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Smart Home Energy Management Based on Renewable Energy Resources

Aya Abd-Elsalam[1,*], Noha H. El-Amary[2], Rania A. Swief[3], Eman Beshr[2]

[1] Electrical and Control Engineering Department, Badr University in Cairo, Cairo, Egypt
[2] Electrical and Control Engineering Department, Arab Academy for Science, Technology and Maritime Transport, Cairo, Egypt
[3] Electrical and Control Engineering Department, Ain Shams University, Cairo, Egypt

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ABSTRACT

The energy management system (EMS) can be used to optimize renewable energy resources and to monitor and schedule household appliances to reduce energy cost and Peak-to-Average-Ratio (PAR). This paper presents a smart home EMS with renewable energy sources and energy storage systems and shows how to use/ sell electrical power from/to the main grid (MG). Detailed information about the electricity selling/buying operation and appliances schedule at each hour during the day are shown. The main objective of the system is to reduce the daily cost and PAR and maximize the user's comfort. The system achieved a reduction in cost by scheduling the appliances and optimizing the renewable and stored energy. Based on the day ahead pricing of electricity and available renewable and stored energy, the appliances are scheduled. The mathematical models of each component in the system and the daily cost, PAR, and user's comfort functions are built in MATLAB. All constraints of the system are considered. Multi-objective optimization with a genetic algorithm (GA) is used to solve this problem. The EMS with PV renewable energy source and battery energy storage is applied on smart home appliances (shiftable and non-shiftable). The efficiency of the scheduled appliances is measured by the electricity cost. The results show that the system helps to reduce the electricity cost and PAR.

1. Introduction

Most of the electricity in the world is still generated by burning fossil fuels in power plants, which have negative environmental impacts and are limited in supply [1]. The main reasons for power losses in the power system are due to long transmission lines and distribution systems [2]. Researchers try to find new methods using renewable energy sources (RES) which have many advantages (clean and the running cost approximately equals zero).

To effectively utilize renewable energy sources, the conventional power grid would be redesigned and transformed into a smart grid. In the smart grid, the consumers who only consume electricity become prosumers who can generate and consume electrical power. Smart grid can enhance the efficiency of all the systems from generation to consumers and enable consumers to participate in

* *Corresponding author.*
E-mail address: aya.abdelsalam@buc.edu.eg

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demand response programs [3,4]. To keep the balance between generation and consumption, the energy management system (EMS) is used.

The main objective of EMS is to optimize electricity consumption and distributed renewable energy to minimize the electricity cost and PAR and enhance the reliability and efficiency of the main grid. Besides the economic objectives, the technical objectives must be considered to avoid a power failure or damage to distribution system equipment. Hence, it is very important to take the power utility into account. EMS becomes a multi-level energy management system. EMS includes Home and Grid EMS [5]. The home EMS manages and controls all home appliances to reduce the cost of electricity consumption. The grid EMS is more concerned with the grid to minimize the operation cost, voltage regulation, and power losses [6]. This paper will focus on home EMS. Home EMS is an optimal system to optimize the energy of distributed renewable energy resources and to monitor and schedule household appliances to reduce energy costs and PAR.

Two main components that make a smart grid more reliable than a traditional grid are Demand Side Management (DSM) and Advanced Metering Infrastructure (AMI). AMI includes information collection and a smart meter. The smart meter can be used for energy measurement by monitoring and analysing real-time data. Information and communication collection keep users updated about the changing in electricity prices. DSM includes demand response programs and energy optimization. Demand response (DR) programs modify the power demand of customers on the main grid to make the balance between consumption power and utility power. Also, the DR program helps to enhance load profiles, reduce peak demand, and improve the use of distributed resources [5].

Figure 1 shows the types of DR programs. DR programs are mainly divided into price-based programs and incentive-based programs. Price-based programs are Time of use, Real-time pricing, Critical peak pricing, and Peak time rebate. Incentive-based programs are Demand bidding, Capacity market, Interruptible load, and direct load control [6]. End customers can choose one way in response to DR programs that are based on price or incentives. DR programs allow users to schedule household appliances to minimize electricity costs without affecting user's comfort.

Price Based Programs	Incentive Based Programs
1. Time of use program [7].	1. Direct load control program [9].
2. Real-time pricing program [8].	2. Interruptible load program [10].
3. Critical peak pricing program.	3. Capacity market program.
4. Peak time rebate program.	4. Demand bidding program.
	5. Emergency demand reduction program.

Fig. 1. Types of Demand Response Programs [4]

Household appliances can be classified into shiftable appliances and non-shiftable. Non-shiftable appliances cannot be shifted the operation hours to low-price hours (refrigerator, printer, TV, microwave, computer, etc.). Shiftable appliances can be shifted the operation hours to low-price hours (lighting, air-conditioner, heater, iron, electric vehicle, etc.). Shiftable appliances can be classified into interrupted or non-interrupted appliances [11]. Interrupted appliances can be interrupted during their work. Non-interrupted appliances cannot be interrupted during their work.

In [12], an artificial neural network-based home EMS controller was created to minimize the energy cost of residential appliances. They used an artificial neural network to anticipate when appliances should be turned on or off. The results indicated that their artificial neural network-based home EMS controller can reduce energy costs and keep total energy consumption under a threshold value without harming the user's comfort. However, they didn't consider energy storage systems (ESS) and renewable energy sources.

The home EMS with RES and battery energy storage system was introduced in [13] to minimize electricity costs. A mathematical formula was introduced. The price of the battery energy storage system was determined by the state of charge. The particle swarm optimization was used to solve the problem. Based on three scenarios of optimization, that are optimizing without scheduling appliances, optimizing with scheduling appliances, and optimizing with scheduling household appliances and using the battery, were all introduced. The results of the simulations showed that the third scenario was more effective to minimize the energy cost. However, electricity sales and user comfort were not taken into account in this study.

In [14], three scenarios of home EMS were shown. The first: is without an EV and PV. The second: is with both an EV and a PV. The third with just an EV. Their goals were to minimize consuming energy, reduce PAR, and increase consumer comfort. To solve the problem, the optimization method of Pareto tribal evolution with Nash equilibrium-based choice was used. The selling process, on the other hand, was not taken into account.

A home EMS with battery ESS and PV renewable energy system was introduced in [15]. Battery ESS and PV renewable energy systems were used in this study to minimize electricity bills in smart homes. The proposed strategy determination planning was described as a stochastic mixed integer nonlinear programming, which was solved using advanced-adaptive particle swarm optimization. Selling operations to the main grid and buying operations were introduced in their home EMS. However, the selling and buying prices were equal. As a result, the impact of varying selling prices was not taken into their account. The scheduled appliances were not considered.

An optimal household energy management system with PV renewable energy source and battery ESS was presented in [16] to optimize energy cost and PAR. Their tariff was based on day-ahead pricing. Many heuristic methods were implemented in the optimization system. Many heuristic algorithms are used such as genetic algorithm (GA), binary particle swarm (BPS), wind-driven, bacterial foraging, and hybrid GA-PS optimization. The lowest cost is given by hybrid GA-PSO and the lowest PAR is given by bacterial foraging optimization. The plane of HEMS is only used to store 30% of PV renewable energy sources and discharged within high-price hours. 70% of PV renewable energy source goes to feed appliances. In this research, there was no mention of the user's comfort.

In [17], energy management with PV sources, wind turbines, and battery ESS for a microgrid with six homes were proposed. The main objective was to minimize the costs and carbon gases and maximize user's-comfort by scheduling the appliances and energy storage and managing the energy market. Grey Wolf Optimization was used to solve proposed problem. The outputs of Grey Wolf Optimization would be compared with Particle Swarm Optimization.

The home EMS was applied by using the wireless automation system [18], which uses recognition of voices. This reference could be included a footstep counter and automatic light switching. The purpose was to have the lights and other associated loads turn on when someone enters the door, even if the user doesn't have time to install the application or if there is a Bluetooth connection fault. In this case, a 1.5 m voice recognition application range has been reported. The accuracy of the algorithm was being reached to 85.25%.

In [19], home automation with multi agent system was used for efficient electricity performance without interruption, solving power demand problems and coordinating appliances. Reel time EMS was implemented and discussed through some required tasks. Solar renewable energy and battery ESS could be used. The data collected by smart appliances, internet of things applications, and wireless. The proposed algorithm could be designed with Python / Thread Simulator. The mathematical model and equation of the system weren't shown. The user comfort and PAR of the system weren't discussed.

In this paper, a smart home EMS with RES and ESS is proposed to minimize the day cost and PAR and maximize the user's comfort. The varying electricity selling factor is considered. Multi-objective optimization is used to reduce energy costs and PAR and maximize the user's comfort.

This paper is consisting of five sections. Section II describes the construction of the system and shows the mathematical model. Section III discusses the results of the system. Section IV shows the conclusion of the paper. Section V shows the references.

2. Mathematical Formulation

Figure 2 shows a construction of smart home EMS that consists of a PV renewable energy source, battery, AMI, a primary controller, and shiftable and non-shiftable electrical appliances. An AMI can acquire data of electricity price, expected temperature, and solar irradiation. The smart meter can measure the energy consumption of each appliance. All data are collected by the main controller to schedule the household shiftable appliances.

There are three sources to cover the load demand of appliances, which are PV, MG, and battery ESS. The output power of PV is used for appliances, and the residual PV power can be stored in the battery. The battery can be charged from MG at low price hours and from PV source. The battery-stored energy is used for home appliances or to sell to MG. The mathematical model code of each component, all constraints of each model, and the algorithm of the system were built in MATLAB.

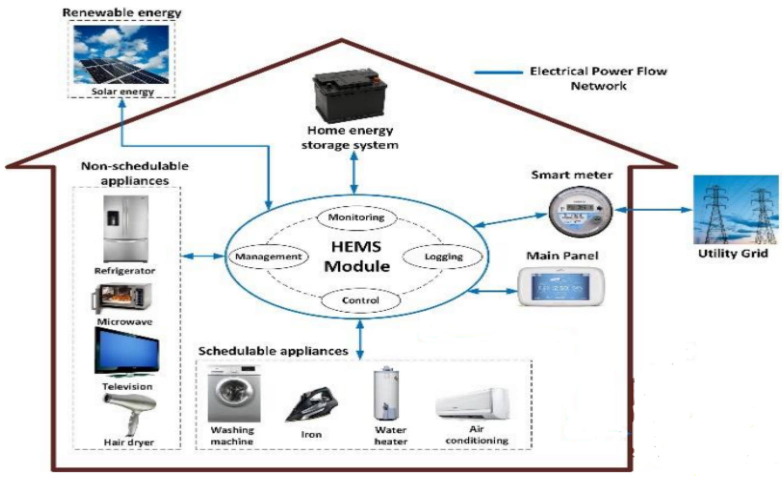

Fig. 2. Architecture of Smart Home EMS [5]

2.1 Renewable Energy Source (RES)

In our system, PV is represented RES. The output power of PV cells can be determined by:

$$P_{PV}(t) = IRR(t)\, A_{PV}\, \eta_{PV} \qquad 1 \le t \le 24 \tag{1}$$

Where IRR is the total irradiation (kW/m^2). A_{PV} is the area (m^2) of PV cells. η_{PV} is the efficiency of solar conversion of PV cells. The energy of PV cells is:

$$E_{PV}(t) = P_{PV}(t)\, \Delta t \qquad 1 \le t \le 24 \tag{2}$$

The PV renewable energy can be used for the appliances and the residual PV energy can be used to store in the battery. Hence,

$$E_{PV}(t) = E_{PVtoload}(t) + E_{PVtoESS}(t) \quad (3)$$

where $E_{PVtoload}(t)$ is the PV renewable energy used for home appliances at any hour, and $E_{PVtoESS}(t)$ is renewable energy used to charge the battery in any hour. The following constraints are considered:

$$0 \leq E_{PVtoload}(t) \leq E_{PV}(t) \qquad 1 \leq t \leq 24 \quad (4)$$

$$0 \leq E_{PVtoESS}(t) \leq E_{PV}(t) \qquad 1 \leq t \leq 24 \quad (5)$$

2.2 Battery Energy Storage Systems (BESS)

The battery can be stored energy from MG at low price hours. Also, the battery can be charged the surplus PV energy (After the PV source cover the load demand of appliances, the remain PV energy can be stored in battery). The battery stored energy can be used to supply household appliances at high price hours and to sell them to the main grid at high price hours. The battery parameters are shown in Table 1. The following formulas describe the charge and discharge status of our battery:

$$E_{CHARGE}(t) = \left(E_{PVCtoESS}(t) + E_{MGtoESS}(t)\right). m(t) \quad (6)$$

$$E_{DISCHARGE}(t) = (E_{ESStoLOAD}(t) + E_{ESSselling}(t)). (1 - m(t)) \quad (7)$$

$$m(t) = \begin{cases} 1 & if\ battery\ charged. \\ 0 & if\ battery\ discarged. \end{cases} \quad (8)$$

where, $E_{DISCHARGE}(t)$ is the sum of energy that battery discharged for home appliances energy and for selling, $E_{CHARGE}(t)$ is the sum of energy that stored in the battery by PV renewable energy and stored from M.G at an hour, $E_{ESStoLOAD}(t)$ is an energy used for appliances at an hour, $E_{ESSselling}(t)$ is an energy used to sell in an hour, $E_{PVCHARGE}(t)$ is an energy stored in battery from PV at an hour, $E_{MGtoESS}(t)$is an energy stored in battery from the MG at an hour, and $m(t)$ is a binary variable which shows the mode of the battery (charged/ discharged) at any hour.

$$E_{LEVEL}(t) = E_{LEVEL}(t-1) + E_{CHARGE}(t) * \eta_{ESS} - E_{DISCHARGE}(t)/\eta_{ESS} \quad (9)$$

where, η_{PV} is the efficiency of the battery. At any hour the following constraints must be satisfied. The charge rate of the battery should not exceed the Chrate, and the discharge rate of battery should not exceed the Dhrate. The value of energy level in battery should not be less than $E_{MIN}(t)$ and should not be more than $E_{MAX}(t)$. Hence, the following constraints must be taken in to account.

$$0 \leq E_{DISCHARGE}(t) \leq \text{Dhrate}*\Delta t \quad (10)$$

$$0 \leq E_{CHARGE}(t) \leq \text{Chrate}*\Delta t \quad (11)$$

$$E_{MIN}(t) \leq E_{LEVEL}(t) \leq E_{MAX}(t) \quad (12)$$

$$0 \leq E_{ESStoLOAD}(t) \leq \text{Dhrate}*\Delta t \quad (13)$$

$$0 \leq E_{ESSselling}(t) \leq \text{Dhrate}*\Delta t \quad (14)$$

$$0 \leq E_{PVtoESS}(t) \leq \text{Chrate}*\Delta t \quad (15)$$

$$0 \leq E_{MGtoESS}(t) \leq \text{Chrate}*\Delta t \quad (16)$$

Note that at T=24, the energy level of the battery must be the same as in the original state. Hence,

$$E_{LEVEL}(24) = E_0(t) \quad (17)$$

2.3 Smart Appliances

Household appliances can be divided into shiftable and non-shiftable appliances. The shiftable appliances (m) are home appliances that the operation time of these appliances can be moved to low price hours to minimize the day cost. The non-shiftable appliances (n) are home appliances that operation hours can't be moved to another hours. The total energy consumption of non-shiftable appliances at an hour is

$$E_{n.}(t) = \sum_{i=1}^{n} P_{rate}(ni) * \mathrm{O(ni,t)} * \Delta\mathrm{t} \quad (18)$$

where, $P_{rate}(ni)$ is the power rating of the non-shiftable appliance Ni that is given by producer, and $O(ni,t)$ is binary variable of non-shiftable appliance which shows the appliance ON/OFF.$O(ni,t)$ is given by users as follows.

$$O(ni,t) = \begin{cases} 1 & if\ Ai \text{ device ON} \\ 0 & if\ Ai \text{ device OFF} \end{cases} \quad (19)$$

The total energy consumption of shiftable home appliances at an hour is given by,

$$E_{m.}(t) = \sum_{i=1}^{m} P_{rate}(mi) * \mathrm{O(mi,t)}\Delta\mathrm{t} \quad (20)$$

where, $P_{rate}(mi)$ is the rating power of shiftable appliance mi that is given by producers, and $O(Mi,t)$ is binary variable to show the appliance OFF/ON at any hour.$O(mi,t)$ is determined by optimization system. There are two constraints which control in $O(mi,t)$. First, the shiftable appliance must be ended its operation hours during a day. Second, the shiftable home appliance cannot be interrupted.

$$O(mi,t) = \begin{cases} 1, if\ \ Ai \text{ device ON, } \mathbf{T_{start}} \leq t \leq \mathbf{T_{start}} + \mathbf{H_{operat}} - 1 \\ 0, if\ Ai \text{ device OFF} \end{cases} \quad (21)$$

Where, $\mathbf{T_{start}}$ *is the start time of appliance.* $\mathbf{H_{operat}}$ is the number of operating hours of appliance.

Hence, the total energy consumption of all appliances equals:

$$E_{APP}(t) = \sum_{t=1}^{24} E_n(t) + \sum_{t=1}^{24} E_m(t) \quad (22)$$

There are three sources (RES, battery, MG) to cover the load demand of appliances. Hence, the total energy consumption of all appliances at any hour can be calculated by,

$$E_{APP}(t) = E_{PVtoload}(t) + E_{ESStoload}(t) + E_{MGtoload}(t) \quad (23)$$

Which has following constraints:

$$0 \leq E_{PVtoload}(t) + E_{ESStoload}(t) \leq E_{APP}(t) \quad (24)$$

Substitute from Eq. (22) in Eq. (23)

$$E_m(t) + E_n(t) = E_{PVtoload}(t) + E_{ESStoload}(t) + E_{MGtoload}(t) \quad (25)$$

$$E_{MGtoload}(t) = E_m(t) + E_n(t) - E_{PVtoload}(t) - E_{ESStoload}(t) \quad (26)$$

3. Objective Functions

3.1 Objective 1: Minimize Day Cost

To calculate the day cost, the load demand from MG ($\boldsymbol{E_{LD}}$) must be calculated. $\boldsymbol{E_{LD}}$ equals the sum of energy needed to charge the battery and energy needed for household appliances minus the selling energy.

$$E_{LD}(t) = E_{MGtoload}(t) + E_{MGtoESS}(t) - E_{ESSsell}(t) \quad (27)$$

From Eq. (26) and Eq. (27)

$$E_{LD}(t) = E_m(t) + E_n(t) + E_{MGtoESS}(t) - E_{PVtoload}(t) - E_{ESStoload}(t) - E_{ESSsell}(t) \quad (28)$$

Hence, the electricity day cost is calculated as follows.

$$COST_{day}(t) = MIN((E_N(t) + E_M(t) + E_{MGCHARGE}(t) - E_{PVtoload}(t) - E_{ESStoload}(t)) * Price_{MG}(t) - E_{sell}(t) * Price_{sell}(t)) \quad (29)$$

where, $Price_{MG}(t)$ is the price of electricity needed from MG at any hour. $Price_{sell}(t)$ is the price of selling electricity to MG at any hour. The price of electricity needed from main grid is usually higher than the price of electricity selling to MG by factor (k). K is the selling factor and equals from 0 to 1 [$Price_{sell}(t)$= K* $Price_{MG}(t)$]. The value of K is determined by users.

In Eq. (29), $E_N(t)$, $Price_{MG}(t)$, and $Price_{sell}(t)$) are constant. $E_m(t)$, $E_{MGCHARGE}(t)$, $E_{PVtoload}(t)$, $E_{ESStoload}(t)$, and $E_{sell}(t)$ are variables.

3.2 Objective 2: Minimize PAR

The second objective is minimizing PAR. $E_{LD}(t)$ can be calculated by Eq. (28).

$$MIN(PAR) = MIN[\frac{MAX\ (E_{LD}(t)\ )}{\frac{1}{T}\sum_{t=1}^{T} E_{LD}(t)}] \tag{30}$$

3.3 Objective 3: Maximize UC

To calculate the user's comfort (UC), it is supposed to be defined two different types of time range for the shiftable home appliance [20]. First, utilization time range is the time that the shiftable appliance can be operate during it.UTR_{mi}= [US_{mi}, UE_{mi}]. Second, best time range is the best time for operation of the shiftable appliance. BTR_{mi}= [BS_{mi} , BE_{mi}]. The time ranges of shiftable appliance are determined by users.

To maximize the comfort of the user, the appliance can be scheduled inside BTR_{mi} or at least UTR_{mi}. Hence, $UC._{mi}$(t) can be calculated by the following.

$$UC_{mi}(t) = \begin{cases} 0 & t \leq US_{mi} \\ \frac{t-US_{mi}}{BS_{mi} - US_{mi}} & US_{mi} \leq t \leq BS_{mi} \\ 1 & BS_{mi} \leq t \leq BE_{mi} \\ \frac{t- UE_{mi}}{BE_{mi} - UE_{mi}} & BE_{mi} \leq t \leq UE_{mi} \\ 0 & UE_{mi} \leq t \end{cases} \tag{31}$$

The user comfort objective function (UC) can be calculated from

$$MAX(UC.) = MAX\ \sum_{1}^{m}(\sum_{t=1}^{24} PRI_{ai}\ UC_{ai}(t)\ O(Ai,t) \tag{32}$$

where, $\mathrm{PRI_{Ai}}$ is the priority of an appliance. The maximum value of priority is 3 and its minimum value is 1 and the users set this value.

3.4 Multi Objective Function

A multi-objective optimization function (MO FUN) is used for this problem to reduce the day cost and PAR and maximize UC.

$$\text{MIN (MO FUN)} = \text{MIN } [\frac{\boldsymbol{COST_{day}(t)}}{W1*UC-W2*PAR}]. \tag{34}$$

Where, $w_1$is the weighting factor of user comfort, and w_2 is the weighting factor of PAR. These parameters are determined by users where $w_1 + w_2 = 1$.

4. Results and Discussion

In this section, MATLAB results of the system are shown and discussed. The mathematical model and the algorithm of the system were built in MATLAB and used genetic algorithm to solve this problem. The EMS with PV renewable energy source and ESS is applied on smart home appliances that consist of 6 non-shiftable appliances and 5 shiftable appliances. The shiftable appliances are Washing Machine (WM), Air Conditioner, Clothes Dryer (CD), Water Heater (WH), and Dish Washer (DW). The non-shiftable appliances are Personal Computers (PC), Security Cameras (SC), Microwave

Oven (MO), Refrigerator (R.F), Television (T.V) and Lighting. Table 2 shows the rating power of all appliances, the operating hours and the starting time of non-shiftable appliances.

The input parameters of the battery can be shown in Table 1. The maximum energy level of the battery equals 5KWH. The minimum energy level of the battery equals 0.5KWH. Maximum charge/ discharge rate equals 0.9KW. All constraints of the battery are considered in the simulation work.

Table 1
Battery parameters

η_{ESS}	Battery Efficiency= 0.95%.
Chrate/Dhrate	Maximum charge/ discharge rate= 0.9KW.
E_0	Initial energy level= 0.5KWh.
E_{MIN}	Minimum energy level= 0.5KWh.
E_{MAX}	Maximum energy level= 5KWh.

Also, the size of the PV renewable energy source is considered. The output of PV renewable energy source can generate shown in Figure 4.

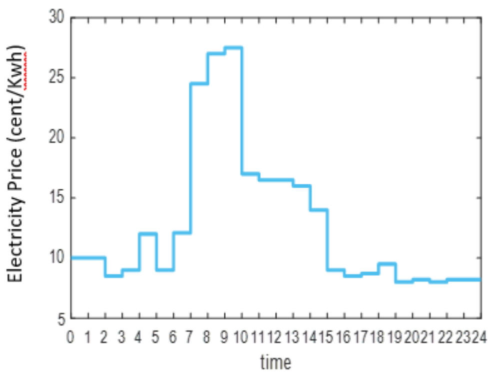

Fig. 3. The Electricity Price (DAP)

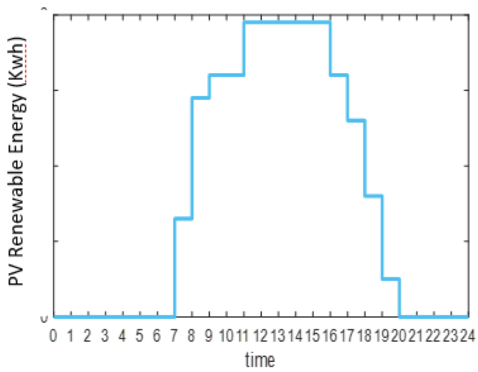

Fig. 4. The PV Renewable Energy

The Input parameters of the system are Day Ahead Pricing (DAP) of MG electricity, (PV) renewable energy, parameters of battery, and ratings of all appliances (shiftable, non-shiftable), operating hours and start operating time of non-shiftable appliances that shown in shown in Figure 3, Figure 4, Table 1 and Table 2 respectively. Home appliances and DAP are the same in [16]. In [16], authors assumed 30% of PV renewable energy is used to charge ESS, and 70% of RES is used for home appliances. The battery is charged only from PV. The stored energy is only used for residential.

Table 2
Home Appliances [16]

A_i	$P_{rating}(KW)$	H_{operat}	T_{start}
WM	0.8	5	
AC	1.3	10	
CD	0.7	4	
WH	1	8	
DW	0.2	3	
PC	0.2	18	7 AM
SC	0.1	24	24 AM
MO	0.5	7	15 PM
R.F	0.9	20	2 AM
T.V	0.2	8	16 PM
Lighting	0.1	6	18 PM

In this paper, PV renewable energy is used for home appliances and residual energy is used to charge the battery. The battery can also be charged at low price hours from MG. The stored energy can be used for home appliances at high price hours and for selling.

To get the lowest cost, the shiftable appliances are scheduled to operate at low price hours and optimize the PV renewable energy to appliances ($E_{PVtoload}(t)$), the PV renewable energy to battery($E_{PVtoESS}(t)$), the main grid energy to battery ($E_{MGtoESS}(t)$), and selling battery energy($E_{ESSselling}(t)$).

Based on load demand, available PV energy, parameters and constraints of battery, and the price of electricity, the optimization technique proceeds as follows:

i. The optimization technique chooses the best hours to charge the battery from main grid.
ii. The optimization technique decides storing the remaining PV renewable energy in battery or selling to MG.
iii. The optimization technique determines the best schedule of shiftable appliances to reduce cost.

The simulation results are shown under four scenarios of scenario I: minimize the day cost only, scenario II: show the effect of Chrate/Dhrate on the Day Cost, scenario III: show the effect of the selling factor on Day Cost, and scenario IV: minimize the day cost and PAR and maximize the user comfort.

4.1 Scenario 1: Minimize Day Cost

In this section, the electricity cost is the only objective of the system. The selling factor of the system can be assumed to equal 1. The minimum cost for the system can be obtained (289.88cent). The PAR of the system in this section equals 3.1. The outputs of the system are illustrated in Figure 5, Figure 6, Figure 7 and Figure 8.

To analyse the outputs and show how the system arrives to the lowest electricity cost during a day.

The system exploits the low-price hours of MG electricity and low peak demand hours to charge the battery at hours 0 A.M. to 4 A.M. and from 5A.M to 6A.M that shown in Figure 6. This low-price energy can be used at high-price hours for smart appliances such as hour's 7A.M-8A.M shown in Figure 5 and for selling such as 7 AM-11 AM as shown in Figure 7.

Although the price of hours from 19 PM to 24 AM are the lowest price hours during the day that shown in Figure 3, the decision of the optimization system wasn't to charge the battery during this period because those hours are peak load demand hours and that will cause the PAR to increase more than possible (PAR= 6.5).

According to the DAP of electricity shown in Figure 3 and PV-generated energy in Figure 4, the PV source generates electricity at high price hours. Most of the generated PV energy is used for smart appliances directly and not stored in the battery which is shown in Figure 5.

The optimization system can be scheduled for the smart appliances to get the lowest cost. The appliances can be supplied from the PV source, the battery, and the main grid. The non-shiftable appliances can't be moved the operating hours. The shiftable appliances can be moved the operating hours. Hence, the load demand of non-shiftable appliances is covered first. To get the lowest cost, the smart shiftable appliances can be scheduled to operate at low price hours as shown in Table 3.

Table 3
Schedule of Shiftable Home Appliances

A_i	H_{operat}	T_{start}
WM	5	19 PM
AC	10	13 PM
CD	4	19 PM
WH	8	16 PM
DW	3	8 AM

From Table 3, most of the smart shiftable appliances are scheduled to supply from the main grid at low price hours such as WM, AC, CD, and WH, while DW is scheduled to supply from PV source (from8A.M to 11A.M) to exploit the high value of PV energy. The system's success to make the load demand at high price hours from the main grid equal to zero (from 7A.M to 15P.M) is shown in Figure 8.

The day can be divided into two periods:

i. **Period I ($E_{PV}(t)$ < $E_{appliances}(t)$)**
During these hours, the PV source supplies the appliances with energy which has. The difference can be supplied from MG and battery that depends on the benefit in cost and battery constraints.
In Figure 5 at hours from 7 AM to 8 AM and from 13 PM to 15 PM, the battery can be supplied the appliances with difference energy which need.

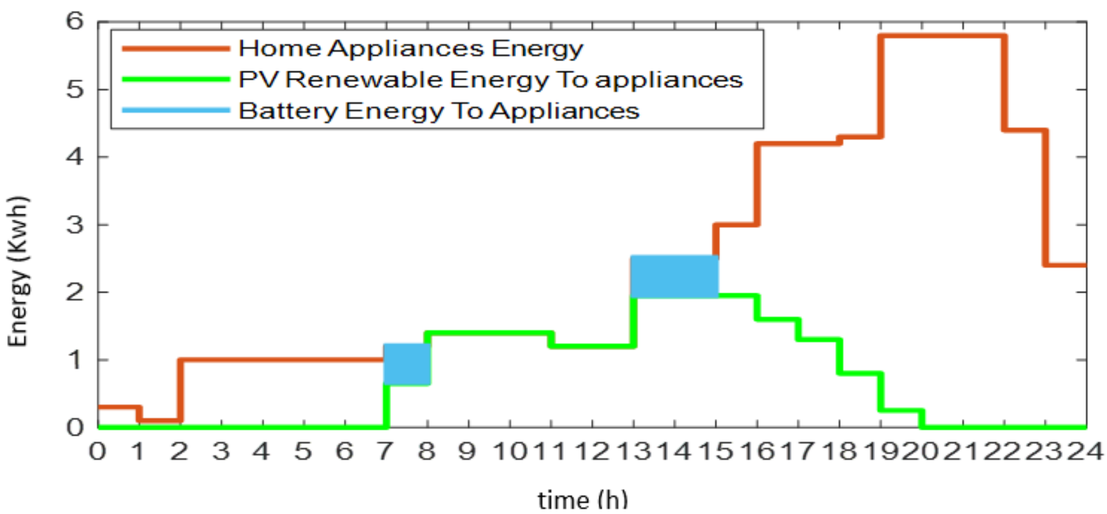

Fig. 5. Home Appliances Energy, PV Renewable Energy to Appliances, and Battery of Energy to Appliances

Also, the battery can sell the remaining energy after supplied the appliances (discharge rate-$E_{PVtoESS}(t)$) to the main grid that is shown in Figure 7. After 15 PM, the stored energy in the battery equals zero.
From 15 PM to 20 PM, the appliances can be supplied from the PV source and from the main grid as shown in Figure 5. From 20 PM to 24 PM, the PV energy equals zero. Hence, the appliances can be supplied only from the main grid as shown in Figure 8.
From 0 AM to 7 AM, the load demand of appliances is low and the price of energy is low. Hence, the battery can be charged from the main grid. From the results of the

optimization system, the best hours to charge the battery from the main grid to get the lowest cost are from 0 AM to 4 AM and from 5 AM to 6 AM as shown in Figure 6.

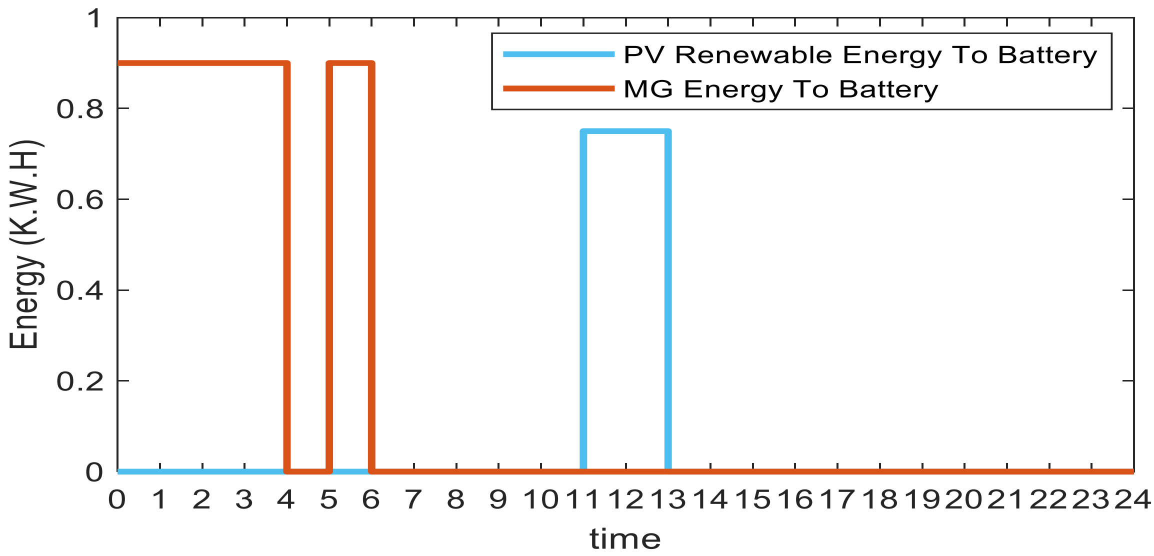

Fig. 6. PV Renewable Energy to Battery and Main Grid to Battery

ii. Period II ($E_{PV}(t)$ > $E_{appliances}(t)$)

At hours from 8 AM to 13 PM, the output energy of the PV source is bigger than the load demand of appliances. Hence, the PV source can be supplied the appliances by the load demand which need. The remaining energy of the PV source can be used to store in the battery or to sell to the main grid.

In Figure 6 at hours from 11 AM to 13 PM, the decision of optimization system is storing the remaining energy of PV source to battery. The remaining stored energy in battery becomes 0.78 KWH. The minimum energy level of battery is 0.5 KWH. Hence, the battery can't be sold to main grid and the best decision is storing the remaining PV energy.

In Figure 7 at hours from 8 AM to 11 AM, the decision of the optimization system is to sell the remaining energy of the PV source to the main grid. The price of selling electricity at these hours is very high. Hence, the system exploits the high price of electricity selling and sells the remaining energy to the main grid not stored in the battery. The remaining energy of source at these hours is wasted. The decision of the optimization system depends on the benefit in the cost and system constraints.

Finally, it can say that the system is succeeded to make the load demand from main grid at high price hours (from 7 AM to 15 PM) equals zero that help to minimize the day cost and that shown in Figure 8.

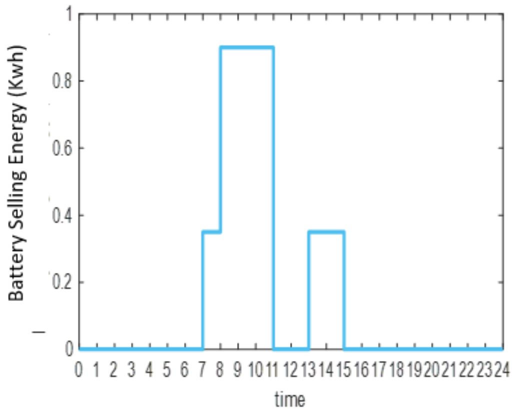

Fig. 7. The Selling Energy by Battery

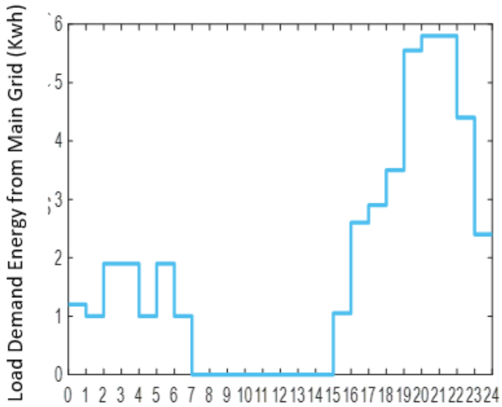

Fig. 8. Load Demand from Main Grid

4.2 Scenario 2: Chrate/Dhrate and Day Cost

To show the effect of the Chrate/Dhrate of battery on the day cost, Chrate/Dhrate is decreased from (0.9KW) to (0.3KW). The day cost is increased from (289.88cent) to (333.625cent) and PAR is increased from (3.17) to (3.46) that shown at Table 4. Hence, the day cost and PAR can decrease with increasing the charge and discharge rate.

Table 4
Chrate/Dhrate and Cost

Chrate/Dhrate(KW)	Cost(cent)	PAR
0.9	289.88	3.17
0.6	309	3.25
0.3	333.625	3.46

4.3 Scenario 3: Selling Factor and Day Cost

To show the effect of the selling factor (K) on the day cost, the different values of K are used and calculate the cost. The day cost is decreased from (313cent) to (289.88cent) with increasing the selling factor (K) from 0.8 to 1 that is shown at Table 5. Hence, the value of K is preferred to be close to 1 to get the lowest cost. If the price of selling electricity is always smaller than the price of MG electricity, the benefit in the cost is low.

Table 5
Changing Selling Factor (K) and Cost

K	Cost(cent)
0.8	313
0.9	305.505
1	289.88

4.4 Scenario 4: Minimizing Day Cost and PAR and Maximize User's Comfort

In this scenario, the objectives are to minimize the day cost and PAR and maximize the user comfort. Multi objective optimization technique with weight method of GA in MATLAB is used to solve this problem. Table 6 shows with increasing the weight of PAR that will decrease the value of PAR and increase the electricity day cost. The PAR becomes equal to (2.3508) and the electricity day cost becomes equal to (322 cent). Hence, it can be noted that there is a trade-off between the day cost and PAR.

Table 6
Different w_1, w_2 and Cost

W	Cost(cent)	PAR	UC
W1=0.6, W2=0.4	311.9	2.735	98.7%
W1= 0.3, W2=0.7	318.5	2.57	98.764%
W1=0.1, W2=0.9	322	2.3508	98.764%

5. Conclusions

In this paper, a Smart Home with PV renewable energy source and battery ESS is introduced. The objective of the system is to reduce the electricity cost and PAR and maximize the user's comfort. The operations of selling from/to main grid are considered. To achieve the objective, the system exploits the low-price hours of MG electricity with supporting PV renewable energy source and battery ESS to supply the appliances. The system is able to sell electricity to MG at high-price hours. The battery can be charged from MG at low-price hours and from PV source. The stored energy can be used for appliances and for selling at high-price hours. The mathematical model of each component, the day cost, PAR, and user's comfort functions are simulated in MATLAB. All constraints of the system are considered. The GA optimization is used to find the optimal schedule of the appliances and optimal optimization of the renewable energy and battery energy.

The results show that the system algorithm successes to make the load demand at high price hours equals zero that help to minimize the cost of the system significantly.

The results also show that when the electricity cost is only objective, the PAR is still high. When PAR and user's comfort are considered with the cost, the electricity cost increased and PAR decreased. Hence, the results show that there is a trade-off between the day cost, PAR, and the user's comfort. Moreover, the decreasing of Chrate/Dhrate will increase the day cost and PAR. The electricity cost is increased by 4% and 12% with decreasing the Chrate/Dhrate from .6KW to 0.3KW. It can say that parameters of the battery are affected on the electricity cost, PAR, and user comfort. Hence, it is important to specify and size sufficient capacity and Chrate /Dhrate of battery to store energy.

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