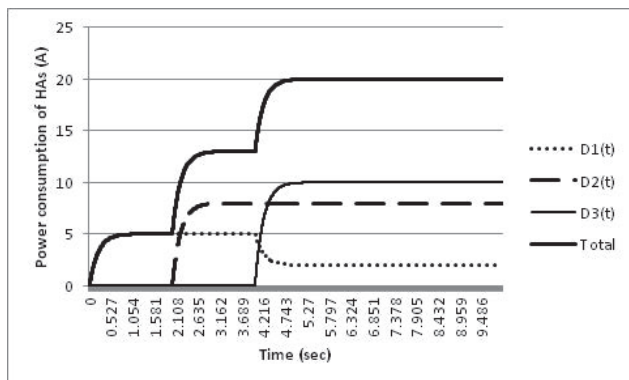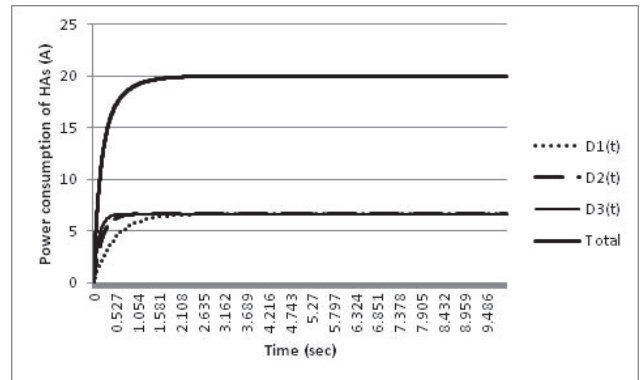

Fig. 6 Power consumption behavior of three HAs with different turn ON time $t = 0$ for HA_1, $t = 2$ for HA_2 and $t = 4$ for HA_3 and $a_i = 5$.

As we can see from the simulations, the total power available for HAs is shared among the HAs based on their priorities. We also notice that if the time constant for each HAs is the same, we can keep the maximum consuming power limit. However, if the time constant for each HA is different, we cannot keep the maximum power limit because the high priority HA has high increasing speed than the lower priority HA.

We also consider some general cases for the better understanding of system parameter (see Fig. 7 and 8)

From Fig. 7, we can observe the effect of system parameter a_i. The maximum consuming power level and priorities for three HAs are same as $D_{imax} = 8$ and $Pri_i = 5$. As all HAs have same priority level, HEMS assign the power to all HAs equally, it depends on the maximum consuming power level of the HAs that which are going to satisfy or not.

In Fig. 8, all HAs have different priority level $Pri_1 = 2$, $Pri_2 = 8$ and $Pri_3 = 15$ respectively. All HAs have different response speed $a_1 = 1$, $a_2 = 5$ and $a_3 = 10$. So, HEMS will assign the power to the HAs according to its priority level. The third HA has the highest value of a, so the increasing speed of

Fig. 7 Power consumption behavior of three HAs with same turn ON time and $a_1 = 1$, $a_2 = 5$ and $a_3 = 10$.
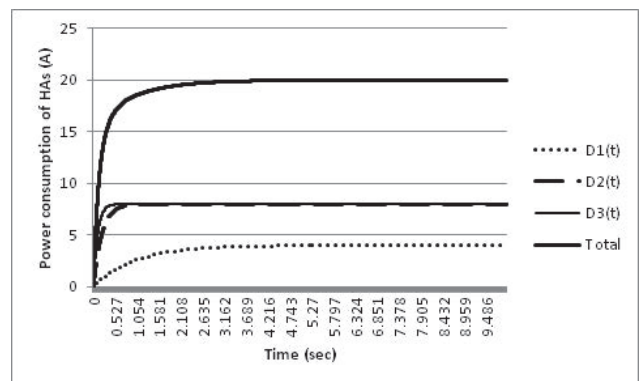
Fig. 8 Power consumption behavior of three HAs with same turn ON time and same $D_{imax} = 8$.

this HA is more fast than other HAs. Depending on each HA priority, more power is assigned to the HA_3, the HA_2 has the second highest priority so second highest part is given to HA_2 and the last remainder of power according to the HA_1 priority is given to lowest priority HA.

5. Conclusion

The efficiency, reliability and stability of the smart home is expected to be significantly improved via home energy management system (HEMS), and smart metr (SM) is the most essential part of the energy management system used to connect individual home appliance (HA) to the energy system of smart home. The introduction of SM has brought a paradigm shift in the analysis of power consumption of HAs in smart home. In this paper, we study the effect of SM that provides access to power supply and demand. The main objective of this paper is to study the power assignment among the HAs based on priorities. To reach above objective, the analyzed the proposed system design in simulation environment. The simulation results showed the dependency of system parameter a_i (appliance response speed), D_{imax} (maximum consuming power level) and Pri_i (appliance priority). We also conduct experiments to show the effect of turn on timing to the system behavior results in overshoot. For our future work, we will try to propose the controlling algorithm for overshoot.

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