CONTROLLING ELECTRICITY CONSUMPTION AT HOME

Smart home

Ahmed S. Abdelwahed
Communications and Computer Department
Benha University
Benha, Egypt

Abdel Halim Zekry
Electronics and Communications Department
Ain Shams University
Cairo, Egypt

Hossam Labib Zayed
Communications and Computer Department
Benha University
Benha, Egypt

Ahmed M. Sayed
Biomedical Engineering Department
Helwan University
Helwan, Egypt

Abstract: Employment of home energy management HEM programs will make the electricity consumption more efficient and smarter. The advantages of HEM are improving and increasing savings bill for consumers as well as utilities, and reducing peak demand and peak to average ratio (PAR). This algorithm is an intelligent HEM for control and manages power consumption household appliances with simulation for demand response (DR) analysis. The proposed algorithm handles household to achieve minimum energy consumption cost and reduce peak load according to their preset priority and guarantees the total household power consumption below certain limit. The methodology is implemented by MATLAB for technical validation and solutions. The accuracy of the tool is illustrated through an example case study for various household scenarios.

Keywords - Demand-Side Management, Home Automation, Home Energy Management, Simulation Tool, Smart Grid.

I. INTRODUCTION

According to the Ministry of Power, [1] it is estimated that Egypt's transmission and distribution losses are about 20 percent of total electricity production. In addition, social behaviour of stealing electricity from the lampposts and overspending in electricity consumption and with the lack of or poor maintenance processes and fuel shortages beside the lack of renewable energy such as wind and solar energy.

To solve the problem of lack of electricity and frequent interruptions there are numerous applications of grid technologies, HEM is probably the most important one to be addressed. Utilities across the globe have taken many steps for efficient electrical consumption. New pricing schemes like, Real Time Pricing (RTP) [2], Shift Load peak by scheduling power [3], Threshold Power by schedule or priority [4], energy consumption scheduler for demand response [5]...etc, have been proposed for smart grid. Distributed Energy Resources (DER) and home appliances coordination along with different tariff schemes requires efficient consumption of electricity.

In our country and environment there are interoperability issues that need to be solved between different appliances among smart appliances and non-smart appliances, i.e. legacy devices, as well. It is expected that current standardization efforts will provide technologies to design smart appliances in order to cope with the current interoperability issues. Although, common electrical devices and actual energy consumption deserve consideration within energy management applications.

This paper discusses the integration of smart and legacy devices into generic system architecture, based on load priority and demand response techniques [4, 5].

Subsequently, the paper elaborates the requirements and components to realize such architecture. The study assesses the feasibility of such an approach with a case study based on a measurement campaign on real households for their integration and management within a HEM system.

II. MATERIAL AND METHODS

A. Reduction of in Line Losses Using Priority of Appliance:

The aim of using appliance priorities is not only to reduce the peak demand but also to reduce the power loses. Additionally, when there is power shortage, some apparatus should stop consuming energy or reduce the consumption. Many apparatus should reduce their power when an energy limit is reached. This can reduce the need for electrical storage or standby generators .So that if a load control device can be applied to shift one peak from the other, not only it reduces the total peak demand but it also improves the load factor, and the line losses in the feeder, which improves the feeder power [4]. Assume two coincident peak loads with the same time duration δt are carried by a line which has a resistance of R Ω. The load currents are Ix and Iy.

The total loss in the system for the duration of the coincident peak is:

$$(Ix + Iy)^2 * R*\delta t \quad (1)$$

$$= (Ix^2 + 2* Ix*Iy + Iy^2) * R*\delta t \quad (2)$$

If the peak loads are controlled with help of home energy consumption (HEC) no coincidences are allowed as shown in Fig.1 and the losses becomes:

$$= (Ix^2 + Iy^2) * R*\delta t \quad (3)$$

If we take the case such that the both load currents are equal (Ix = Iy= I), the total loss in first case becomes:

$$= 4*I^2 * R*\delta t \quad (4)$$

In another case the total loss becomes:

$$= 2*I^2 * R*\delta t \quad (5)$$

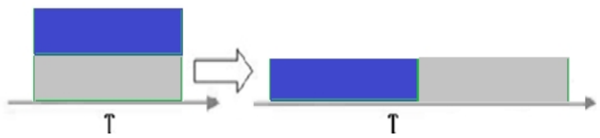

Fig.1. Line losses in two different cases during power scheduling

The difference in the losses in the two cases is 100%. So power scheduling not only reduces the losses but also improves the load factor of the feeder. This type of power scheduling is shown in fig.1.

B. Energy Efficiency and Demand Response:

Energy efficiency (EE) and demand response (DR) are closely related concepts[6]. EE refers to permanent changes to electricity usage through installation of or replacement with more efficient end-use devices or more effective operation of existing devices that reduce the quantity of energy needed to perform a desired function or service. DR is defined as a period during which the customer demand needs to be shortened to relief a system stress condition. Participating customers in a DR program can be informed of a DR event by an external signal from a utility via their process of priority of appliance and estimate power. For our study, we assume that the external signal received by the HEM system is in a form of a demand restriction request (kW) and a number of priorities.

C. Type of Power Appliance:

Each power appliance has its own power consumption characteristics [7], and this section categorizes them into 3 classes.

1. Baseline load is the power consumption of those appliances that must be run immediately at any time, such as lighting.
2. Regular load is related to appliances that are constantly in a running position during a long period, such as air condition.
3. Burst load is the power consumption of those appliances that are operating for a fixed duration and start and stop within the given deadline such as washing machines.

III. The Proposed HEM Algorithm

The purpose of this paper is to show how to turn an ordinary home into a more energy efficient one. The proposed HEM algorithm takes into account both load priority and power consumption, HEM system plays a essential role in achieving automated DR within a house as most residential customers do not have time, nor proactive enough to perform DR manually. An effective HEM system should provide load shifting [8] and shedding ability when needed with the least impact on customer lifestyle during a DR.

A. The HEM Manages Strategy by priority Type:

The first step before the proposed HEM algorithm can operate is for a homeowner to set DL. The HEM algorithm starts with gathering information, which includes the DL and check status, load priority (LP) and appliance power (P_APP) of all appliances, to estimate the total energy consumption (TEC).

Table I: summarizes the parameters used to model this house, which include house structure and appliance characteristics. For this house, the (LP) is set to reflect the importance of appliance and its power characteristics, regardless of whether the device is smart or legacy.

B. Flowchart

The flowchart starts by collecting priorities for all the appliances and separate them into three categories; high priority (most important), medium and low priority (less important).The DL allow running the appliances, as long as the DL is not reached. If the DL is reached, other appliances are not allowed to operate. The flowchart in fig .2, illustrates the proposed HEM framework according to the customer preference settings, ranging from the least important loads to the most important ones to guarantee the requested demand limit.

The flowchart begins with initializing priorities for each appliance and arranging them in an ascending order. Then an additional sorting process within each priority is performed, according to their power. If the operating appliances lead to a TEC less than the DL then the algorithm turn them on. If another load is required to operate then the algorithm loops back again and sees the running appliances to maintain the DL. The process is repeated for the other priorities (1, 2).

The main advantage of the algorithm is turning off appliances having lower priority with higher power, while higher priority appliances are kept running. The proposed settings for each appliance are summarized in Table 1

Appliance	**Load priority (LP)**	**Power Appliance (P_APP)**
Refrigerator	0 , 1 , 2	100 , 190 , 350
Heater	0 , 1 , 2	1200 , 1500 , 1800 , 2000,2500
Iron	0 , 1 , 2	1000 , 1500 , 1700, 2000, 2200
TV	0 , 1 , 2	70 , 90 , 120 , 150
Kettle	0 , 1 , 2	900 , 1100 , 1500 , 1700,2000
Wash **M**achine	0 , 1 , 2	1000 , 1500 , 1800 , 2000
Light	0 , 1 , 2	150 , 350 , 550
Air **C**ondition	0 , 1 , 2	1250 , 1700 , 2250 , 3000, 3750

Table 1: Appliances with their associated priority and power

C. The HEM Software Implementation.

A simulation tool is developed in MATLAB that incorporates the proposed HEM algorithm; the HEM graphical user interface (GUI) and DR-enabled load models are described in the following sections.

The HEM graphical user interface (GUI) is developed as a part of the proposed HEM software as shown in Fig [3]. It serves as a control panel for customers to set and monitor appliances status, appliances power consumption, TEC and DL Customers can use the control panel to change their load priority and preference settings. All parameters shown on the control panel is updated when the user wants to turn an appliance on / off.

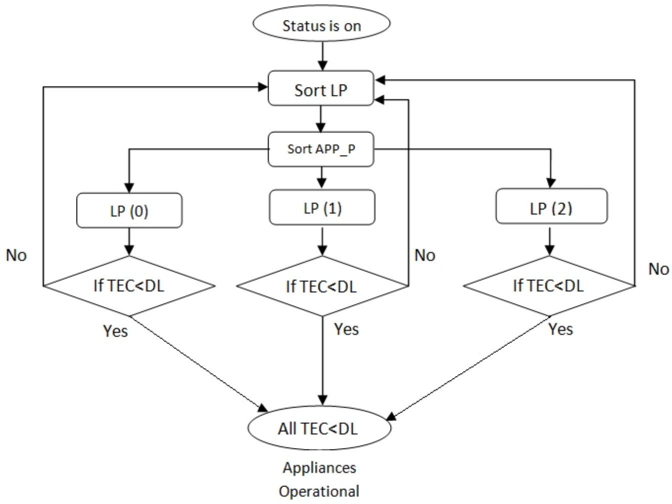

Fig 2. Flowchart of the algorithm

Fig. 3. The HEM graphical user interface (GUI)

D. Demand Response Case Studies:

This section demonstrates the applicability of the developed simulation tool in managing high power consumption appliances and analyzing how much load curtailments are possible for residential customers. This study involves the interpretation of all types of electrical use carried out on an ordinary day that it is believe to be a typical day of a family home. Although each day is a different day, almost every day there is a family routine caused by work, and home activities (cooking, cleaning, leisure and rest). The following appliances: a fridge, an AC, a heater, a few bulbs (for lighting), an Iron, a washing machine, a TV set and a kettle. But we can always estimate an average set adjusted to the normal family needs. Let us take the average home (single-family) in Giza city at Friday in weak end as an example. For this house, the load priority is set as follows: (refrigerator, TV and light) have higher priority (priority of 0), (heater, kettle and AC) have medium priority (priority of 1), (washing machine and iron) which have low priority (priority of 2) because it is used only one time per day.

Appliance	**Priority**	**Power**
Refrigerator	0	350
Heater	1	1500
Iron	2	1500
TV	0	90
Kettle	1	1100
Wash Machine	2	1800
Light	0	350
Air Condition	1	1700

Table 2: select Appliances with priority and power

IV. EXPERIMENT AND RESULTS

A. Simulation Results:

Taking care of our household energy can lower our power costs. In fact, the following results show that it became more energy efficient. The purpose of this simulation is to prove that almost every home has the potential to become more energy-efficient, not from a theoretical point of view, but from a practical one, starting from real data and ending in the savings in the electricity bills. In addition, using electricity more efficiently we will be contributing to a more reliable electricity system and we will be doing our part to help protect the environment.

To illustrate the performance of the proposed HEM algorithm in managing power consumption and keeping the total household use below selected demand limits, simulation of the household performance under no control of HEM is performed by not specifying the DL, then simulation under control of the HEM algorithm is performed by choosing the hourly limits of 2.5 kWh and 3.5 kWh. The results for the three scenarios are shown in Fig. (5, 8, and 11).

As figure 4 shows, it is clear that in the case of not using the algorithm, the average consumption per hour equals 3.19 kWh, many consumption peaks appear because of the lack operation control, which affects the load and energy networks, especially in high demand hours; from (14 to 21) as illustarated in Fig. 5. It is worth mentioning that the continuous use of the AC alone resulted in an energy consumption of about 40kwh per day, as shown in Fig. 6.

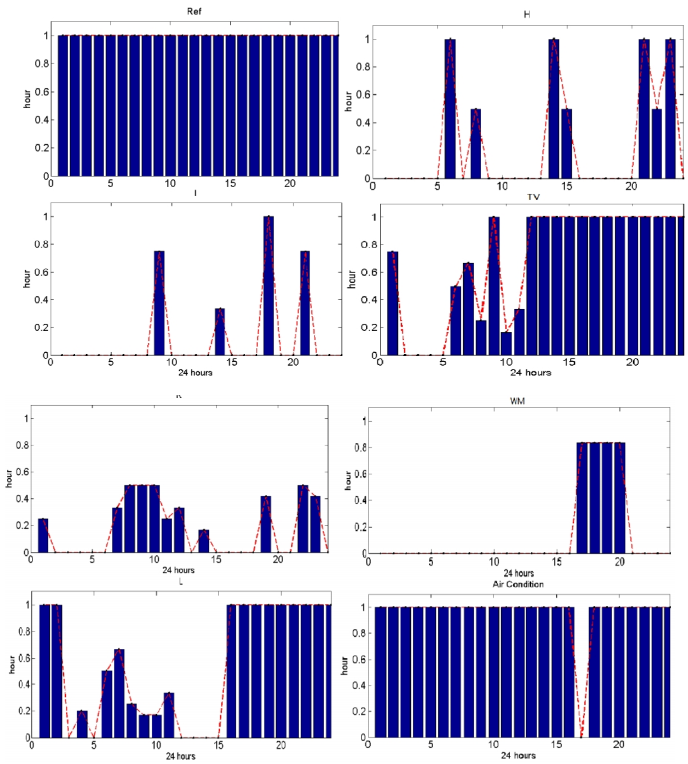

Fig. 4**.** Demand response simulation for all appliances (Ref, H, I, TV, K, WM, L, and AC) without using the HEM algorithm.

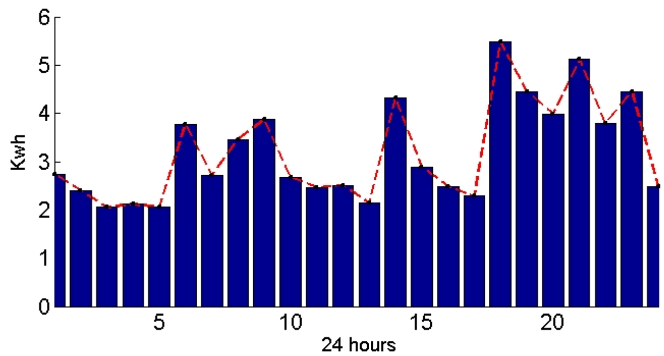

Fig. 5. TEC without using the HEM algorithm

In the next cases, the HEM algorithm is applied by specifying a DL on energy consumption on the same appliances with the same running time, the effect on the consumption rate is so evident.

When applying the algorithm with a DL of 3.5 kWh, according to the load priority and the rate of consumption, some devices was not allowed to operate, especially the heater, iron, Kettle and AC, as shown in Figure 7 and 9. The daily TEC profile became more equalized. In addition the TEC profile exhibits minor peaks, compared with the profile shown in Figure 8 Note that the DL was fulfilled, and a lower average energy consumption rate of 2.33 kWh was achieved, which equals 26% of the consumption rate without HEM control.

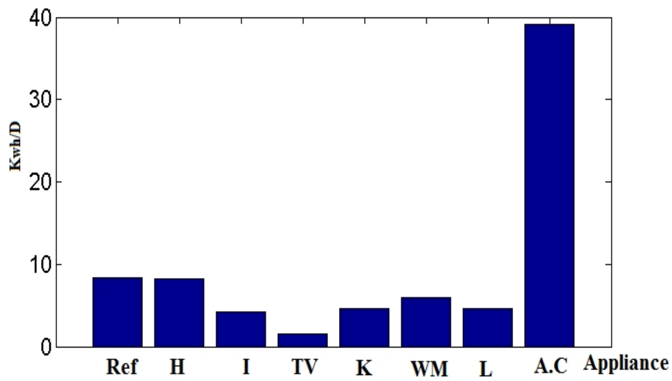

Fig. 6. Energy consumption rate for each device without using the HEM algorithm

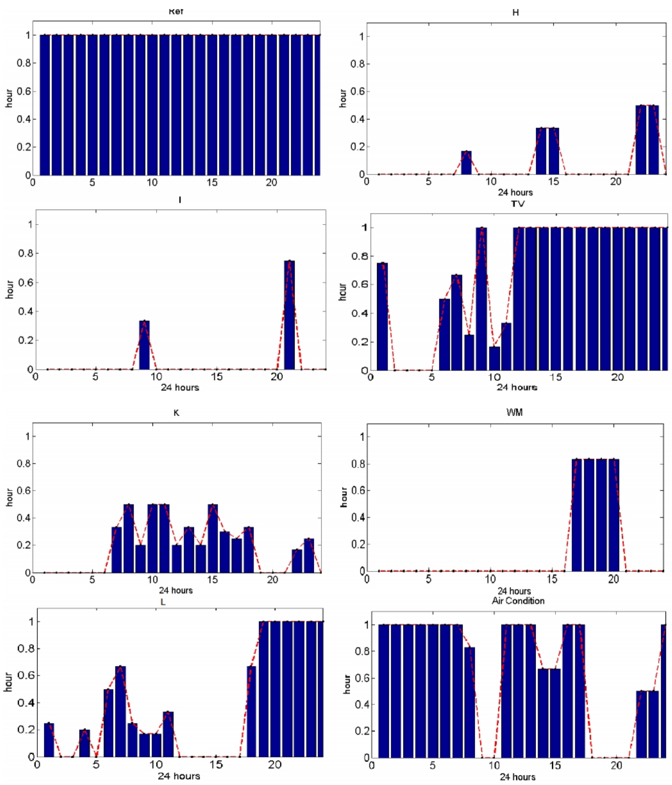

Fig.7**.** Demand response simulation for all appliances (Ref, H, I, TV, K, WM, L, and AC) with use HEM algorithm at DL=3.5 kWh.

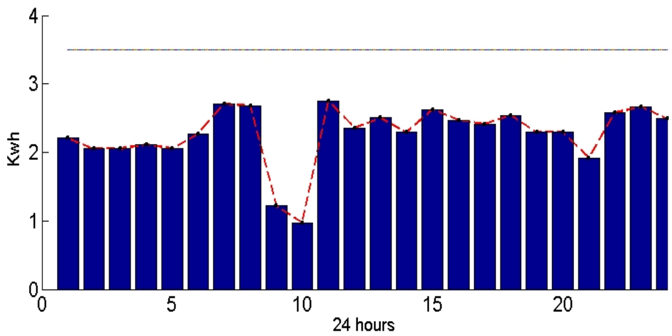

Fig.8**.** TEC with use HEM algorithm at DL = 3.5 kWh

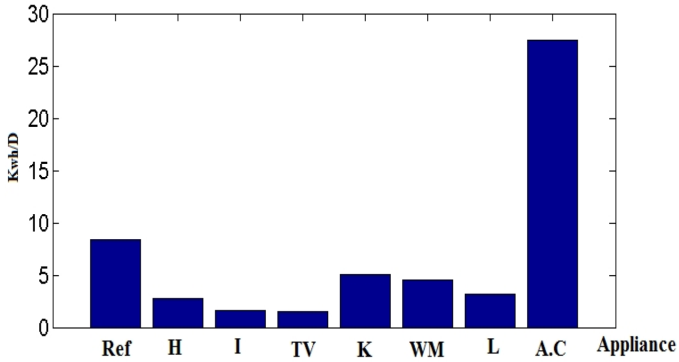

Fig.9. Energy consumption rate for each device in the home with use HEM algorithm at DL = 3.5 kWh

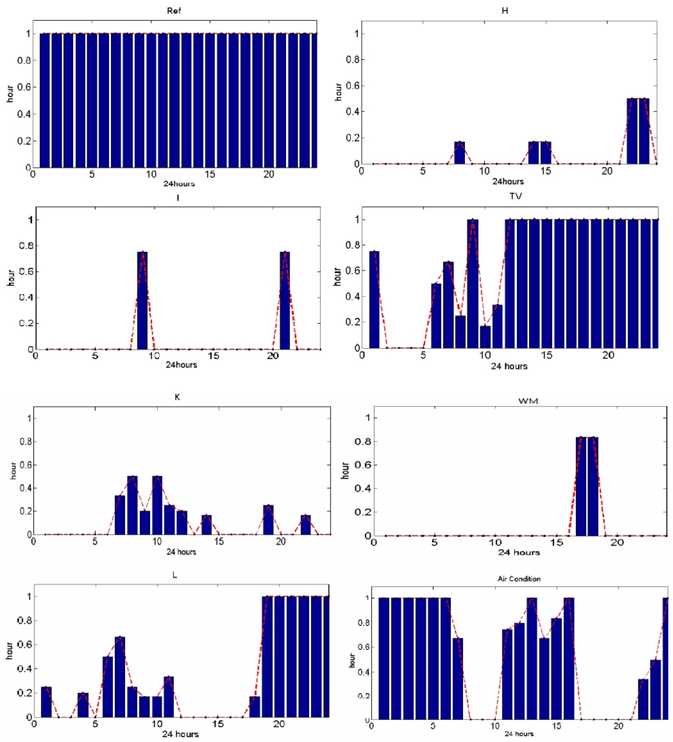

Fig.10. Demand response simulation for all appliances (Ref, H, I, TV, K, WM, L, and AC) with use HEM algorithm at DL=2.5 kWh.

When applying the algorithm with a DL of 2.5 kWh, this results in further reduction in the energy consumption. Again, the DL was fulfilled, and even a lower average energy consumption rate of 1.92 kWh was achieved, which equals 39.5% of the consumption rate without HEM control, as shown in Figures 10 and 12. The daily TEC profile became even more equalized, with almost no consumption peaks, Fig11. This effect would lead to an improved service provided by power companies, including lack of power cuts.

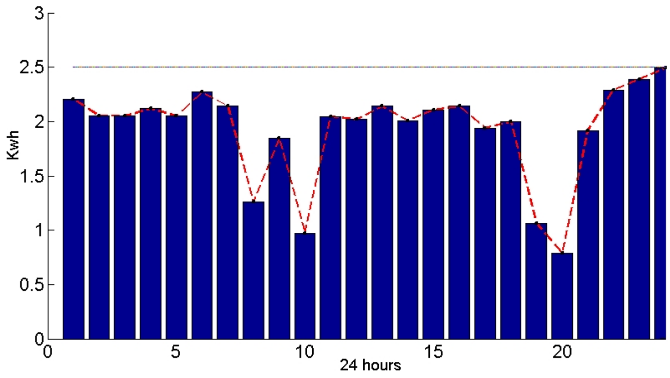

Fig.11. TEC with use HEM algorithm at DL = 2.5 kWh

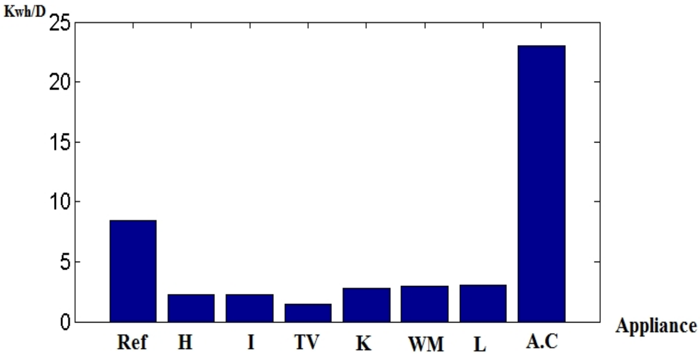

Fig.12. Energy consumption rate for each device in the home with use HEM algorithm at DL = 2.5 kWh

For all cases, three observations are worth mentioning. First, the fridge is always operational, which is normal, as it is continuously connected to power. Second, the highest appliance in the energy consumption is the AC where the consumption rate reached almost 40kW per day without the algorithm and then the consumption fell to about 28kW per day after the application of DL of 3.5kWh, which was further reduced to 23kW per day after applying a DL of 2.5kWh. Third, it should be taken into account devices running under control programs, such as the WM, as it runs according to the program time. Such devices should not be turned off until the control program ends. Therefore, the DL should be chosen carefully when using such devices. In addition greater priorities should be given to such program controlled devices, or as an alternative the operation time of other devices should be reduced. It is necessary to make the load consumption rate lower than the allowable DL, so that no closure occurs for program controlled devices, such as the WM.

IIV. DISCUSSION AND CONCLUSIONS

At this point two interesting observations should be mentioned:

1) The proposed HEM algorithm can effectively keep the total household power consumption below the demand limit requirement for selected loads according to their priority and

the preset comfort level settings [9]. However, if the demand limit is lower than a certain value, some customer's comfort must be sacrificed, e.g. room temperature violation.

2) A low demand limit level may result in adverse effects by preventing programs running on certain appliances, such as washing machines, which may result in reheating the used water, and hence waste some energy.

The two observations indicated above imply that, in any DR event, the demand limit level to be assigned for each house should be carefully chosen; and it should be above a certain value, in order to prevent either: a) a comfort level violation b) wasting some energy while resuming specific appliances' operation when the algorithm allows it to operate.

So, it is worthwhile to investigate the lowest possible demand limit level that can be assigned to a house before any violation can occur.

Constraints on Demand Limits:

The lowest demand limit for a particular house will vary according to:

- Rated power (kW) and type of appliances in a house.
- appliance usage patterns
- Start time and duration of a DR event.
- Comfort level settings or assigned priorities.

In conclusion, this paper presents an intelligent home energy management (HEM) algorithm for demand response applications aiming at reducing the peak load in individual homes and evaluated the performance of power consumption. The model incorporates the load priority, power appliance, actuation time, and the consumption profile. Simulation results show that the proposed HEM algorithm can proactively and effectively control and manage the appliance operation to keep the total household consumption below a specified demand limit. The proposed HEM algorithm takes into account both load priority and power consumption that this scheme is able to reduce the peak load by up to 26.1%, compared without HEM.

Simulation results indicate that at a low demand limit level, the energy consumption profile has been equalized, although the HEM was able to keep the total household demand below a certain limit, appliance may need to turn off to save DL. This implies that there is a limit on how much DR can be performed. This paper analyzes this limit and demonstrates that DR potential is a function of customer comfort preference and the demand limit level that does not cause high load compensation after a DR event. It is expected that the results of this work can benefit electrical distribution utilities and DR aggregators in providing an insight into the limits and potentials of DR available in residential markets.

Our future work will consider judging the system performance would include calculation of energy savings, customer satisfaction questionnaires, and customer interactions with system. Also, automatic detection of the appliances power ratings will be considered, which can be done through the use of power meters.

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