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Professional paper

AN INTELLIGENT SMART HOME ENERGY MANAGEMENT ALGORITHM

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Abstract

Increased power demand and integration of renewable energy sources is impossible with today's power grid infrastructure. To overcome these problems, smart grid is the new solution which is more reliable, flexible and controllable. Home energy management system (HEMS) in the smart home allows the customer to control, optimize and monitor the energy consumption. In this paper, a brief overview on the architecture and functional modules of smart HEMS is presented. Then, the advanced HEMS infrastructures and home appliances in smart houses are thoroughly analyzed and reviewed. This paper presents an intelligent HEM algorithm for managing high power consumption household appliances. The proposed algorithm manages household loads according to their preset priority and guarantees the total household power consumption below certain levels. The home server monitors and controls the energy consumption and controls the home energy use to reduce the energy cost. The remote energy management server aggregates the energy information from the home servers, compares them and creates statistical analysis information.

Keywords: Smart Home Energy Management System, Control Algorithm, load priority

1. Introduction

Smart grid is the integration network of information, communication and network technologies, which is able to utilize the electrical energy efficiently, sustainably, reliably and safely. The features of this power system should be more attractive, secure, reliable and intelligent comparing to the existing systems. A smart HEMS is a system between home appliances and energy providers to optimize energy consumption. Smart homes are characterized by the presence of smart devices, which give the opportunity to monitor and to remotely control key equipment within homes. Renewable energy sources (RES), such as wind power, solar power and fuel cell etc., should be utilized to fulfill energy demand as well as conventional energy sources based mainly on fossil fuels. A challenge is by integrating RES into the grid and increasing power demand causes the redesigning of the conventional power system architecture and infrastructure.

With the increased concerns on global energy security and environmental emissions, more and more distributed renewable energy generations, such as wind turbines, solar panels, and plug-in electric vehicles (PEVs), etc., would be grid-integrated into the active distribution networks. Coupled with the rapid development in advanced power electronics and alternative energy technologies, building renewable and stored energy sources installed at the residential premises can be incorporated in SHEMS to improve the home efficiency of energy conversion and utilization [1].

One of the main research areas in the smart grid is energy management applications. Energy management applications provide several benefits to both utilities and consumers. Utilities are able to improve power with higher reliability and stability, and lower operational costs while consumers can utilize the energy in cost saving way. Another important valuable benefit with respect to environmental issues is reducing the greenhouse gas emission. Several demand response (DR) programs are widely implemented on the commercial and industrial side [2].

SHEMS is an essential home system for the successful demand-side management of smart grids [3]. It monitors and arranges various home appliances in real-time, based on user's preferences via the human–machine interface in smart houses, in order to conserve electricity cost and improve energy utilization efficiency [4,5,6].

SHEM system, as important part of smart grid, provides a number of benefits such as savings in the electricity bill, reduction demand in high rate and meeting the demand side requirements.

Several SHEM algorithms by which consumers are able to manage their electricity consumption have been proposed in the literature [7, 8, 9,10,11]. These algorithms are based on different methods such as: load shifting, optimal scheduling, charges the battery from renewable sources and from the grid during low rate period etc. Operating and duration time of home appliances can be shifted by load shifting and optimal scheduling methods [12]. Many of SHEMS consider only grid supply. In [13], is proposed an optimal model for SHEMS in which wind and solar power sources are considered.
This paper proposes a SHEMS framework that includes loads, batteries, and renewable generation interconnected with the grid through a home server. The proposed SHEM control algorithm uses load shifting for smart homes. The algorithm schedules the operation of home appliances, batteries, and renewable generation as well as the optimal power distribution among loads, batteries, renewable sources, and power grids.

2. Architecture of smart home energy management system

2.1 Home Appliances: To implement optimal or coordinated planning strategies of devices, smart home appliances should be divides into two groups:

- Non-schedulable home appliances, e.g. fridge, printer, microwave, TV, hair dryer, lights, computers;
- Schedulable home appliances, which can be scheduled for an optimal function or switched on/off at any time, e.g. water heater, air conditioner, clothes dryer, electric vehicle (EV). [14]

Devices which can perform their work in an automated form, such as the air conditioner and boiler, are schedulable. Whereas, non-schedulable devices, such as: lights, computers and TVs, rely on manual control to complete their operation and are needed only when users are at home. The users' comfort is quite sensitive towards services of non-schedulable devices at a real time.

Energy management researchers predict that the amount of EV will increase in a near future, which would help reduce air pollutants and greenhouse gas emissions (GHG) [15]. Since EV can be charged or discharged when connected to the power grid, an increasing number of practical services can now be realized in the power grid [16]. Vehicle-to-grid, as a new concept, enables the transmission of the stored power in the EV battery to the power grid [17-19]. In a SHEMS, EV is able to balance the energy at high rates, which means that EV can supply energy during high rates, while consumer consumes energy during low rates period.

2.2 Home Server: The home server manages all EMCUs installed on each outlet and on the light switch via ZigBee, Wi-Fi, UTP/ FTP cable. It also controls and monitors the performance of all EMCUs through control elements. The control table manages the home appliances and lights connected to the EMCU. Through this control table, the home server identifies home appliances and lighting. The data related to power consumption of appliances and lighting is stored in the database, so the aggregated data are accumulated at every moment. The energy consumption manager (ECM) continuously analyzes the data collected on a daily, weekly and monthly basis [14].

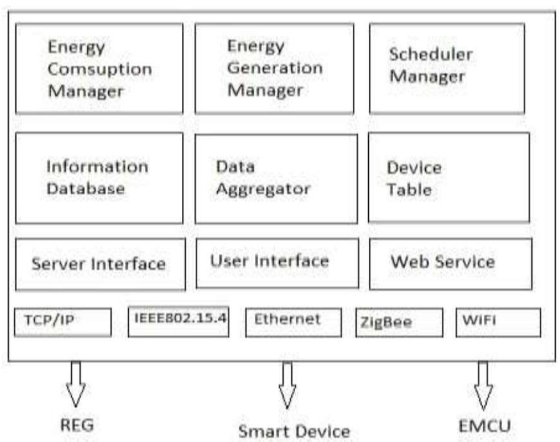

Figure 1. Function blocks of a home server [14]

The user interface (UI) in smart homes provides sufficient information to home users about energy consumption. The UI shows the energy consumption information over time. Users can check and browse energy usage of each appliance and each light. The home server provides information to smart devices on request, and they access it through smart applications. The home server transfers the home energy information to the REMS, which manages several client-homes.

2.3 Energy Management and Communication Unit (EMCU: EMCU belongs to the energy consuming devices and consists of measurement and communication blocks. The measurement device block measures the consumed energy and the power factor of home appliances [14]. The power measurement is carried with UI measuring factor. The measurement block stores the information and calculates the power and power factor on demand. The measurement block, in its content, includes also the power control block which enables switching on or blocking the electric appliance to the connection to the electric energy. The communication device block enables the transfer of aggregated information between the EMCU and the home server. This communication is enabled by ZigBee, Wi-fi or UTP/STP cable and it transfers data about the voltage, current, power and power factor.

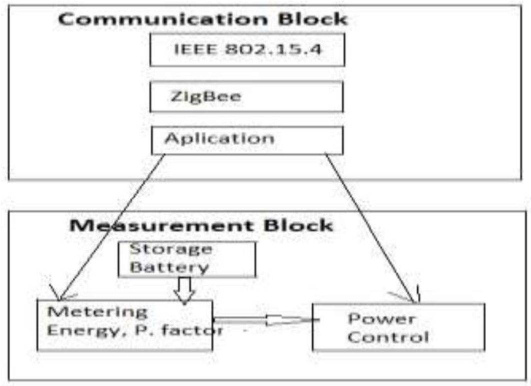

Figure 2. Function block of Energy measurement and communication unit (EMCU) [14]

2.4 Remote Energy Management Server (REMS): The home server from each home transfers the aggregated home energy information to the REMS [14]. The REMS aggregates all energy information from each home server, from which it aggregates data on the energy consumption by home appliances and lights. All aggregated information is stored in the information database, from where, the REMS calculates the average, maximum, minimum of every home appliance. These calculated values help to create a standard energy usage pattern, which serves as a comparing pattern related to energy consumption by different clients.

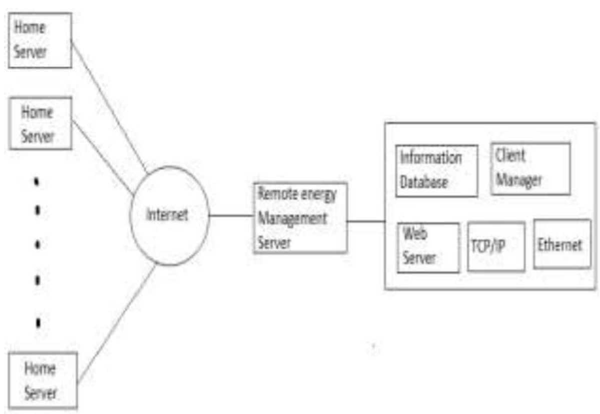

Figure 3. Function block of Remote energy management server [14]

3. The Proposed SHEM Algorithm

An SHEMS plays an important role in achieving automated Demand Response (DR) within a smart house, as most residential customers do not have enough time, to perform DR manually. An effective SHEMS should manage load shifting with the least impact on customer lifestyle during a DR event.

3.1 A demand response (DR): with a DR period, customers can be informed of a DR event by an external signal from a utility via their smart meters. For our study, we assume that the external signal received by the SHEM system is in a form of a demand request (kW) and duration (hours).

Appliances of non-schedulable categories are managed by the SHEM algorithm and can be switched to power when necessary and their work cannot be interrupted by the SHEM algorithm. The SHEM algorithm also manages schedulable appliances, whose operation can be shifted.

If SHEMS receives any external signal, where a request for power with a certain duration is included, then the algorithm is responsible to guarantee the smart home power general consumption under the specified level of demand (kW) during the specified duration (hours).This level of demand limit can change every 15 or 30 minutes, depending on system requirements. The high-power consumption appliances that should be managed by SHEMS are the schedulable group appliances: water heater, air conditioner, clothes dryer and electric vehicle charger. Critical load should be monitored at all times so it is not exceeded. The proposed SHEM algorithm allows the costumer to operate the appliances according to priority (Table 1)under the condition that the total smart home power consumption remains below the limit specified by the demand response. At the same time, the algorithm takes into account the load priority and customer preference.

Table 1. Load priority and preference settings in smart house

Appliance	Load Priority	Preference Data
Water Heater	1	Water temperature: 50ºC—70ºC
Air Conditioner	2	Home temperature:18ºC—25ºC
Clothes Dryer	3	Maximum OFF time: 15 min Minimum ON time: 15 min
EV	4	Fully charged by 9 AM

3.2 Load Priority and Customer Preferences: The first step for the proposed SHEM algorithm functioning is determining the load priority and customer preferences. An example of the load priority and preference parameters is shown in Table 1.As shown for this house, the water heater (WH) has the highest priority. It is followed by the space cooling device (AC), the clothes dryer (CD) and finally the electric vehicle. The level of preferences can be adjusted for each appliance within a certain interval. For the water heater, the preference of hot water temperature can be set, e.g., between 50ºC —70ºC. For the air conditioner (AC), the room temperature preference can be specified, e.g., between 18ºC — 25ºC. For the clothes dryer, the costumer can specify its complete time and the maximum heating temperature. For the electric vehicle, the costumer can specify the time of charging the EV, e.g. after 9am.

3.3 HEM Control Strategy by Appliance Type: The specified limit of power quantity demand is an important factor in determining the status of appliances in the algorithm. Exceeding the demand limit will result in disconnection of selected appliances based on their priority. Customer preferences are allowed to be violated from the less important loads to the most important ones to guarantee the maximum demand limit. The functioning of each appliance according to SHEM algorithm are presented below.

1) *Electric Water Heater (WH):* The water heater can be set for a temperature interval. When the hot water temperature falls below the minimum required temperature (T_{WHS}-ΔT_{WH}) then WH is ON. If the water temperature reaches the required temperature, WH is OFF. If the water temperature is between the interval, $T_{WHS}-\Delta T_{WH} \leq T_{WHN}$ then it keeps their previous status.

$$S_{WHN}=\begin{cases} S_{WHN-1}, & T_{WHS}-\Delta T_{WH} \leq T_{WHN} \\ 1, & T_{WHN}<T_{WHS}-\Delta T_{WH} \\ 0, & T_{WHN}>T_{WHS} \end{cases} \tag{1}$$

Where:

T_{WHS}- hot water temperature set point (ºC)

ΔT_{WH} - temperature tolerance (ºC)

T_{WHN}- hot water temperature in time interval *n*(ºC)

S_{WHN}-WH status in time interval *n*(0—OFF, 1—ON)

SHEM Control Strategy for WH:–If load limit reaches critical value in a smart home and WH is on, then SHEM algorithm required WH turn off according to load priority. Thus, is WH has the highest priority it will be the last appliance to be turned off.

2) *Air Conditioner (AC)*:When air temperature in the smart home exceeds the maximum allowable temperature $T_{ACS}+\Delta T_{AC}$,the air conditioner (AC) will turn on, thus the air temperature will gradually decrease.When the air temperature is below$T_{ACS}-\Delta T_{AC}$, AC will turn off.When the air temperature is within the interval$T_{ACS}-\Delta T_{AC} \leq T_{ACN} \leq T_{ACS}+\Delta T_{AC}$, the state of the air cooler will remain unchanged.

$$S_{ACN}=\begin{cases} S_{ACN-1}, & T_{ACS}-\Delta T_{AC} \leq T_{ACN} \leq T_{ACS}+\Delta T_{AC} \\ 1, & T_{ACN}>T_{ACS}+\Delta T_{AC} \\ 0, & T_{ACN}<T_{ACS}-\Delta T_{AC} \end{cases} \tag{2}$$

Where:

T_{ACS}- room temperature set point(ºC)

ΔT_{AC}- time interval (ºC)

T_{ACN}-room temperature in time interval n (ºC)

S_{ACN}-AC status in time interval n (0—OFF, 1—ON)

SHEM Control Strategy for AC: - If the critical power consumption limit is achieved on this house and the air conditioner (AC) is on, the SHEMS allows turning off the cooling device according to the set priority. If the air temperature exceeds the set level, the air conditioner will be turned on to keep the temperature at the set level, but under the condition that the total amount of power consumption does not exceed the maximum energy consumption level.

3) *Clothes Dryer (CD)*: CD consists of 2 parts: a rotating part with low power consumption (300-500W) and drying part with high power consumption (3-4KW). CD should be turned on to power for the set time for the drying process to be completed. If any interruption occurs, then CD will be turned on until the accumulated time is reached.

$$S_{CDN} = \begin{cases} 0 & CT_n \geq CT_{max} \\ 1, & CT_n < CT_{max} \end{cases} \tag{3}$$

Where:

CT_n -Clothes dryer's accumulated ON time (minutes)

CT_{max} - Clothes dryer's required ON time (minutes)

S_{CDN}- Clothes dryer status (0—OFF, 1—ON)

SHEM Control Strategy for CD: SHEM algorithm controls the CD by turning of the drying part, while leaving running the rotating motor to continue the drying process without any interventions by the owner (if there was an interruption prior to drying process is completed). In case of turn off, the turning off time should be set for which CD will not lose the temperature critical point. This necessary turn off is allowed if any other appliance of higher priority must operate and for which the power consumption maximum load is reached.

4) *Electric Vehicle (EV):* A plugged EV will be charged until its battery's state of charge will reach the maximum state of charge (SOC_{max})

$$S_{EVN} = \begin{cases} 0 & SOC_n \geq SOC_{max} \\ 1, & SOC_n < SOC_{max} \end{cases} \tag{4}$$

Where:

SOC_n- battery state of charge in time interval n(%)

SOC_{max} -maximum battery state of charge (%)

S_{EVN} -EV status in time interval n (0—OFF, 1—ON)

SHEM Control Strategy for EV: Considering the lowest priority of EV battery charge and not exceeding the maximum consumption by a smart home, SHEM algorithm allows EV battery charge at several intervals. Therefore, if the operation of any appliance of higher priority is required then the EV battery charge can be shifted.

3.4 SHEM Load Management Algorithm: The proposed SHEM algorithm manages every appliance through the gathered information at each interval, such as: total power consumption by all appliances, load priority of appliance operation and customer preference settings, water and room temperatures, demand limit and duration. This means that the SHEM algorithm controls:

1. Water temperatures for the WH
2. Space temperatures for the air conditioner unit
3. The required ON time, the maximum OFF time and the minimum ON time for the clothes dryer
4. The fully charge time and the minimum charge time requested for the EV.

Based on this information, SHEM algorithm decides to change the status of an appliance, by sending control signals to the selected appliance. The total power consumption is compared to the demand limit. If thetotal power consumption is lower than the demand limit then no action is taken, namely no appliance is turned off. If the total power consumption is higher than the demand limit then SHEM algorithm compares priorities of all turned appliances and will turn off the appliance with the lowest priority in order to maintain the level of power consumption under the demand limit. Flow chart of SHEM algorithm is presented in figure 4.

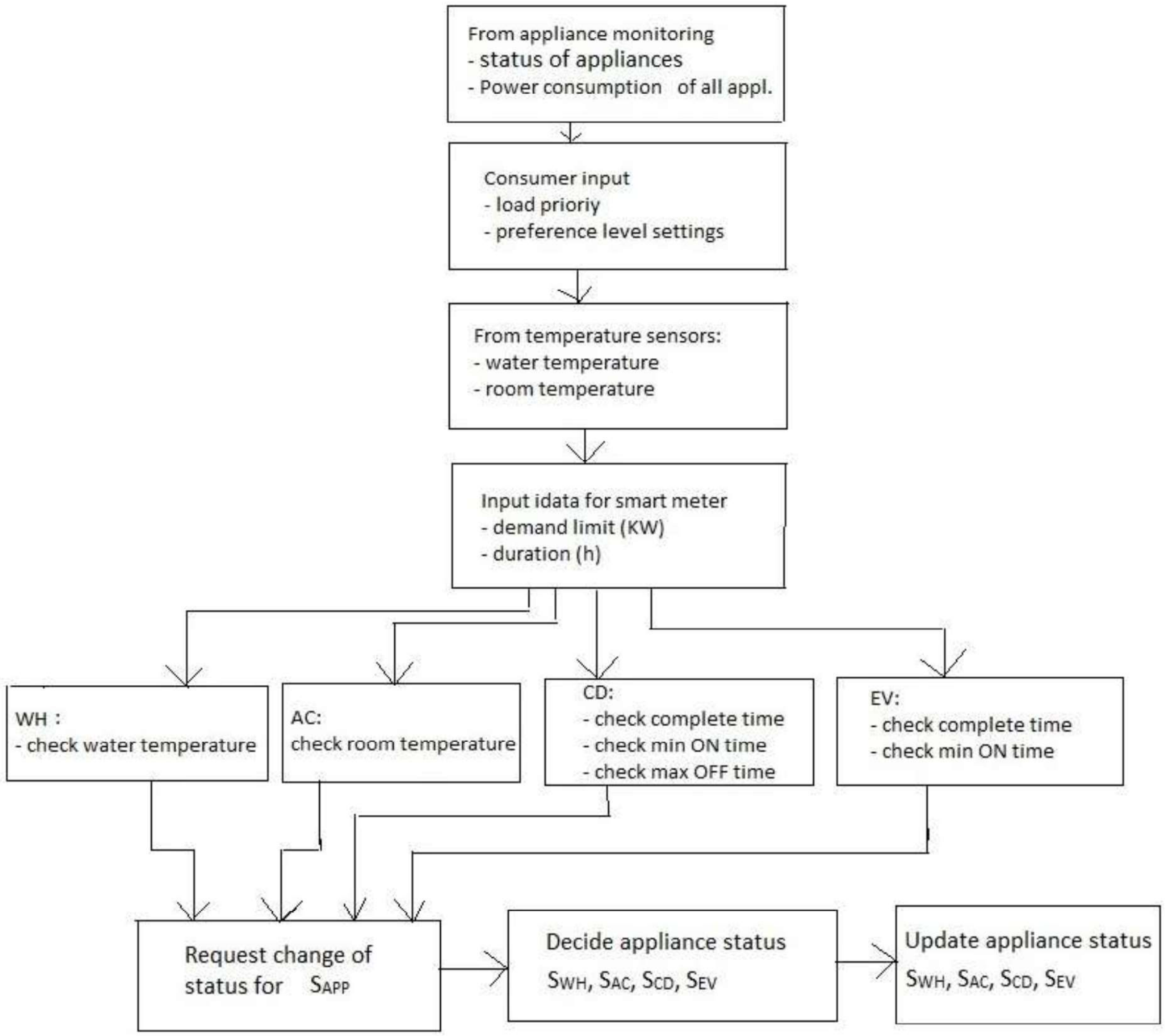

Figure 4. SHEM algorithm flow chart

4. Conclusion

This paper presents a new intelligent smart home energy management (SHEM) algorithm for demand response applications, implemented in the description system architecture. The proposed SHEM algorithm effectively control and manage the appliance operation to keep the total household consumption below a specified demand limit. The proposed SHEM algorithm takes into account both load priority and customer preferences settings. SHEM algorithm is designed to keep the total household demand below the limit level, customers may need to sacrifice their comfort preferences (i.e., water temperature, room temperature exceeds the preference setting).

In this paper, a theoretic detailed description of the algorithm for home energy management is done. The practical implementation of the algorithm will be realized in the future since it presents a very complex system, especially the architecture of the control system. The architecture of the control system, which we have chosen for the implementation of the SHEM algorithm, is also described in this paper. We will have closer values of cost reduction after the practical implementation of the algorithm.

In the future, building upon the simulation results of this study, we will continue to develop our home energy management algorithm using the real smart home prototype. So the performance of the algorithm would be evaluated in real environment.

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