International Journal of Mechatronics, Electrical and Computer Technology (IJMEC)
ISSN: 2305-0543 (Online), ISSN: 2411-6173 (Print)
Vol. 11 (42), Oct. 2021, pp. 5091-5094

Energy Consumption Scheduling in the Presence of Home Energy Management System

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Abstract— providing an optimal and automated framework for home load planning with the aim of achieving the lowest payment cost to home consumers is one of the future goals for optimal load management. With optimal energy planning of controllable loads in the home can be shifted productive periods with high electricity prices to periods of low electricity. The Home Energy Management System (HEMS) is the main solution for smart home energy management, which is a two-way communication between the smart meter in the home and the electricity distribution company operator. This paper presents an efficient model for optimal planning of electrical energy management in a smart home by considering controllable and uncontrollable loads in order to reduce the cost of electricity consumption of a smart home. The modelling results of this study have been simulated by Gams software.

Keywords— smart home, energy efficient planning, controllable loads, uncontrollable loads, home energy management system

I. INTRODUCTION

Electricity distribution companies offer incentives in the form of tariff reductions to encourage home consumers to participate in consumption management programs, and consumers respond to the distribution company's request through the HEMS system. This two-way communication between the home energy management system and the microgrid operator requires telecommunication infrastructure at different levels of home, local and large scale. Automatic control of household loads in terms of reducing consumer costs by home energy management system, convinces consumers to participate in consumption management. In the home energy management process, part of the energy consumption by household loads may be transferred to other time periods. Of course, in this process, a multi-price electricity tariff has a great impact on this management. In fact, consumers respond to this change in electricity prices [1]. In the energy management process, the operation time of smart equipment and home load response is managed to achieve a smooth curve. Therefore, the home energy management system will play a major role in the optimal planning of the operation of distribution networks at the medium pressure level. The HEMS system is in fact the main solution for managing energy distributed at low voltage levels on the home subscriber's side. The HEMS system consists of an intelligent meter (SM), a home controller (HC) and distributed actuators installed on home appliances. In fact, HC processes the burden-sharing issue from the end-user perspective [2]. Power Generating Companies (GENCOs) and Power Distribution Companies (DISCOs) submit their bids to the Day A-Head Market (DAM) based on their projected load and output. Therefore, the target market is settled by an independent and non-profit system operator (ISO) and prices are announced to market participants. Therefore, distribution companies offer retail tariffs to end users and retailers based on wholesale market prices. In the smart home, the smart meter receives price information via a local area network (LAN), then the home control system associated with each of the smart meters is responsible for controlling home loads and setting performance for appliances and other available equipment. In other words, the home control system announces the issue of cargo operation taking into account time-varying tariffs. In the proposed structure, control signals are transmitted from the home control system to the controllable equipment through a home network (HAN) [3]. The HEMS system plays a key role in the implementation of energy management programs in the field of home loads [4]. Energy management programs encourage residential consumers to participate in price-based management programs [5]. In the price-oriented method, the energy controller controls the smart home appliances in order to respond to the price signal at any time interval. Therefore, prioritization on the importance of home loads in responding to these incentive signals is managed and planned by the distribution company through the home energy management system. One of the tasks of the HME system is the integrated management of home loads in responding to the price signal [4]. In fact, the HEMS system is the main controller of all devices and equipment in a smart home. Therefore, by entering the received information such as price signal through smart meter and through the implementation of optimal management programs that are embedded in the home energy management system software, optimal control signals for all equipment such as smart thermostat, car washing machine, dishwasher, dryer and other intelligent equipment are extracted [6]. According to the above topics, the main equipment that is necessary for consumption management are smart meters that must, in addition to measuring the basic parameters, be able to measure other parameters such as manipulations, production harmonics of subscribers and the network. Have the ability to receive and send subscribers and many parameters. Other equipment includes in-home display

Article History:
Received Date: Jul. 17, 2021, Accepted Date: Sep. 06, 2021, Available Online: Oct. 01, 2021

(IHD), which is used to display consumption information in a shared area and for optimal control and management of consumption by the consumer. Smart thermostat or programmable telecommunication thermostat (PCT) is another essential equipment that controls the cooling and heating systems in homes. Finally, there is smart home electrical appliances, some of which are controllable and programmable, while others are uncontrollable and unplanned. The HEMS system is responsible for controlling all household appliances in order to reduce the cost of household energy consumption. Home appliances are basically divided into two groups: controllable and price sensitive, as well as uncontrollable and therefore insensitive to price. Price-sensitive home appliances can be used optimally to reduce consumer electricity costs. The home load controller and optimizer actually provides the optimal decision for the response time of the responsive equipment. One of the load response programs for managing household load consumption is Direct Load Control (DLC) program. DLC is actually performed by the distribution company, managing the time of consumption of household loads, including turning off specific household appliances as controllable equipment at certain intervals [7]. This is done based on an agreement between the distribution company and the volunteer consumers, which determines the controllable equipment and the number of time intervals during which the machine can be controlled.

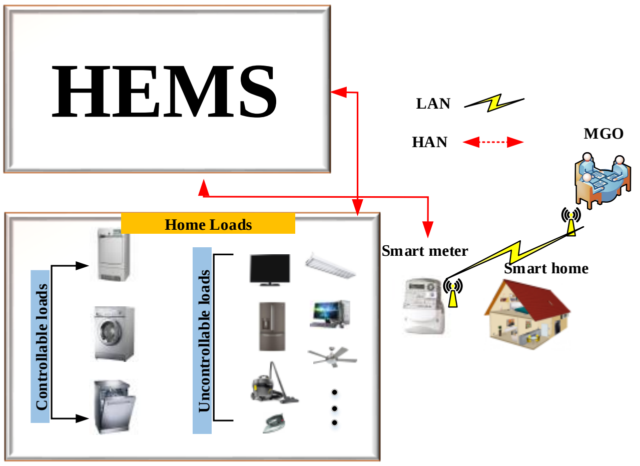

FIGURE 1- HEMS IN A SMART HOME.

II. MODELING OF THE STUDIED SYSTEM

The HEM system presented in this study is expressed as an energy cost reduction function. In this function, the total energy cost (EC) of the smart home along with the home appliances in the home is optimized as follows.

$$TEC = \sum_{t\in T}\left(Per_t^{E^{total}} \times \varphi_t\right) \qquad (1)$$

In this equation, t and T represent the index and time periods, respectively. $Per_t^{E^{total}}$ and φ_t shows energy consumption in period t which is equal to percentage of peak load and electricity tariffs, respectively.

Total energy consumption in each time interval t which is equal to percentage of peak load is expressed based on the energy consumption of home appliances in the following relation.

$$Per_t^{E^{total}} = x\%\left[\overbrace{E_t^{fixed}}^{1} + \overbrace{\sum_{i\in I}\left(E_i^C \times \Delta_{i,t}\right)}^{2}\right] \qquad \forall t \qquad (2)$$

In this equation X% is the percentage of peak load which is equal to 1. The first part of this equation shows the total energy consumption of uncontrollable loads in each time interval t. The second part is related to controllable loads of energy consumption time periods, where i and I are related to controllable load index. Also, E_i^C is the amount of energy consumption of controllable loads. In this section, $\Delta_{i,t}$ is a binary variable that is used for the i-th load in the t-th interval, which if 1 indicates that the i-th load is on. The status vector for i-th load is shown in the following equation.

$$\Delta_i = \left[\Delta_{i,1}, \Delta_{i,2}, \cdots \Delta_{i,T}\right] \qquad \forall i \qquad (3)$$

In a residential home, there are various sections such as living room, kitchen, study room, etc., which are equipped with electrical appliances. The list of smart home electrical appliances is reported in Article [9], which includes controllable appliances that can be changed for the duration of their use, as well as uncontrollable loads whose consumption period is unchangeable. In the case of controllable loads, the allowable intervals for the use of these devices are considered as follows.

$$\sum_{t=e_i}^{f_i} \Delta_{i,t} = \Theta_i \qquad \forall i \qquad (4)$$

In this regard, ei and fi, respectively, indicate the start and end times of the use of the controllable electrical device i. Θ_i *is* the operating time required for i-th electrical device. Due to the above relation, the binary variable related to any electrical device that is specified outside the range is considered equal to zero. For programming any electrical device that works without interruption, the time interval considered should be continuous and uninterrupted. Therefore, the following relations are considered for each i-th device.

$$\Upsilon_{i,t} - \zeta_{i,t} = \Delta_{i,t} - \Delta_{i,t-1} \qquad \forall i,t \qquad (5)$$

$$\sum_{t\in T} \Upsilon_{i,t} = 1 \qquad \forall i \qquad (6)$$

$$\Upsilon_{i,t} + \zeta_{i,t} \le 1 \qquad \forall i,t \qquad (7)$$

In these relations, $\Upsilon_{i,t}$ and $\zeta_{i,t}$ are the binary variables determine the start-up and shutdown of i-th electrical device, respectively. $\Upsilon_{i,t} = 1$ means turning on i-th device at time t

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EISSN: 2305-0543, PISSN: 2411-6173

and turning off i-th device at time t. $\zeta_{i,t} = 1$ is the amount of energy flowing from the mains to the smart home must be limited. Lack of restrictions on energy consumption of any smart home creates technical barriers such as load density and peak load at different time intervals [10]. To prevent such problems in distribution networks, the energy consumption limit for each home is considered as follows.

$$0 \leq Per_t^{E^{total}} \leq Per_{t,\max}^{E^{total}} \qquad \forall t \tag{8}$$

In this regard $Per_{t,\max}^{E^{total}}$ is the maximum amount of energy that each smart home can receive from the main grid at any time interval t.

III. Simulation Results

A standard three-level TOU electricity tariff is considered as in Figure 2. As can be seen in this study, a time interval of 10 minutes is considered for smart home energy planning. Therefore, the number of time intervals for a day is equal to 144 time intervals. This time-varying price can encourage home consumers to change their consumption patterns to minimize energy costs.

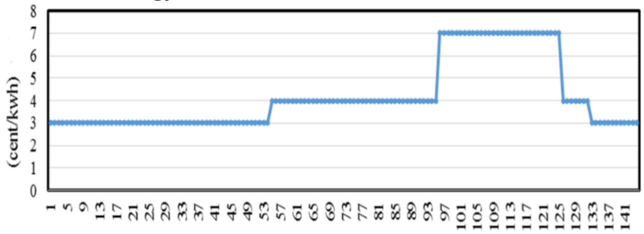

Figure 2 - The time of use price.

There are two types of household loads, including energy-controllable home appliances, and uncontrollable home appliances. Figure 3 shows the energy consumption curve of uncontrolled household appliances.

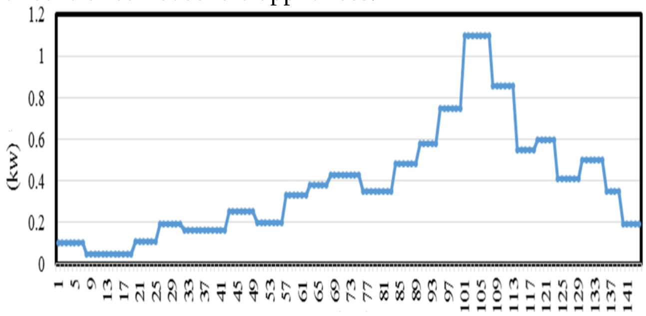

Figure 3- Uncontrollable energy consumption load curve of home appliances.

As shown in Figure 3, the productivity and productivity periods for these appliances for a day are specified. Therefore, there is a possibility of productive time intervals in the proposed HEMS, which can be used with energy management to minimize costs and smooth the load curve. In this study, three controllable electrical devices for energy consumption time are considered. The first electrical appliance is the dishwasher, which requires 4 intervals of operation, 40 minutes. The energy consumption of this device is 700 Wh/day, 175 Wh/interval. The operating intervals of this device are considered to be between 79 and 144. The second electric appliance is a clothes dryer with 8 working intervals, 80 minutes. The energy consumption of this device is 3120 Wh/day, 390 Wh/interval. Operating intervals of this device are considered between the intervals of 1 to 96. Finally, the third electrical device is a washing machine with 6 working intervals, 60 minutes. The energy consumption of this device is 1200 Wh/day, 200 Wh/interval. Operating intervals of this device are between 1 and 144. Therefore, according to the curve of Figure 3 in this smart home is about 10% of controllable load consumption and 90% of uncontrollable load consumption. It should be noted that in this study, all numerical studies and simulation results are performed using General Algebraic Modeling System (GAMS) software and optimization with CPLEX Solver. Table 1 shows the scheduling results of the use of controllable household loads with the aim of reducing energy costs.

Table 1- Simulation results.

objective function (Cent)	Optimal operating intervals of controllable appliances		
	dishwasher	Clothes dryer	washing machine
281.34	141-144	25-32	2-7

As shown in Table 1, the goal is only to minimize the cost of energy consumption per day of the smart home, the total amount of energy cost is equal to 281.34 cent. The load curve for the studied smart home is shown in Figure 4. Comparing Figure 3 and Figure 4, it can be seen that the energy consumption of controllable loads in Figure 4 has been added to the energy consumption of uncontrollable loads in Figure 3, and in total the daily load curve of a house with the aim of minimizing energy consumption.

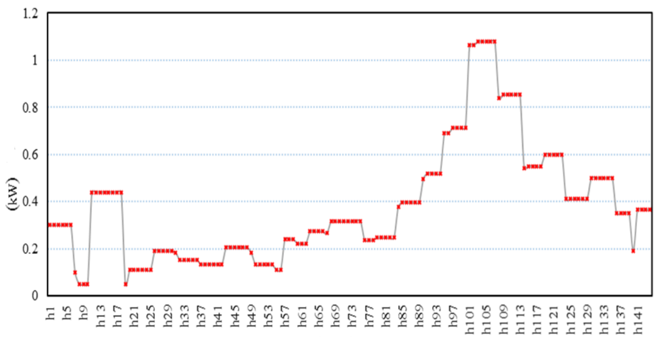

Figure 4- Energy consumption load curve.

IV. Conclusion

This study presents an optimal energy management approach for smart home appliances. Numerical studies have shown that minimizing the daily energy cost of a smart home is economically viable. With optimal planning for load consumption, controllable loads in the home can be shifted from productive periods with high electricity prices to periods of low electricity. In this study, it was stated that HEMS is a key solution for smart home energy management, which is a two-way communication between the smart meter in the house and the electricity distribution company operator. Due to the expansion of energy resources on the consumption side and the participation of responsive loads in energy management, the study of household loads with the presence of energy sources in the home can be considered very important for short-term and long-term planning.

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EISSN: 2305-0543, PISSN: 2411-6173