Day-Ahead Power Consumption Scheduling in a Smart Home with Solar Panels and Battery Storage Integration

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Abstract- This study investigates the implementation of a power scheduling strategy in a smart home with solar panels and Battery Storage (BS) integration. In general, the user has to choose between two objectives. Either to minimize the Electricity Payments (EP) while scarifying his comfort, or to maximize his comfort while paying more. To this end, the main target behind this strategy is to find a compromise solution between EP and the User Discomfort (UD). Generally, the discomfort is caused due to the way the home devices operate. In this work, the discomfort is associated not only with the delay of the Time Controllable Appliances (TCAs) but also with the power deviation of the Power Controllable Appliances (PCAs). Assuming that the electricity tariffs and the solar panel generation are already known, the suggested scheduling technique is structured as an optimization problem including continuous and integer variables. Optimal solvers are deployed to yield exact solutions. To prove the efficiency of the proposed scheduling strategy, two functioning modes (EP minimization and UD minimization) are used for comparison. The simulation findings demonstrate that the proposed strategy provides exact scheduling patterns and achieves the desired tradeoff between the EP and UD. As a result, the daily electricity consumption is reduced by 18.03%, and a daily cost of 5.25$ is charged while tolerating a discomfort of 1.81.

Keywords Power scheduling strategy; electricity payments; user discomfort; solar panels.

1. Introduction

The energy demand throughout the world has increased, depleting the energy sources and creating pollution. To face that issue, transforming the conventional grid into a smart one has become a real need [1-4]. The integration of Renewable Energy Sources (RES) and Battey Storage Systems (BSS), the deployment of the Advanced Communication Technologies (ACT), the usage of Smart Metering (SM), and automated infrastructure have strongly contributed to the development of the Smart Grid (SG) [5-8]. A research field very close to SG is Demand Side Management (DSM). It refers to the techniques, that are designed to match the present production with the demand by managing the energy usage and optimizing the appliance's functioning at the user side with the view of reaching financial, societal, and environmental benefits [9-10].

1.1 Related works

A great deal of study has been done in the field of DSM in the residential sector with the aim of scheduling home appliances efficiently. EP and UD minimization are the most challenging objectives behind DSM. To achieve that target, Optimization Algorithms (OA) and Artificial Intelligence (AI) are widely applied [11-12].

The study reported in [13], suggests a self-scheduling technique modeled as a Mixed Integer Linear Programming (MILP) multi-objective problem to manage the residential loads in order to minimize both the EP and the UD index. Another work in [14] proposes a hybrid scheme based on Genetic Algorithm (GA) and Binary Particle Swarm Optimization (BPSO) to schedule the residential loads. The focus of the suggested mechanism is to minimize the EP and the UD without neglecting the peak consumption. In the same context, GA and PSO are also combined in [15] to deal with the scheduling problem in a smart home. The major aim of the suggested method is to minimize the EP, reduce the peak power consumption, and maximize the UC. The obtained results confirm that the suggested model reaches a significant reduction in EP with acceptable waiting time. Authors in [16] adopts a residential power scheduling technique depending on cost efficiency for smart homes. The fractional programming approach is elaborated to effectively improve user satisfaction while saving costs. In the same context, the work in [17] provides a Teacher Learning Genetic Optimization (TLGO) algorithm capable to manage the controllable loads while minimizing the EP and the UD. Similarly, the work in [18] investigates the home energy scheduling problem when the electricity tariff is already indicated. The energy scheduling is formulated as an optimization problem to achieve the ideal compromise between EP and UD. Also, authors in [19] propose a residential load scheduling model under a day-ahead pricing scheme. The main focus is to reduce the EP at the minimum UD level. The performance of Teacher Learning-Based Optimization (TLBO) is compared to those of GA. Simulation outcomes indicate that TLBO outperforms GA.

Moreover, other studies consider EP and UD while integrating renewable energy sources. The work reported in [20] proposes a MILP technique to optimally manage the usage of the electrical appliances with solar power integration such that EC and UD are minimized. The obtained results prove that the proposed method optimally schedules the home appliances as required by each user. Another work in [21] proposes a multi-objective integer programming approach to schedule the starting time of the home appliances in presence of photovoltaic panels and battery storage. The suggested method proves to be efficient in reducing the EP and the UD. In [22], the authors adopt a dynamic time and load preference to optimally manage the usage of the electrical appliances with RES integration and budget limitation to purchase energy from the grid utility. A MILP is deployed in [23] to efficiently assign the home appliances usage depending on a predefined priority of the user's loads with solar panels and energy storage integration. A multi-objective MINLP model with RES and ESS is proposed in [24]. The main target behind the proposed scheme is to balance between the EP, UC, and PAR. A multi-objective approach is proposed in [25] with the intention to minimize energy consumption while considering the user comfort from thermal and visual standpoints. The generated results show that the proposed approach is capable of estimating appropriate and coherent temperature and lighting set points that ensure user comfort and rise energy savings by 11%. The work reported in [26] suggests a multi-objective self-adaptive multi-population-based Jaya algorithm to perfectly manage the energy consumption in a smart home with PV and BSS. In the proposed method, electrical tasks and the operations of the distributed energy resources are handled efficiently to reach the expected trade-off between cost and CO2 minimization. Another work in [27] suggests the PSO method to schedule the electric appliances while taking into account the UC level and the renewable energy consumption rate. Simulation results demonstrate that the proposed technique achieves EP minimization and PAR reduction by losing the end-user comfort.

1.2 Contributions

In the assessment of the previous research, the present work suggests an exact strategy to schedule the home appliances with solar panels and BS integration. The primary focus of the proposed day-ahead scheduling technique is to alleviate the EP and the UD. While a great number of studies like [13-15] relate the UD only to the waiting time, the present work takes into account both the time delay as well as the power deviation from the usual power consumption. Though, the studies reported in [16-19] deal with the scheduling problem of the TCAs and PCAs as the current work, however, no attention is addressed to the integration of the RES and BS in their proposed model. Moreover, most of the works that integrate RES and BS in their scheduling model like [20-27] neglect the EP coming from RES and BS, thus these parameters should not be neglected. They are taken into consideration in the present work. Hence, the main contributions of this research paper can be listed as:

- A day-ahead scheduling strategy for the home appliances is elaborated to find a compromise solution between EP and UD.
- The UD is associated not only with the delay of the Time Controllable Appliances (TCAs) but also with the power deviation of the Power Controllable Appliances (PCAs).
- Optimal solvers are deployed to fix the optimization problem and find exact solution that would yield to accurate scheduling patterns.
- A series of simulations are performed to analyze the effectiveness of the suggested strategy. The obtained results are discussed in terms of EP, and UD minimization.

1.3 Paper organization

The remaining of this paper is structured as follows: After the introduction in Section 1, Section 2 represents the system model. Section 3 elaborates the problem formulation. Section 4 deals with the implementation of the optimization and the data Settings. Section 5 analyses the obtained outcomes. Section 6 concludes the work.

2. System Model

The suggested Home Energy Management System (HEMS) architecture considered in this work is exhibited in Fig. 1. In this model, the smart home is supposed to be

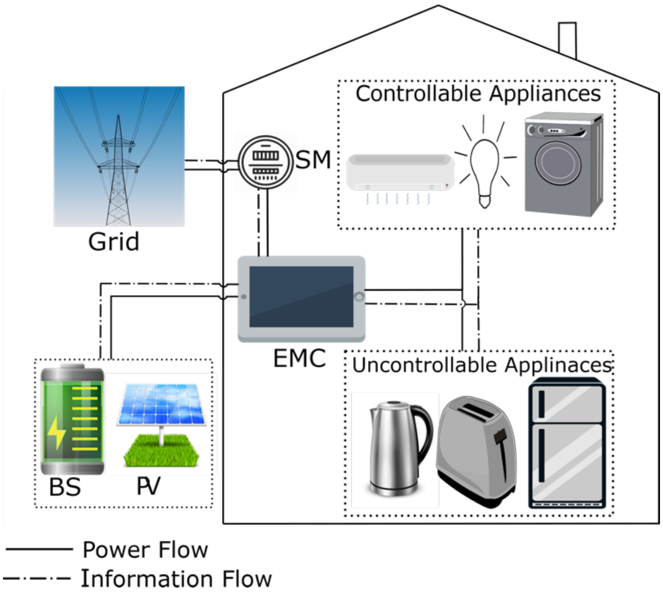

Fig. 1. The HEM architecture.

furnished with a Smart Meter (SM) which is embedded with an Energy Management Controller (EMC), various controllable and uncontrollable appliances, solar panels, and BS. An inside and outside communication infrastructure is essentially required to ensure the connection between the householder and the grid utility and also between the EMC with the appliances, the solar panels, and BS. The power flow is represented by solid lines while the information flow is drawn with dashed lines. The detailed description of the power consumption models as well as the power source models is elaborated hereinafter.

2.1 Mathematical formulation of the TCAs

TCAs refer to the home appliances which operate continuously with a fixed power P_a during l_a hours such as the washing machine. The TCAs have flexible operating time start t_a^{op}during a scheduling time horizon predefined by the user. Let's denote $[t_a^s, t_a^e]$ the scheduling time horizon, t_a^{op}must be in between the start time t_a^s and the end time t_a^e; $t_a^{op} \in [t_a^s, t_a^e]$. For every single appliance $a \in A_1$, where A_1 is the set of the TCAs, the power consumption of the appliance is defined as follows:

$$P_a^t = \begin{cases} P_a \,, \forall t \in \{t_a^{op}, \dots, t_a^{op} + l_a - 1\} \subset [t_a^s, t_a^e], \forall a \in \{A_1\} \\ 0, \forall t \in T / \{t_a^{op}, \dots, t_a^{op} + l_a - 1\}, \forall a \in \{A_1\} \end{cases} \quad (1)$$

2.2 Mathematical formulation of the PCAs

PCAs such as the light and the air conditioner, refer to the home appliances that operate in a predefined starting and ending time interval $[t_a^s, t_a^e]$with power between a maximum $P_a^{max}$and a minimum power P_a^{min}. A_2 denotes the set of PCAs. For each appliance $a \in A_2$, the power consumption of the appliance is defined as follows:

$$\begin{aligned} P_a^{min} \leq P_a^t \leq P_a^{max}, \forall t \in [t_a^s, t_a^e], \forall a \in \{A_2\} \\ P_a^t = 0, \forall t \in T / [t_a^s, t_a^e], \forall a \in \{A_2\} \end{aligned} \quad (2)$$

2.3 Mathematical formulation of the solar panels' generation

Environmentally friendly power sources and BSS have been progressively integrated in smart homes to meet the user's electrical requirements. Out of all existing sources, solar energy is easily accessible. Based on the daily solar irradiation and temperature, the PV power output can be obtained using the following equation [28]:

$$P_{PV}^t = \eta_{PV} \times A_{PV} \times I_r^t\left(1 - 0.005(T_a^t - 25)\right) \quad (3)$$

where η_{PV} represents the efficiency conversion of the PV system, A_{PV} is the area of the PV, I_r^t is the solar irradiation, and T_a^t is the outside temperature.

The PV produced power must be equal to the power transmitted from the PV system to load P_{PV2L}^t , from the PV system to Batteries P_{PV2B}^t and from the PV system to Grid P_{PV2G}^tas expressed in Eq. 4:

$$P_{PV}^t = P_{PV2L}^t + P_{PV2B}^t + P_{PV2G}^t \quad (4)$$

2.4 Mathematical formulation of the battery storage

To explore more efficiently the power generated by the solar panels, Battery Storage BS is utilized. BS stores power from the solar panels when there is a surplus generation in order to use it where the electricity price is high. The State Of Charge (SOC) of the BS can be expressed by the following formula [29]:

$$SOC^t = SOC^{t-1} + \frac{P_{bch}^t \times \eta_{ch}}{E_{batt}} \times \Delta t - \frac{P_{bdis}^t}{\eta_{dis} \times E_{batt}} \times \Delta t \quad (5)$$

where P_{bch}^t, P_{bdis}^t are the battery charging and discharging rates, and it must not exceed the maximal charging/discharging rate. Accordingly, the following constraints should be respected:

$$\begin{aligned} 0 \leq P_{bch}^t \leq P_{bch}^{max} \\ 0 \leq P_{bdis}^t \leq P_{bdis}^t \end{aligned} \quad (6)$$

η_{ch},η_{dis} are the efficiency charging and discharging and $E_{batt}$is the battery capacity.

To remain a longer lifecycle of the batteries, the energy stored should not overtake the limits defined by the manufacturer:

$$SOC^{min} \leq SOC^t \leq SOC^{max} \quad (7)$$

2.5 Mathematical formulation of the discomfort

According to the considered kind of the home devices, the discomfort can be created by delaying the functioning of the TCAs or operating the PCAs at a lower power consumption level. The discomfort created by the TCAs can be expressed as follows [18]:

$$Dis_{TCAs}(t_a^{op}) = \delta_a(t_a^{op} - t_a^s)^\alpha \quad (8)$$

where δ_a represents a discomfort factor that must satisfy 0< δ_a<1. α denotes the operation characteristic of each device $a \in A_1$, $\alpha \geq 1$

The discomfort created by the PCAs is formulated using Tougchi loss function as represented by the following expression [31]:

$$Dis_{PCAs}(P_a^t) = \varphi_a^t(P_a^t - Pn_a)^2 \quad (9)$$

where φ_a^tdenotes a proportional factor of the external cost structure of Taguchi loss function, P_a^t represents the deviated power from the normal power usagePn_a.

Then, the total discomfort caused by TCAs and PCAs can be modeled as follows:

$$Dis_{Total} = \sum_{a\epsilon A_1}\left(\delta_a(t_a^{op} - t_a^s)^\alpha\right) + \sum_t \sum_{a\epsilon A_2}(\varphi_a^t(P_a^t - Pn_a)^2 \quad (10)$$

3. Problem Formulation

As already mentioned, the purpose of this study is to manage the electrical devices in such a way the EP and the UD are minimized. The scheduling technique is designed for a smart user equipped with solar panels and BS. Hereinafter, the formulation of the optimization power scheduling problem based on three functioning modes.

3.1. Functioning mode 1

In this mode, the user has the whole priority for EP minimization and can bear the discomfort created by the functioning of the home devices. Thus, the objective function is composed of four parts: the first part is about the energy cost transferred from the PV system, the second part denotes the energy cost transferred from the batteries, the third part is the energy cost transferred from the utility companies, and the fourth part represents the revenue from vending the energy to the utility grid.

$$Min\ EP = Min\left(\sum_t (P_{PV2L}^t \lambda_{PV2L}^t + P_{B2L}^t \lambda_{B2L}^t + P_{G2L}^t \lambda_{G2L}^t - P_{PV2G}^t \lambda_{PV2G}^t)\right)$$

s.t

$$\sum\nolimits_{a\epsilon A_1} P_a^t + \sum\nolimits_{a\epsilon A_2} P_a^t = P_{PV2L}^t + P_{B2L}^t + P_{G2L}^t$$
$$Eq.(1-2) \quad (11)$$

where λ_{PV2L}^t, λ_{B2L}^t, λ_{G2L}^t, λ_{PV2G}^t are the kWh price transferred from PV to loads, from battery to load, from grid to load and from PV to Grid respectively. More details about the kWh price of each source are provided in the data settings section.

3.2. Functioning mode 2

Unlike the functioning mode 2, the householder in this mode attempts only to minimize hid discomfort without any attention to minimize the EP. Thus, the optimization problem can be formulated as follows:

$$Min\ Dis_{Total} = Min\left(\sum_{a\epsilon A_1}(\delta_a(t_a^{op} - t_a^s)^\alpha) + \sum_t \sum_{a\epsilon A_2}(\varphi_a^t(P_a^t - Pn_a)^2)\right)$$

s.t

$$\sum\nolimits_{a\epsilon A_1} P_a^t + \sum\nolimits_{a\epsilon A_2} P_a^t = P_{PV2L}^t + P_{B2L}^t + P_{G2L}^t$$
$$Eq.(1-2) \quad (12)$$

3.3. Functioning mode 3

To optimally benefit from the energy locally generated, stored in the batteries, and soled back to the utility grid, while taking into account the user discomfort as well. The optimization problem can be formulated as follows:

$$Min(k_1 EP + k_2 Dis_{Total}) = Min\Big(k_1\left(\textstyle\sum_t (P_{PV2L}^t \lambda_{PV2L}^t + P_{B2L}^t \lambda_{B2L}^t + P_{G2L}^t \lambda_{G2L}^t - P_{PV2G}^t \lambda_{PV2G}^t)\right) + k_2\left(\textstyle\sum_{a\epsilon A_1}\left(\delta_a(t_a^{op} - t_a^s)^\alpha\right) + \sum_t \sum_{a\epsilon A_2}(\varphi_a^t(P_a^t - Pn_a)^2)\right)\Big)$$

s.t

$$\sum\nolimits_{a\epsilon A_1} P_a^t + \sum\nolimits_{a\epsilon A_2} P_a^t = P_{PV2L}^t + P_{B2L}^t + P_{G2L}^t$$
$$Eq.(1-2) \quad (13)$$

wherek_1 and k_2 are the cost weight and the discomfort weight, respectively.

The optimization problem in Eq. (13) includes both integer and continuous variables. Then, we can reformulate it in two sub-optimization problems as follows:

$$Min(k_1 EP + k_2 Dis_{TCAs}) = Min\Big(k_1\left(\textstyle\sum_t (P_{PV2L}^t \lambda_{PV2L}^t + P_{B2L}^t \lambda_{B2L}^t + P_{G2L}^t \lambda_{G2L}^t - P_{PV2G}^t \lambda_{PV2G}^t)\right) + k_2\left(\textstyle\sum_{a\epsilon A_1}\left(\delta_a(t_a^{op} - t_a^s)^\alpha\right)\right)\Big)$$

s.t

$$\sum\nolimits_{a\epsilon A_1} P_a^t = P_{PV2L}^t + P_{B2L}^t + P_{G2L}^t$$
$$Eq.(1) \quad (14)$$

And

$$Min(k_1 EP + k_2 Dis_{PCAs}) = Min\Big(k_1\left(\textstyle\sum_t (P_{PV2L}^t \lambda_{PV2L}^t + P_{B2L}^t \lambda_{B2L}^t + P_{G2L}^t \lambda_{G2L}^t - P_{PV2G}^t \lambda_{PV2G}^t)\right) + k_2\left(\textstyle\sum_t \sum_{a\epsilon A_2}(\varphi_a^t(P_a^t - Pn_a)^2)\right)\Big)$$

s.t

$$\sum\nolimits_{a\in A_2} P_a^t = P_{PV2L}^t + P_{B2L}^t + P_{G2L}^t$$

$$Eq.(2)$$

(15)

4. Implementation of the Optimization and Data Settings

The optimization problem expressed in Eq. (14) includes integer variables t_a^{op} for the TCAs. This problem can be solved using the "min" tool in MATLAB. However, the problem expressed in Eq. (15) includes continues variables P_a^t for the PCAs. This problem can be fixed using the nonlinear programing solver "fmincon".

In this study, the electrical appliances highly used in homes such as the Washing Machine (WM), the Air Conditioner (AC), the Lighting (L), and the TV are chosen for the simulation tests. For more realistic results other non-controllable appliances are added. Table 1 presents the loads parameters. An example of day-ahead electricity price is illustrated in Fig. 2, and a PV output generation is presented in Fig. 3. While most of the works ignored the $\lambda_{PV2L}^t$and λ_{B2L}^tin their objective functions, assuming that it is an incremental cost. In this work, we imply that the PV power is not free and equals 0.1$/kWh as in [32]. Furthermore, we suppose that the battery is a lead-acid battery, as in [29], and the degradation cost is equal to 0.1124$/kWh. For the λ_{PV2G}^tit is assumed to be 10% lower than the λ_{G2L}^tin [33]. Other parameter values used in the simulation are outlined in Table 2.

Table 1. Appliance specifications [18]

Appliances	Category	P_a (kW)	P_a^{min} (kW)	P_a^{max} (kW)	Pn_a (kW)	t_a^s	t_a^e	l_a	α	δ_a	φ_a^t
Washing Machine (WM)	TCA	0.7	-	-	-	6pm	7am	2h	3	0.001	-
Light (L)	PCA	-	0.2	0.8	0.8	6pm	11pm	-	-	-	[0.5-1]
Air Conditionner (AC)	PCA	-	0	1.4	1.4	8am	8am	-	-	-	[0.4-1]
Toaster (Tos)	UCA	1.2	-	-	-	8am	9am	10min	-	-	-
Refrigerator (Ref)	UCA	0.2	-	-	-	8am	7am	24h	-	-	-
Kettle (K)	UCA	1.2	-	-	-	8am 4pm 8pm	9am 5pm 9pm	15min	-	-	-

Table 2. Battery specifications [29]

Battery parameter	Specifications
E_{batt}	13.44 kWh
SOC^{min}, SOC^{max}	0.2, 1
η_{ch}, η_{dis}	0.9, 0.9
P_{bch}^{max}, P_{bdis}^{t}	2, 2

5. Discussion

In order to scrutinize the efficiency of the proposed day-ahead scheduling strategy, three functioning modes are studied and the obtained results are discussed. According to the appliance specifications predefined by the user, the EMC is run to cover optimally the electricity needs from the most suitable energy source.

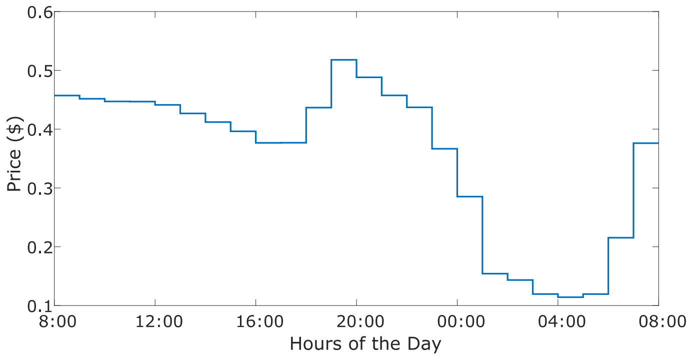

Fig. 2. Day-ahead electricity prices.

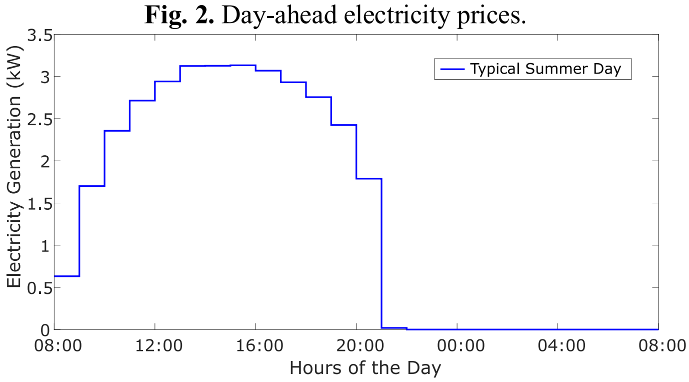

Fig. 3. Photovoltaic power output.

The simulation outcomes on the power usage of the proposed appliances based on the first functioning mode is shown in Fig. 4a. As it can be seen, the washing machine schedules its operation to time slots where is solar power generation, while, the PCAs such as the air conditioner and the lighting operate at their lower power level. Since the main target behind this functioning mode is to minimize the EP, the suggested strategy schedules the power usage according to the source that provide the lowest kWh price. The total power exchange is demonstrated in Fig. 5a. As it is shown from this figure, the right minimum power to operate the appliances is transferred from the locally produced power. The rest is used for charging the batteries or sold back to the utility grid to gain more money. As it can be seen, less electricity is purchased from the electricity grid. The battery SOC of this functioning mode is shown in Fig. 6. Initially, it is assumed that the battery is empty, and it starts charging through the solar panels without exceeding the SOC maximum value. The battery is discharged only to meet the power needs without reaching the SOC minimum value. In time slots between 00:00 and 05:00, the battery SOC is kept fixed since the kWh price gets from the grid is lower than the kWh price gets from the batteries. Moreover, at the end of the scheduling time interval, the SOC of the battery is 0.8 which is gainful for the user the next day. In this functioning mode, yet the EP is minimized, however, the householder has to accept the discomfort created.

Unlike the previous mode, the functioning mode 2 is about the UD minimization. The user in this case, cares more about his comfort than his EP. The simulation outcomes on the power usage of the proposed scheduling strategy are

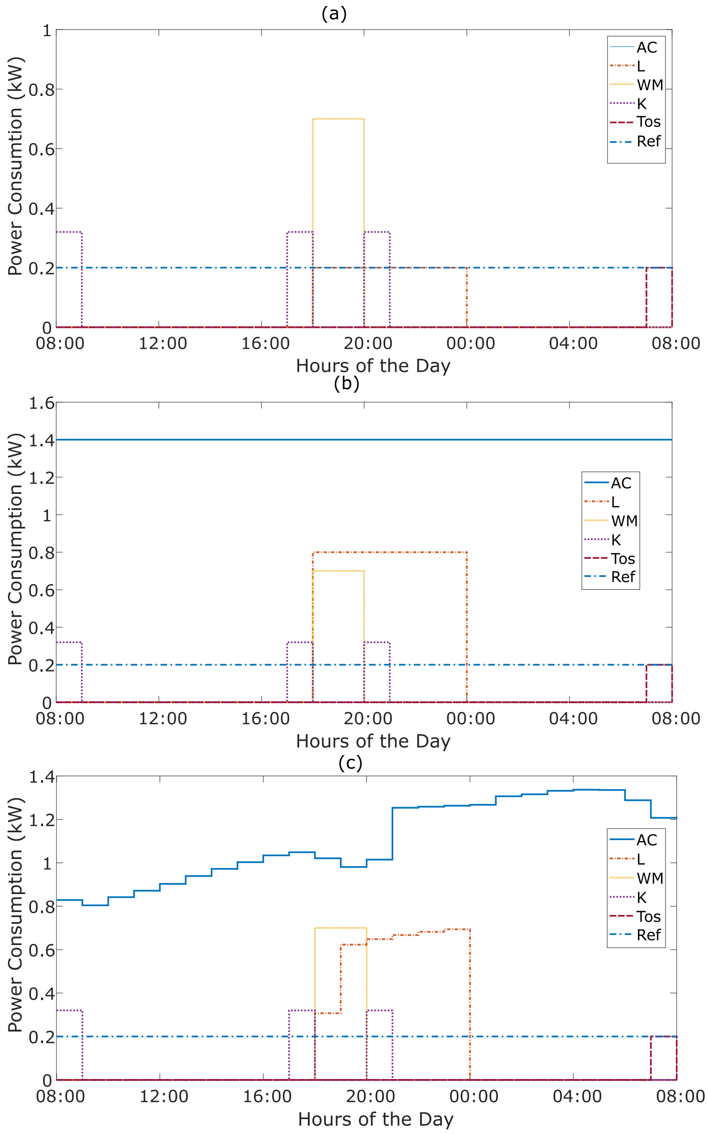

Fig. 4. Power consumption of the considered appliances for (a) functioning mode 1, (b) functioning mode 2, and (c) functioning mode 3.

displayed in Fig. 4b. In this mode, the TCAs start functioning at the beginning of the scheduling time interval, and the PCAs operate at their maximum power consumption in order to offer maximum level of comfort to the householder. The EMC gives precedence to the energy generated locally to cover the appliance energy demand. In the case of energy deficit, the EMC switches to batteries or to the grid utility. The daily power exchange is shown in Fig. 5b. As it can be seen in this mode, the user profits from the energy locally generated to cover his high energy demand and then charges the batteries. Moreover, the user purchased a huge amount of electricity from the utility grid. However, no attention is addressed to save the energy produced locally in order to sell it back to the utility grid. The battery SOC during the scheduling time horizon is depicted in Fig. 6. Given the same initial SOC as the previous mode, the battery charges from

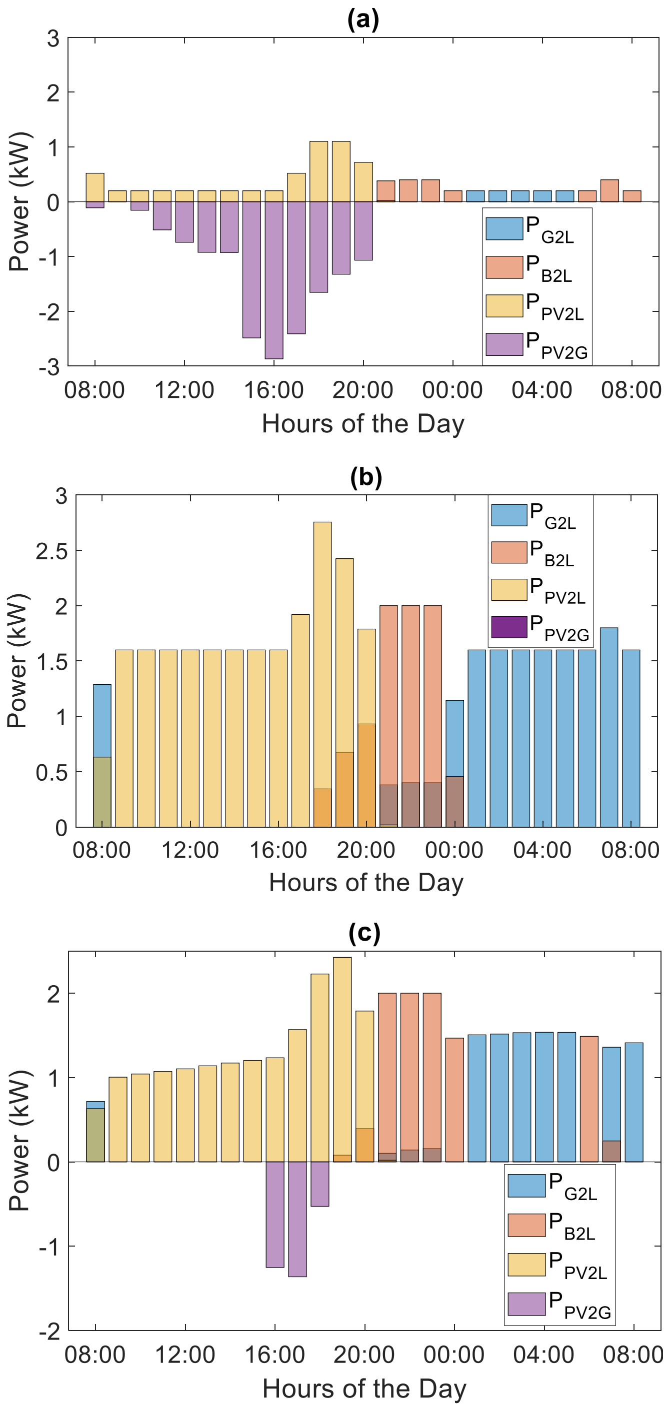

Fig. 5. Total power exchange for (a) functioning mode 1, (b) functioning mode 2, and (c) functioning mode 3.

the solar panels and discharges through the appliances while keeping its state between the maximum and minimum value. As it can be observed from this figure, the battery discharges earlier in order to cover the high energy demand of the appliances. At midnight, the SOC has already achieved its minimum value. In this case study, the user has to pay more since maximum comfort is achieved.

To take advantage of both EP as well as UD, the functioning mode 3 is proposed. Fig. 4c displays the power consumption of the different electrical devices considered in the simulation. As it can be seen, the PCAs function at a power consumption between the maximum and minimum level. However, the washing machine schedules its operation into solar panel generation time slots. The other uncontrollable appliances operate with respect to the price and availability of the different energy sources considered in the system. The daily power exchanged is shown in Fig. 5c. During PV generation hours, the EMC optimally manages the energy usage and profits from the locally generated power without ignoring the user comfort. Thus, a part of the energy is used to cover the needs, to be stored in batteries and sold back the rest to the utility companies. When PV generation is not enough, the EMC chooses the sources that provide power at a low price to start operating the appliances. Fig. 6 illustrates the battery SOC of this functioning mode. As expected, the battery charges from the PV during generation periods and discharges through the appliances during high grid prices time slots. Unlike the functioning mode 2, the battery discharge in the present mode is postponed until 7 am of the next day.

In view of identifying more the previous functioning modes, the daily power consumption profiles are shown in Fig. 7. During the scheduling horizon, the power consumption profile under-functioning mode 3 is in between the two modes, 1 and 2. The total power consumption of functioning mode 1 is the lowest among all the operation modes. Compared to functioning modes 2 and 3, this operation mode, is considered the most economical mode. Instead of paying the electricity bills to the utility grid, it is the householder who gets paid from the grid. The user in this mode has a daily income of 4.57$ as indicated in Table 3. In contrast to that gaining money, a high amount of discomfort of 35.92 must be tolerated. The total electricity consumption of the functioning mode 2 is recognized as the highest among all the other operation modes. The user in this mode guaranties his comfort, however the highest amount of money must be paid. To cover the energy demand of 47.36 kWh, the user has to pay 8.09$. As a compromise solution, the functioning mode 3 has been proposed, the user pays less while keeps being comfortable. In this mode an electricity reduction of 18.03% is reached, and a daily cost of 5.25$ is charged while tolerating a discomfort of 1.81.

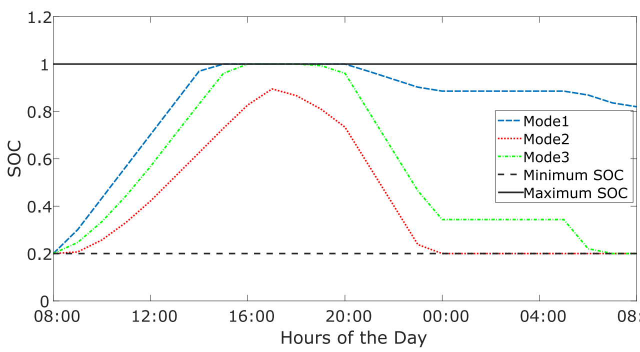

Fig. 6. The battery SOC of the three functioning modes.

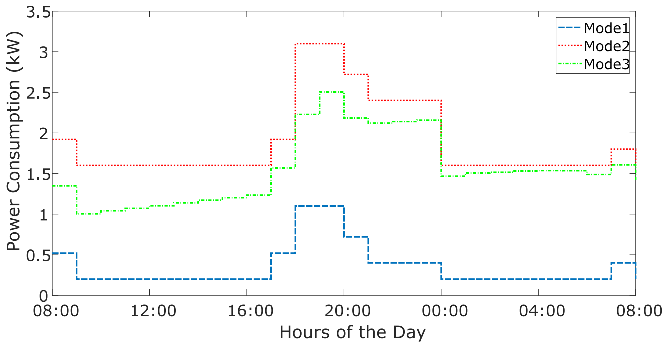

Fig. 7. Comparison of the power consumption profiles under the three functioning modes.

Table 3. Comparison between functioning modes

Functioning Modes	Total electricity consumption (kWh)	Cost ($)	Discomfort
Mode 1	8.76	-4.57	35.92
Mode 2	47.36	8.09	0
Mode 3	38.82	5.25	1.81

6. Conclusion

This research paper investigates the implementation of a power scheduling strategy in a smart home with solar panels and BS integration. The main target behind this technique is to minimize the EC and UD while taking benefiting from the energy locally generated. The power consumption is modeled for two types of appliances and the discomfort in this study is associated not only with the waiting time but also with the power deviation. For more realistic results other uncontrollable appliances are added to the simulation. The suggested scheduling technique is formulated as an optimization problem with continuous and integer variables. Exact solution that would yield to a trade-off between EP and UD minimization is obtained. To scrutinize the efficiency of the suggested scheduling technique, the obtained outcomes are compared with two functioning modes which consider either the EP minimization or the UD minimization. Findings demonstrate that the user under the trade-off functioning mode pays less while keeping being comfortable. In this mode, an electricity reduction of 18.03% is reached, and a daily cost of 5.25$ is charged while tolerating a discomfort of 1.81. In future works, our focus will be on the development and implementation of other scheduling techniques for electrical home appliances based on other optimization algorithms.

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