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A collaborative energy management among plug-in electric vehicle, smart homes and neighbors' interaction for residential power load profile smoothing

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ABSTRACT

With the modernization of the smart grid, Plug-in Electric Vehicles (PEVs) have attracted attention thanks to the effective energy support through the bi-directional power flow exchanging. In particular, vehicle-to-home technology has drawn a significant interest in PEVs' parked at smart home to enhance the power consumption profile. This paper proposes a collaborative energy management among PEVs, smart homes and neighbors' interaction. For that, a new supervision strategy based on PEVs power scheduling for smoothing the residential power load profile is developed. The objective of this study is to improve the power demand profile by controlling the PEV power charging/discharging amount to fill the valley of the power consumption curve or by providing power to home especially during peak periods to shave peak. The home energy management for achieving a flattened power load profile is divided into two parts: a local control according to the base demand profile of the considering home, the availability of their PEVs, their arrival and departure times and their initial state of charge (SOC) values. A global control according to the power demand of the specific home, the total power demand of neighbors and the availability of PEVs' neighbors (arrival and departure times, initial energy of the battery). The simulation results of the power load profile of such smart homes highlights the interaction between PEVs, smart home and their neighbors in order to flatten the power demand curve to the greatest extent possible.

1. Introduction

Recently, the growing interest in Plug-in Electric Vehicles (PEVs) development has greatly gained attention worldwide, especially owing to their environmental and economic advantages for reducing greenhouse gas emissions and fossil fuels dependence [1–4]. Indeed, pollution, global warming issues and increasing concerns about fossil fuels reserve as well as the rushed surge in electricity demand, which can harm the power grid stability, have motivated the appearance of new technologies such as the penetration of PEV in smart grid [5–7].

With the growing technologies progress and the advanced two-way communication flow, smart grids and evenly smart homes have become an important challenge as new concepts for electrical power distribution and management systems to improve energy efficiency, reliability and security [8–11]. Besides, each PEV involved to join Vehicle-to-Home (V2H) and evenly Vehicle-to-Grid (V2G) concepts should have its full charging connectivity information understanding very well and certainly, the data security must be guaranteed between each PEV owner and individual households within the neighborhood. Evidently, there is a security system of the information ensured by the cyber security system, which is the practice of protecting systems, networks, and programs from cyber-attacks designed to destroy businesses, sensitive data, extort money or damage people's financial and personal lives. While the emerging development of PEVs reduces the greenhouse gases and eventually the excessive consumption of fossil fuels, it could also generate a huge electricity demand. Certainly, uncoordinated usage of PEVs will significantly elevate the peak load especially at rush hours and the coincidence between PEV charging peaks and household appliances will cause a burden on power grid, minimize the power quality by triggering severe voltage fluctuations and producing harmonics and blackouts [12]. Facing this issue, controlled PEVs power charging and improving home energy management within smart homes are crucial as an effective solution to decrease the demand fluctuations, reduce the peak load intensity and maximize customers' satisfaction [13–18]. Recently, many researches have concentrated on the optimal energy management in home and building [19–23]. For example, a study in

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Ref. [24] has discussed the contribution of smart home's technologies with the internet of things technology and the renewable energy integration to minimize the power demand and enhance the energy performance by achieving the "low" or "net zero" energy home. Ref. [25] has proposed a centralized energy management system for off-grid operation using a mathematical model in order to achieve an optimal energy management in residential building. This model is given in real-time by considering realistic parameters regulation and client preferences. Researchers in Ref. [26] are interested in household energy consumption optimizing aiming to save energy cost in approximately 20%. They achieved a trade-off between customer comforts, electricity cost taking into account several constraints, and using an advanced global model based anticipative building energy management system. Others in Ref. [27] have explored an automatic and optimal home energy consumption scheduling approach, which aims to ensure a good trade-off between the energy prices and the drawbacks of electrical and thermal operation in a smart house. A mixed-integer nonlinear scheduling method to fulfill an optimal energy management with energy generation and thermal storage integration has been elaborated in Ref. [28]. Many recent works have proposed demand response strategies to manage energy consumption [29–31]. Ref. [32] has dealt with a dynamic load priority approach to modify the operation of the household appliances during the demand response event. Ref. [33] has presented the scheduling of different types of controllable loads under real-time pricing scheme to demonstrate an optimal day-ahead appliance scheduling of a smart household and peak power limiting. On the other hand, the coordination charging of PEV plays an important role in the demand-side of the electricity demand/supply balance in residential sector. Several studies have emphasized the PEV integration in energy management systems for residential buildings. A study in Ref. [34] has focused on the participation of PEVs and smart appliances in demand-side management program to regulate the daily load curve and reduce the electricity cost. In Ref. [35], a multi-objective power dispatching issue including PEVs as storage units is elaborated. This study aims to minimize the total micro grid costs and the PEVs batteries utilization. An energy management model for residential energy local network is formulated in Ref. [36] with the presence of smart appliances and PEVs according to the demand-side management concept. Therefore, a mixed integer-programming model for this energy management optimization is solved for achieving an optimal and automatic energy flow control for the residential energy local network. Authors in Ref. [37] have developed an intelligent home energy management systems algorithm to manage the controllable appliances consumption in a smart household incorporating electric vehicle and electric water heater. This algorithm is developed for a smart home with the integration of a rooftop photovoltaic system with an energy storage system. Others in Ref. [38] have investigated a double layer supervision strategy for residential application to achieve a smooth power load curve. The first strategy consists in demand response algorithm, which aims to move the shiftable loads from peak to off-peak hours. The second algorithm aims to achieve an optimal bi-directional PEV power flow. An electricity household consumption and production pattern corresponding to electricity utilization associated with electric vehicle home charging and distributed photovoltaic power production for residential application in the city of Westminster is explored in Ref. [39] and modelled with a Markov-chain model. Works in Ref. [40] have adapted a predictive control model in order to reduce the total operation cost according to load demand uncertainties analyzing and storage impacts in residential sector.

Although these proposed methods have achieved sound contributions for energy management, PEVs charge scheduling, electricity cost minimization and therefore power consumption reducing in residential sector. However, it is notable that the relationship between different smart homes is not elaborated. Accordingly, the interaction between smart homes, neighbors and bi-directional PEVs power can be evaluated to guarantee a better energy balance and a flattened household demand profile.

In order to fulfill the same objective, a novel supervision strategy based on collaborative energy management among PEVs, smart homes and neighbors to investigate the PEV power scheduling of the proper smart home and PEVs neighbors' interaction in concert with the smart grid is implemented in this paper. The aim is to guarantee a smooth household power load profile. In this context, an appropriate control strategy is achieved to manage the power charging/discharging operation of PEVs parked at home or neighbors' PEVs. Focusing on a smart city concept as part as smart grid technology, the home energy management for improving the power demand profile of any smart home is decomposed into two parts: A local control according to the base power demand and PEVs availability of the proper home aiming to ensure an optimal power scheduling of their PEVs charging/discharging procedure. A global control according to the total power consumption of neighbor homes and PEVs neighbors' availability to highlight the interaction of neighbors' PEVs for smoothing the demand profile. This gives a collaborative home energy management and an interaction between the smart home and its neighbors to show an effective power grid support especially through the vehicle-to-home or vehicle-to-neighbor home energy exchanging. To this end, the main contribution of this study was to regulate the power load profile of each considered home according to three specific operating modes aiming to peak-shave and valley-fill the power demand curve. The main challenge of this proposed strategy was to show the relationship between PEVs, smart homes and neighbors in the concept of smart city to ensure a regulated PEVs charging/discharging process by absorbing a required power from electrical grid in case of lack in demand or supplying power to the grid in case of excess in demand. The simulation results of three-household interactions demonstrate that the peak load intensity reduces with proper home control and decreases further with neighbor home energy management interaction. Besides, the results prove that this supervision strategy fulfills the valley filling and the peak shaving for each power demand and highlights consequently a flattened load profile.

The rest of this study was arranged as follows: In Section 2, the system architecture, the PEV modelling and control were introduced. In Section 3, the proposed supervision strategy was investigated. Section 4 discusses the simulation results and shows the impact of the optimally PEVs charging/discharging scheduling on peak shaving and valley filling the power demand profile. Finally, the conclusion of this paper is drawn in Section 5.

2. Proposed system architecture and modelling

2.1. Proposed system architecture

Due to the growing significance given to V2H and evenly V2G technologies within smart grid concept, the focus of study is achieving a smooth power demand profile for any number of smart houses thanks to a coordinated charging/discharging PEVs power from/to the grid. A collaborative energy management in residential sector with neighbors' interaction is presented in this work. Fig. 1 shows a schematic representation of a household energy management with neighbors' interaction.

We consider that each smart home is equipped with smart household appliances, a smart socket and PEVs and is modelled by a specific power demand profile. Furthermore, a smart meter is important to successfully collect information measured for the energy needed or supplied to grid [41–43]. In the smart grid context, the effective bi-directional communication and information flow can perform a collaborative home energy management between PEVs, homes and neighbors to establish an optimal power dispatch in residential application ensuring a flattened power demand to the greatest extent possible.

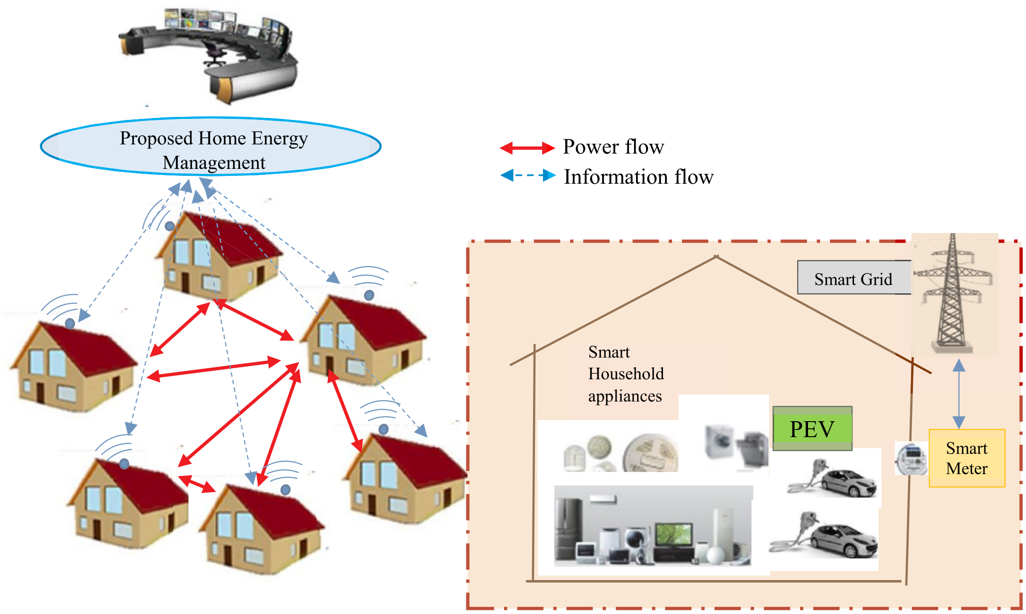

Fig. 1. Schematic representation of a household energy management with neighbors' interaction.

2.2. PEV modelling and control

With the successful modernization of smart grid as well as smart homes concepts, each PEV is equipped with an effective and high-energy battery pack, a bidirectional DC/DC converter, a DC-link capacitor, a bidirectional DC/AC converter and a line represented as an RL filter. These bidirectional power electronic converters are used to ensure the bidirectional power exchange between the PEV battery and the power grid. Accordingly, PEVs are considered as not only a load to store power from grid, but also an electric supplier to release energy to power grid at appropriate times. For these purposes, the high penetration of PEVs can be evaluated taking into account the bidirectional DC/DC, DC/AC converters, and PEV battery technology. Indeed, the battery is considered as the principal PEV energy resource. Thus, the current widespread battery technology of PEVs deployment is lithium-ion battery. In this study, lithium-ion battery was selected from the most commercial battery technology thanks to its major performance parameters such as higher energy densities, higher specific power, longer lifetime, security, light-weight nature and potentially lower waste of charge [44–46]. The PEV charging/discharging procedure is related to the equation of lithium-ion battery in a charging and discharging process, the state of charge battery equation SOC_{PEV} and the allowed PEV charging power P_{PEV} [38].

Eq. (1) indicates the characteristic equation of the voltage source of lithium-ion battery for charging procedure.

$$V_{batt} = U_0 - R.I - K\frac{Q}{I.t - 0.1Q}I^* - K\frac{Q}{Q - I.t}I.t + Ae^{-B.I.t} \tag{1}$$

Eq. (2) presents the characteristic equation of the voltage source of lithium-ion battery for discharging procedure.

$$V_{batt} = U_0 - R.I - K\frac{Q}{Q - I.t}I^* - K\frac{Q}{Q - I.t}I.t + Ae^{-B.I.t} \tag{2}$$

It is noteworthy that the simplest model of the battery is a voltage source associated in series with an internal resistance. The criterion to define the battery charging or discharging phase is the battery current sign. Positive and negative battery currents identify the discharging and charging process, respectively.

Eq. (3) describes the battery State Of Charge (SOC), which is the available state of the PEV that can be charging, discharging or remaining in idle state. The battery SOC is expressed as a percentage of the present battery capacity according to maximum capacity at the current moment of integration into the home to establish the battery capacity evolution over time. Indeed, the energy battery state should not deviate from its minimum and maximum bounds.

$$SOC = 100\left(1 - \frac{I.t}{Q}\right) \tag{3}$$

Eq. (4) lets avoiding the deep discharge through imposing a least "SOC_{min}" and the full charge of the battery through imposing the maximum state of energy "SOC_{max}" limitations within 20–80% for every PEV.

$$SOC_{min} \le SOC \le SOC_{max} \tag{4}$$

Moreover, the SOC depends on the distance running by each PEV and Eq. (5) determines the essential power for traveling "$P_{travelling}$" depending on the distance travelled by the customer "$AD_{travelling}$" and the vehicle efficiency "μ_{PEV}".

$$P_{travelling} = \mu_{PEV}.AD_{travelling} \tag{5}$$

Similarly, Eq. (6) fixes a PEV power charging and discharging restriction by commanding the minimum operating power stored from the electrical grid "P_{min}" and the maximum power range to be injected back into the grid "P_{max}".

$$P_{min} \le P_{PEV} \le P_{max} \tag{6}$$

The characteristics of each studied PEV are presented in the Appendix.

On the other hand, the control of the bidirectional power electronic converters is also a critical issue that must be taken into account to manage the power flow between smart homes and PEVs. Indeed, each PEV includes a DC/DC converter associated with an inductor filter to guarantee the bidirectional power flow exchange with the adjustment of the voltage levels between the battery and the DC bus. Furthermore, a bidirectional DC/AC converter is located between the DC bus and the RL line to absorb (or inject) sinusoidal currents from/into the power grid. The RL filter is used to improve the current quality and attenuate harmonics generated by power converters switching operation. The DC/DC converter acts as a buck or as a boost converter during the charging or the discharging mode, respectively. It is regulated by the battery current control using a PI controller aiming to adjust the battery current to the reference value "$I_{bat-ref}$" as expressed as follows:

$$U_{m-bat} = U_{bat} - PI\left(I_{bat-ref} - I_{bat}\right) \quad (7)$$

In addition, a Pulse Width Modulated (PWM) of the DC/DC converter control is achieved to sustain the battery output voltage adequate with the proper inverter input voltage. The duty ratio of the DC/DC converter control is expressed as follows:

$$m_{bat-ref} = \frac{U_{m-bat}}{U_{DC}} \quad (8)$$

A PI controller is performed to regulate the DC bus voltage by setting the battery exchanged power "$P_{bat-ref}$" as expressed by the following equation [18]:

$$P_{bat-ref} = P_{DC-ref} - P_D \quad (9)$$

Where "P_{DC-ref}" is the required power to manage the DC bus voltage and "P_D" represents the needed power to satisfy the demands. In addition, the control of the DC bus voltage depends mainly on the reference power to be absorbed or supplied from/to the PEV according to the proposed strategy constraints.

Fig. 2 shows the DC/DC converter control diagram.

To this end, the DC/AC converter exerts its influence on the DC bus by its absorbed or injected reference currents, which are coordinated according to algorithm constraints. The proposed home energy management algorithm is elaborated to coordinate the PEV power flow in order to calculate correctly the optimal PEV power "$P_{PEV,ref}$", which absorbed or injected to home ensuring a smooth power demand curve. The reactive power "$Q_{PEV,\ ref}$" is equal to zero confirming power factor equivalents to one. This bidirectional converter operates as a rectifier during PEV charging process to store the required reference power or as an inverter during the PEV discharging operation to inject the power back to the grid. This converter is regulated to set reference phase voltages "V_{md-reg}, V_{mq-reg}" as given in the following equations [18]:

$$V_{md-reg} = \frac{2}{U_{DC}} V_{md} \quad (10)$$

$$V_{mq-reg} = \frac{2}{U_{DC}} V_{mq} \quad (11)$$

By the computation of these two reference voltages, d–q components grid currents "i_{td-ref}, i_{tq-ref}" are controlled through two PI regulators.

Therefore, the active and reactive powers transferred into the grid through the RL line are given, in the Park reference frame, as follows [18]:

$$P_{Grid} = V_{Gd}\ i_{td} + V_{Gq}\ i_{tq} \quad (12)$$

$$Q_{Grid} = V_{Gq}\ i_{td} - V_{Gd}\ i_{tq} \quad (13)$$

Fig. 3 presents the DC/AC converter control structure.

As mentioned earlier, each smart home is equipped with a flexible number of PEV and in order to perform the collaborative energy management between the smart home and their neighbors, each PEV involved should have its full charging information understanding very well. As a result, each PEV needs to establish its information connectivity such as the identity number "PEV_i", the model "PEV_{mod}", the battery type "BAT_{type}", the battery capacity "BAT_{cap}", the allowed battery SOC lower limit "SOC_{min}", the allowed battery SOC upper limit value "SOC_{max}", the PEV time departure "T_{dep}" and arrival at home "T_{arr}" and the initial battery SOC value when the PEV is plugs-in at home "SOC_{int}". According to the information exchange between each PEV owners, smart homes and initial conditions indicated to the control strategy, each PEV could achieve its PEV specific charging/discharging power profile and deduce the battery SOC profile. Besides, the scheduling V2H and H2V concepts will be performed. Fig. 4 summarized the PEV basic model.

3. Proposed supervision strategy

The growing development of smart grid concept and home energy management can remarkably encourage the relationship between smart houses and their neighbors. In this context, this work presents a flowchart of energy management to ensure a flattened power consumption curve of each studied home. This control is assisted with the regulated PEVs power charging/discharging of the proper home and the neighbors' PEVs interaction. This will aim to peak shaving and valley filling the power demand of each home making it in the proposed allowable power margin. In this direction, a supervision strategy built on "Collaborative energy control among PEVs, smart homes, and neighbors' interaction for home energy management" was investigated and presented in Fig. 5. This control algorithm for energy management of each smart home under study is made up of two steps: a local control according to the PEVs availability of the proper home and a global

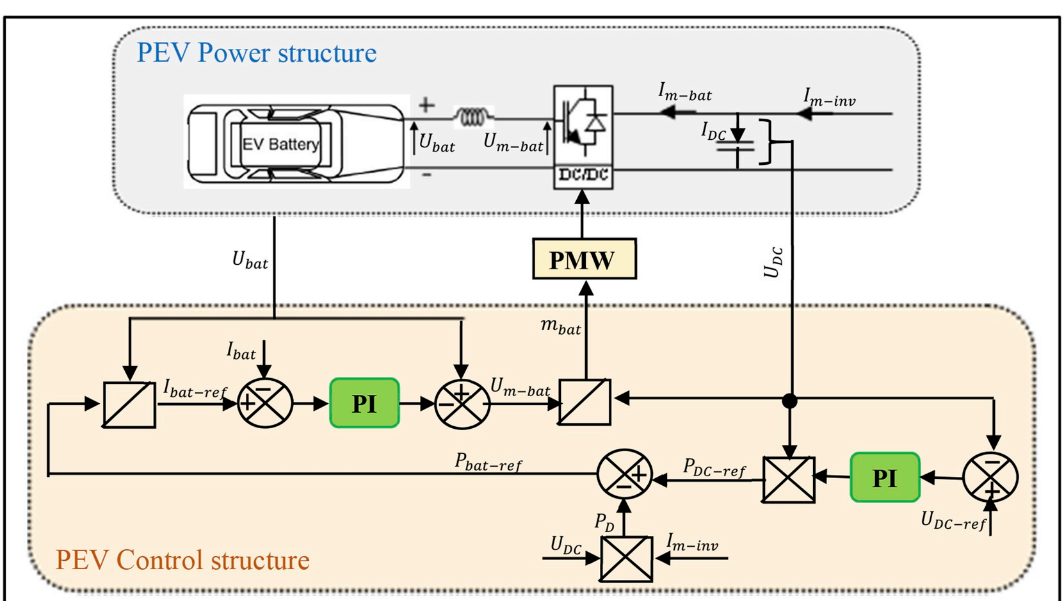

Fig. 2. DC/DC converter control diagram.

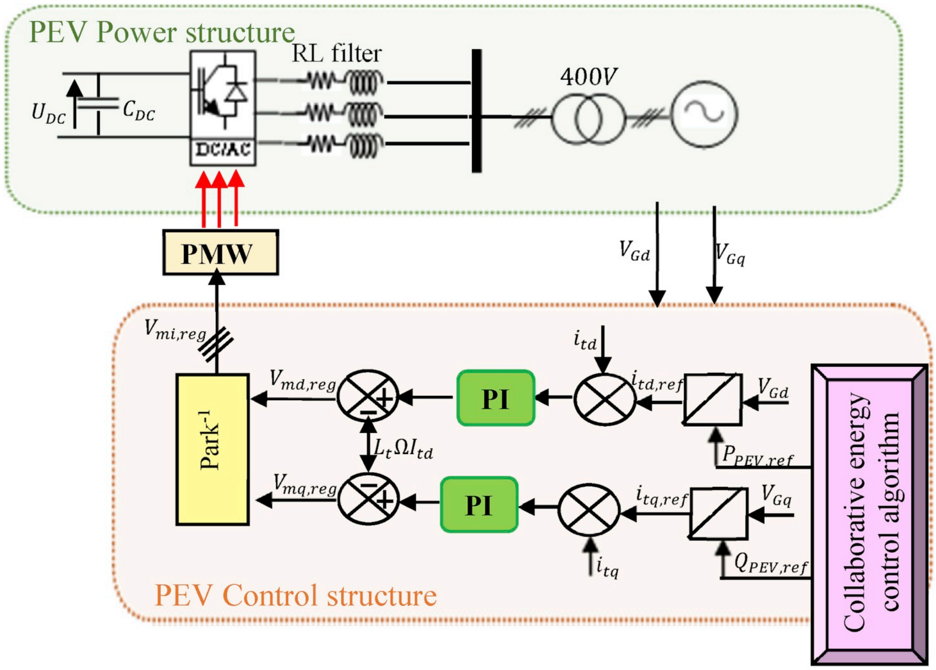

Fig. 3. DC/AC converter control structure.

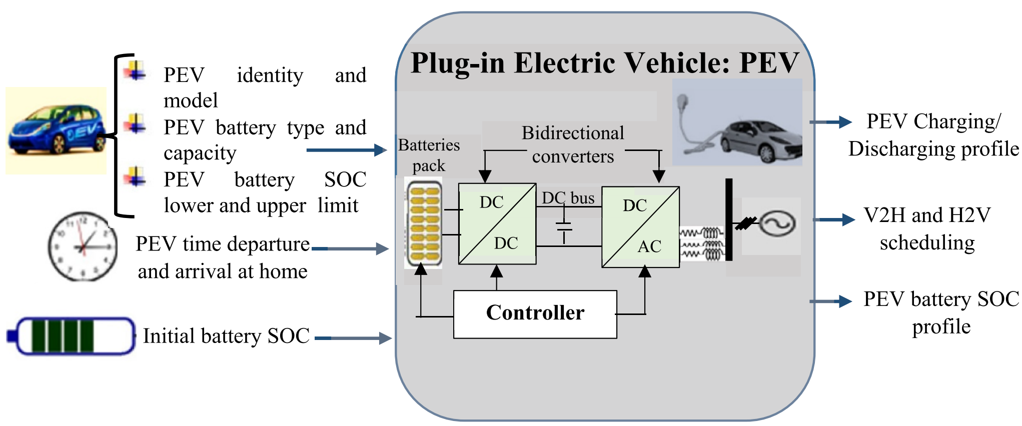

Fig. 4. PEV basic model.

control according to the power consumption of neighbor homes and PEVs neighbors' availability. Therefore, three operation modes can be distinguished: unchanged operating mode, self-control or control with neighbors' interaction. The objective involves in smoothing the total power profile of each considered house with scheduling the charging/discharging process of both PEVs parked at proper home or parked at neighbor homes. The key challenge of this supervision strategy is to achieve a bidirectional power flow of PEVs in residential sector calculating the required PEV power to be absorbed or injected to the grid in case of lack in demand or in case of excess in consumption, respectively. This would help to fulfill the following objectives:

- Checking the charging/discharging process of PEVs of the considering home according to their availability for storing or injecting power, their initial battery SOC value and the total power demand configuration of the studied home.
- Ensuring a coordinated bi-directional power charging/discharging procedure of neighbors' PEVs taking into account their availability for absorbing or delivering power into the considered home, their initial energy of each neighbor's PEVs battery, the total power demand configuration of the studied home and the total power consumption of neighbor homes.
- Improving the peak shaving and the valley filling of the power load profile of the studied home thanks to the required power absorbed or injected from/to grid whatever of PEVs of the proper home or neighbors' PEVs in order to satisfy a flattened profile.
- Controlling the energy charged and discharged to and from each PEV with lower and upper limits to prevent their overcharging and deep discharging, respectively.

Indeed, the energy transactions between households in a neighborhood is supervised and ascertained according to the adequate mode designed from our proposed control algorithm. Certainly, each smart home is equipped with a smart meter, which receives parameters and requirements in order to measure the multi-period and multi-mode active and reactive power rates of the energy metering usage, send data information, accept instruction information and collect data. In addition, smart metering systems provide aggregated metering to smart grid thanks to supporting the bidirectional communication flow to control the energy balance between production and consumption within

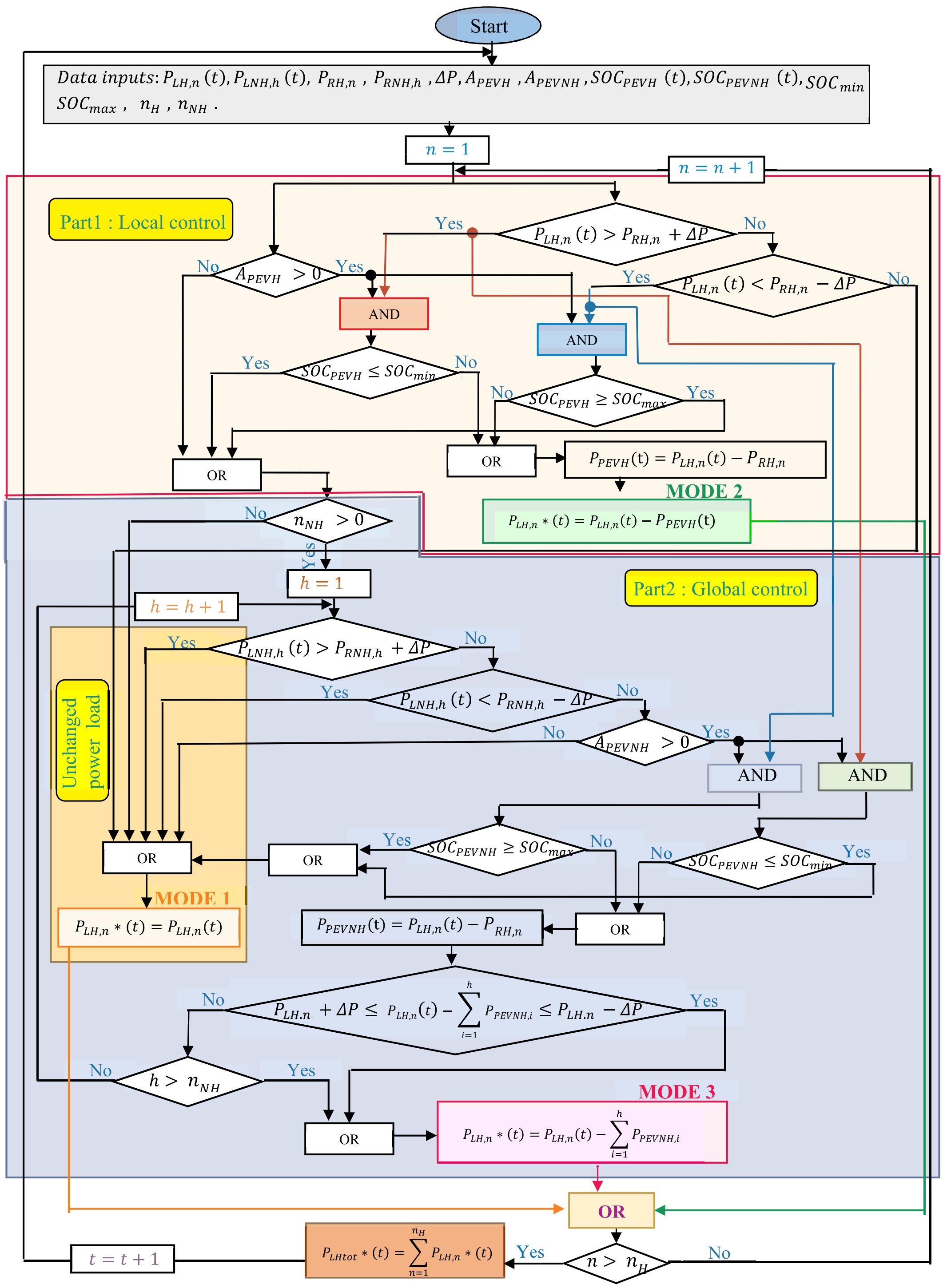

Fig. 5. Collaborative energy control among PEVs, smart homes, and neighbors' interaction for home energy management.

smart building concept. Therefore, our proposed supervision strategy will operate depending on the information collected by the smart meter and it can manage and optimize the transfer of the bidirectional PEVs power flow between households and neighbors according to considered operating mode. In order to satisfy these objectives, the proposed home energy management algorithm receives this information as inputs:

$''P_{LH,n}(t)''$	The total power demand profile of the studied home
	The home reference power
	The connection availability of each PEV for the considered home
	The initial energy battery state of each PEV for the considered home
	The total power demand profiles of each neighbor home
	the neighbor home reference power
	The connection availability of each neighbor's PEV
	The initial battery energy state of each neighbor's PEV
	The allowable power variation margin
	The acceptable battery SOC lower limits of PEVs
	The acceptable battery SOC upper limits of PEVs
	The total number of homes
	The total number of neighbor homes

Then, the power demand of each home under study is managed into three operating modes, which are detailed in these sub-paragraphs as follows:

MODE 1: Unchanged operating mode.

This mode is achieved by the activation of one of these different cases: The total power demand of the considered home is within the desirable power margin ($''[P_{RH,n} - \Delta P,\ P_{RH,n} + \Delta P]''$), or there are no neighbors, the total power demand of neighbor homes is not within the acceptable power margin ($P_{LNH,h}(t) > P_{RNH,h} + \Delta P$ *or* $P_{LNH,h}(t) < P_{RNH,h} - \Delta P$), or there are no neighbor's PEVs parked at home or the neighbors' PEV was connected but the charging/discharging procedure is not taken immediately because this neighbor's PEV reached its maximum SOC value $''SOC_{max}''$ (the neighbor's PEV is fully charged) or its minimum value $''SOC_{min}''$ (the neighbor's PEV is completely discharged).

In this situation, there is no power exchanged with the considering home nor with neighbor homes $''P_{PEVH}(t) = 0$, $P_{PEVNH}(t) = 0''$, the power demand remains unchanged and the modified expression $''P_{LH,n}*(t)''$ is given as follows:

$$P_{LH,n}*(t) = P_{LH,n}(t) \tag{14}$$

MODE 2: Self-home control' operating mode.

This mode is selected when there are PEVs of the proper home connected and available to join the home-to-vehicle H2V or vehicle-to-home V2H operation. If the total power demand of the studied home $''P_{LH,n}(t)''$ was less than the reference power minus the power variation margin $''P_{RH,n} - \Delta P''$ and the value of the PEV battery SOC was less than the $''SOC_{max}''$, then the PEV of the proper home stored energy to compensate the lack in demand during off peak periods (it is charging process: H2V operation). Whereas if $''P_{LH,n}(t)''$ was more than the reference power plus the power variation margin $''P_{RH,n}+ \Delta P''$ and the PEV battery SOC value was more than the $''SOC_{min}''$; consequently, the PEV of the proper home should deliver power to the grid during peak hours to decrease the surplus of the demand (it is discharging process: V2H operation). Considering these cases mentioned above, the reference PEV power is given by: $''P_{PEVH}(t) = P_{LH,n}(t) - P_{RH,n}''$ and the modified power demand of the considered home $''P_{LH,n}*(t)''$ is expressed as follows:

$$P_{LH,n}*(t) = P_{LH,n}(t) - P_{PEVH}(t) \tag{15}$$

MODE 3: Neighbors interaction' operating mode.

This mode is obtained when these conditions are achieved:

- There is no PEV of the proper home parked.
- The PEV connected at home reached the maximum $''SOC_{max}''$ or the minimum $''SOC_{min}''$ energy of battery levels when it was fully charged or absolutely discharged, respectively.
- There are neighbors and the total power demand of neighbor homes is in the desirable power margin ($''P_{LNH,h}(t) \le P_{RNH,h} + \Delta P$ *and* $P_{LNH,h}(t) \ge P_{RNH,h} - \Delta P''$).
- There is neighbors' PEV parked at home. Indeed, if the total power demand of the considered home $''P_{LH,n}(t)''$ was less than $''P_{RH,n} - \Delta P''$ and the value of the neighbor's PEV battery SOC was less than the $''SOC_{max}''$, then the neighbor's PEV operated to absorb energy from the home. However, if $''P_{LH,n}(t)''$ was more than $''P_{RH,n} + \Delta P''$ and the neighbor' PEV battery SOC value was more than the $''SOC_{min}''$, then there was an excess in the home consumption which should be injected to the home through this neighbor's PEV (it is the discharging operation of neighbor's PEV).

According to these conditions, the reference neighbor's PEV power is expressed as: $''P_{PEVNH}(t) = P_{LH,n}(t) - P_{RH,n}''$. If all the neighbor homes have participated to the power consumption flattening or the modified power demand of the considered home becomes in the allowable power margin, the new power load $''P_{LH,n}*(t)''$ will be equal to:

$$P_{LH,n}*(t) = P_{LH,n}(t) - \sum_{i=1}^{h} P_{PEVNH,i} \quad \mathrm{h} \in [1, {''NH}] \tag{16}$$

The proposed supervision strategy is flexible to integrate any number of PEVs and practical to be applied for a large number of household $''n_H''$ consisting in a smart city as part of a smart grid concept. To this end, if all the houses under study have accomplished their home energy control, each house keeps its new power load profile $''P_{LH,n}*(t)''$. Else, this approach should be applied to the next home number $''n+1''$.

The modified total power load of all households is expressed by the following equation:

$$P_{LHtot}*(t) = \sum_{n=1}^{n_H} P_{LH,n}*(t) \quad \mathrm{n} \in [1, {''H}] \tag{17}$$

4. Simulation results

In order to assess the validity of the proposed approach and illustrate the performance of the cooperative energy among PEVs, smart homes and neighbors for home energy management, simulation of the power load curve for three households with their specific power request and initial constraints was implemented. The aim is to test the effectiveness of the control algorithm to smooth the household power demand according to the various operating modes while controlling the PEVs charging/discharging scheduling of the proper home and the neighbors. To ensure a better energy control, we examine the simulations for a whole day (24 h) which was divided into 96 time-intervals. For instance, for a 15-min period, 1 h includes four 15-min periods.

The simulation results are carried out using the power load profile of each home, the reference power, the acceptable power margin and the PEVs characteristics. The main features of PEVs involved in each home are presented in Table 1.

The availability of each PEV to join the V2H and H2V concepts is illustrated in Fig. 6. As shown, the departure and arrival times of PEV1 and PEV2 to the home number1 is presented in Fig. 6a. Indeed, the PEV1 was connected to home1 at 6 p.m. and it will be disconnected from grid at 6 a.m. of the next day. During [6a.m, 6p.m] time interval, this PEV1 is inaccessible to join the bidirectional power exchanging. The PEV2 arrives at home number1 at 10 a.m. and leaves at 5 p.m. During [10a.m, 5p.m] time interval, this PEV2 is unavailable. As it can be seen in Fig. 6b, the PEV was plugged-in to home number 2 at 6p.m. and plugged-out at 10 a.m. of the following day. Fig. 6c shows that the PEV leaves home number 3 at 4a.m. and returns at 6p.m.

Fig. 7 shows the PEVs power profile of homes during a 24-h period.

Table 1
Characteristics of each involved PEV.

	PEV_i	$T_{arr,i}$	$T_{dep,i}$	$BAT_{cap,i}$ (KWh)	$P_{min,i}$ (KW)	$P_{max,i}$ (KW)	$SOC_{ini,i}$	$SOC_{min,i}$	$SOC_{max,i}$
Home1	PEV1	6p.m	6a.m	14	-2	2	0.5	0.2	0.8
	PEV2	10a.m	5p.m	11	-1	1	0.32	0.2	0.8
Home2	PEV	6p.m	10a.m	14	-2	2	0.2	0.2	0.8
Home3	PEV	6p.m	4a.m	14	-2	2	0.6	0.2	0.8

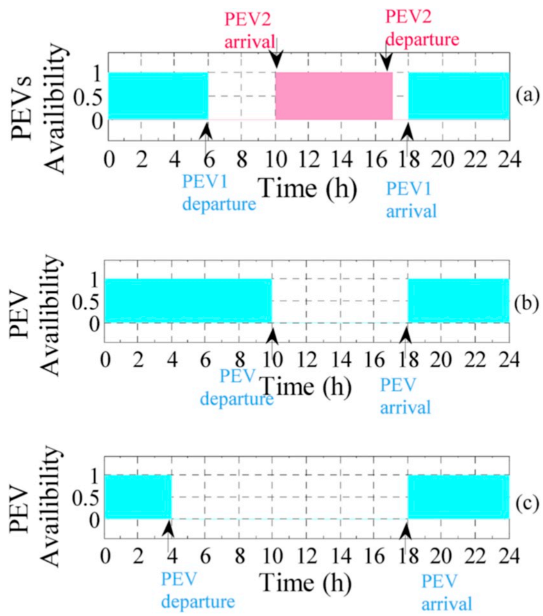

Fig. 6. PEVs state of availibility of homes: (a)Home1, (b)Home2, (c)Home3.

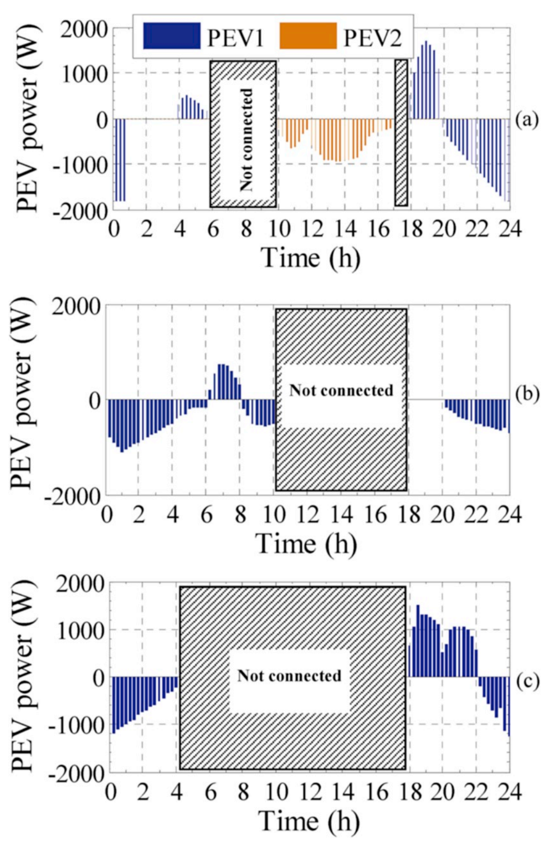

Fig. 7. PEVs power profile of homes: (a)Home1, (b)Home2, (c)Home3.

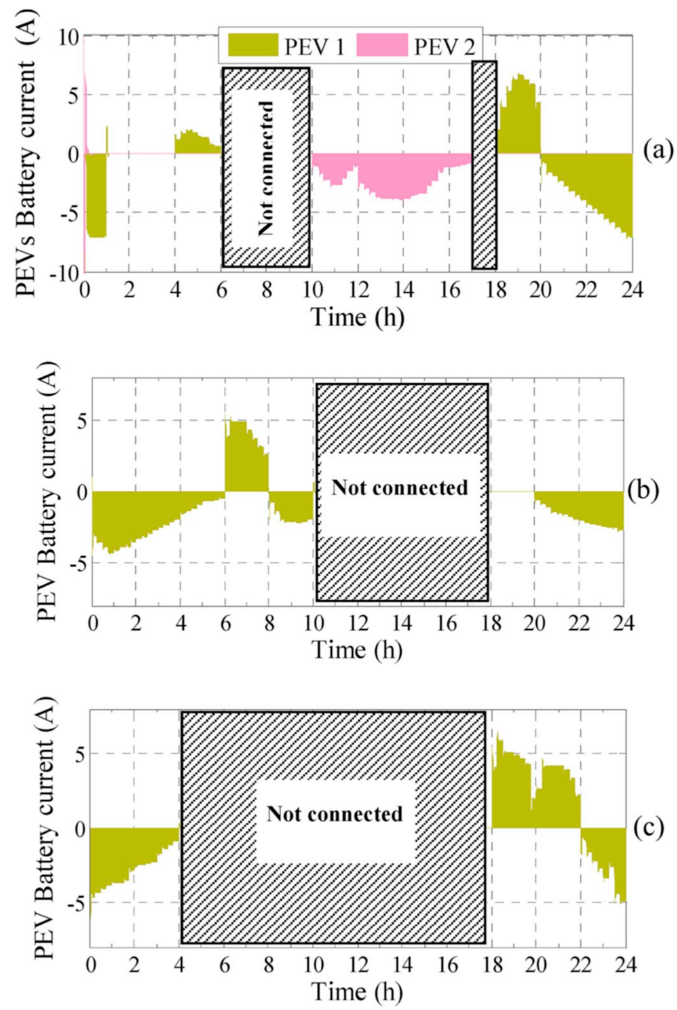

Fig. 8. PEVs Battery current profile of homes: (a)Home1, (b)Home2, (c)Home3.

The convention chosen in this study proves that the negative powers correspond to the charging process where each PEV behaves to store energy during off peak time periods. While the positive powers were designated to the discharging procedure where the available PEV acts to feedback energy to the home especially during rush hours. According to Fig. 7a, it is observable that, during [1a.m, 4 a.m.], [6a.m, 10a.m] and [5p.m, 6p.m] time intervals, both PEV1 and PEV2 can not absorb or supply power to electrical grid. According to the PEV power profile of home2, which is illustrated in Fig. 7b, the PEV can not be charged or discharged during [10a.m, 8p.m] time interval. Fig. 7c confirms that the PEV of home3 is not available to improve the power demand during [4a.m, 6p.m] time interval.

Fig. 8 depicts the simulation results of PEVs battery current for the three homes. As it can be seen in Fig. 8a, b and c, the results are confirmed by the selected convention in which the charging and discharging procedures of PEVs required negative and positive currents, respectively.

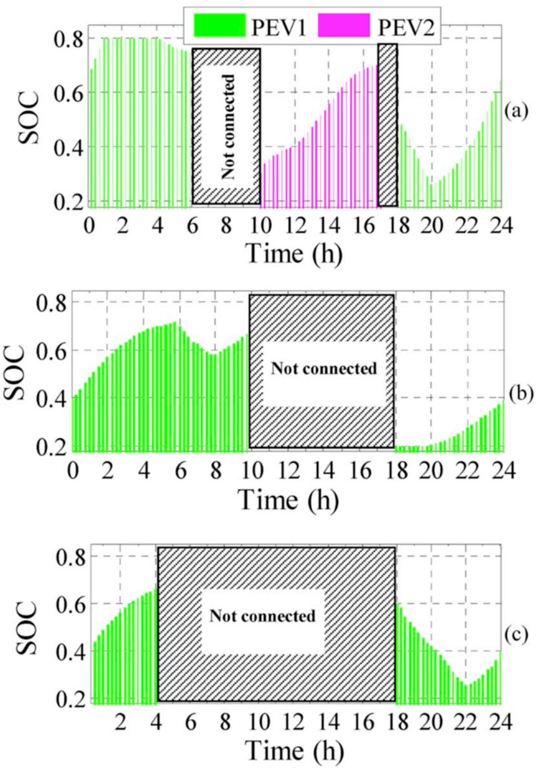

Fig. 9. PEVs state of charge curve of homes: (a)Home1, (b)Home2, (c)Home3.

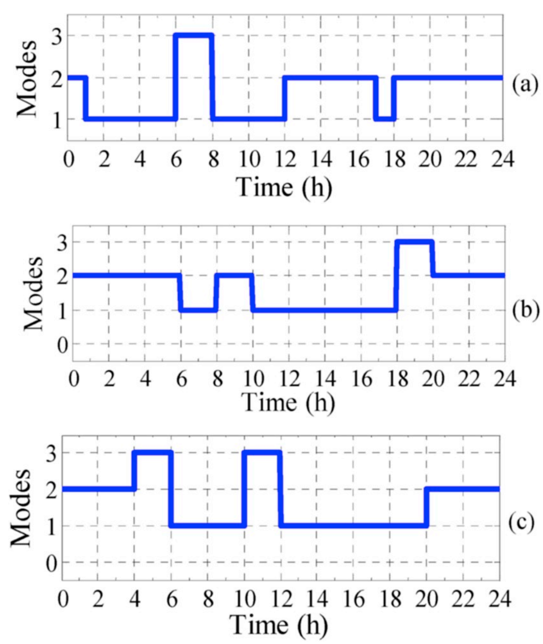

Fig. 10. Different operating modes for homes: (a)Home1, (b)Home2, (c)Home3.

In the frame of this study, the charging and discharging procedure can be examined by the evolution of the battery SOC profile for each PEV connected at homes which are illustrated in Fig. 9. It can be noticed that the discharging process, when the PEV is connected at home, is proven by SOC value reducing.

According to the home energy management algorithm developed in this study, Fig. 10 displays the transitions between three different modes of the modified power load for these three homes. It is notable that, for each household, mode1 indicates that there is no control by the proper smart home nor by PEVs neighbors and the power load curve remains unchanged. Mode 2 points out a local control in which the power demand of each home is improved owing to its proper PEVs contribution. Mode 3 illustrates a global control in which the power demand is flattened owing to the neighbors' PEVs contribution.

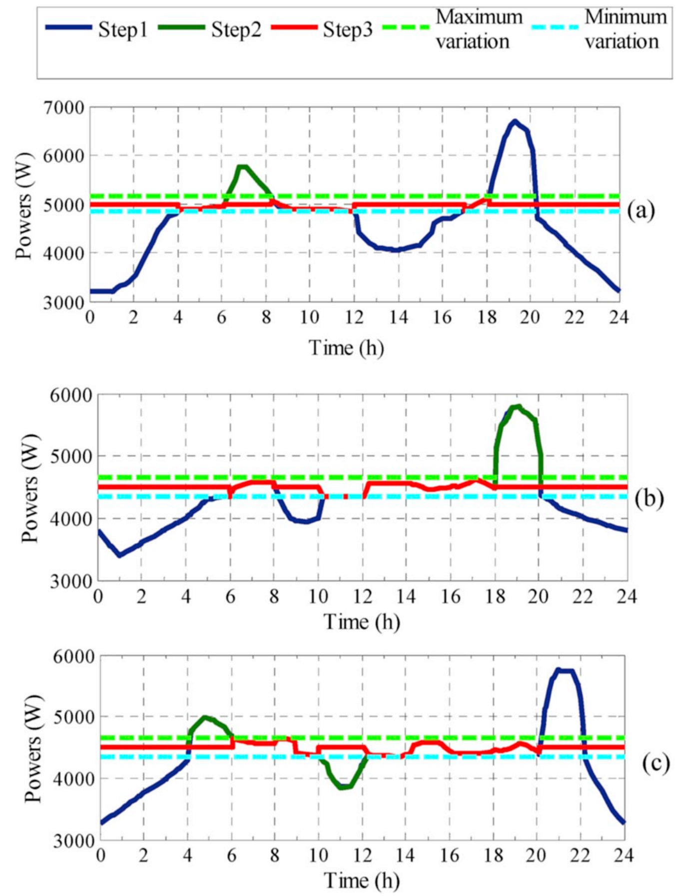

Fig. 11. Evolution of power demand of studied homes: (a)Home1, (b)Home2, (c)Home3.

Fig. 11 clearly illustrates the evolution of the power demand profile for each home following three different steps. Indeed, step 1 which is exposed in blue curve, presents the base power load without any control. It may be observed that, by the integration of the PEVs power control of their proper home, the power consumption profile is noticeably improved attaining an acceptable power profile. This describes the local

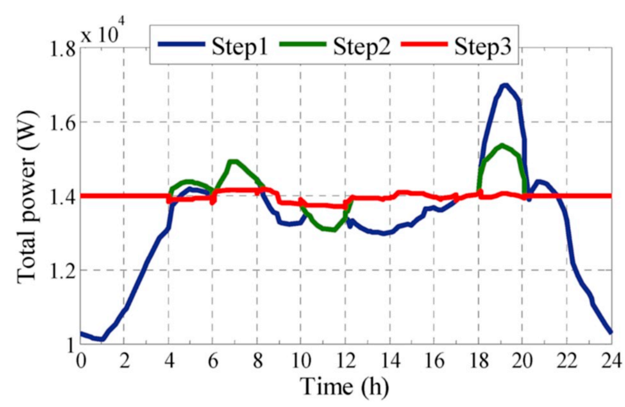

Fig. 12. Comparison of total power load curves of the three residential customers.

control of PEV power charging/discharging scheduling in step2, which is shown in green curve. It may be demonstrated that by accomplishing step3, which consists in the contribution of neighbors' PEVs power control, the power load profile can evidently fulfill its smoothness. Accordingly, the valley filling and peak shaving of the power demand profile of the three homes, illustrated in red curve, are carried out. As it can be seen in Fig. 11a, the power demand of home1 was improved thanks to its PEV1 and PEV2 power management during [6p.m, 1 a.m.] and [12, 5p.m] time intervals, and further enhanced owing to PEV of neighbor home2 interaction during [6a.m, 8 a.m.] time interval. As shown in Fig. 11b, the power load of home2 was regulated with its PEV contribution during [8p.m, 6 a.m.] and [8a.m, 10a.m] time intervals, and more ameliorated with the coordinated power of PEV of neighbor home3 during [6p.m, 8p.m] time interval. As seen in Fig. 11c, the power consumption of home3 was enhanced during [8p.m, 4a.m] time interval through the self-control of its PEV connected at home3 and achieved its smoothness using the neighbor home1′ PEV1 and neighbor home1' PEV2 power control during [4a.m, 6a.m] and [10a.m, 12] time interval, respectively.

Fig. 12 presents the total power load profile of these three residential customers. It is observed that the total power demand was improved in step 2 and further flattened in step 3, compared to step1.

5. Conclusion

The present study considered a case of some residential customers in the frame of the vehicle-to-home V2H concept aiming to flatten each power demand owing to a collaborative energy management among PEVs, home and neighbors. The proposed algorithm is based on the PEV charging/discharging power scheduling. This work involved as input both the power consumption profile of the studied home and neighbors to ensure an optimal PEVs power coordination for home energy management mechanism. This approach was developed considering some constraints such as: each PEV departure and arrival time at home, initial energy of battery, upper and lower state-of-charge battery bounds, PEVs power charging/discharging limits as well as the required PEV energy to successfully integrate and dispatch the required energy amount. The main contribution of this study is the fulfillment of a new supervision strategy to effectively perform the valley filling and peak shaving of each power demand profile according to three distinctive operation modes. The obtained simulation results show that the local control (self-control operating mode) aims to improve the load profile. By employing the global control (PEVs neighbors' interaction operating mode), the simulations highlight that the fluctuation in demand was reduced and the power profile was enhanced to the greatest extent possible. The evolution of the different power curves demonstrates the effectiveness of this proposed algorithm to ameliorate the power demand by absorbing power from the home in case of lack in demand or injecting power to home when there is an extra consumption. The performance of this approach was evaluated trough the interaction of three households. Each one is equipped with a flexible number of PEV to reduce especially the load peak intensity, flatten the demand fluctuation and consequently minimize the stress on power grid. As a future work, we will focus on the dynamic and performance of the PEV battery as well as the development of battery degradation cost models. Furthermore, PEV battery lifetime modelling might also be implemented for PEV charging/discharging improving in the future studies.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jobe.2019.100976.

Appendix

Li-ion battery cell (3.3 V, 2.3 Ah) data.

Characteristics	Value
U_0	3.366 V
R	0.01 Ω
K	0.0076 Ω
A	0.26422 V
B	26.5487 $(Ah)^{-1}$
μ_{PEV}	$\frac{1}{6}(KW/Km)$

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Nomenclature

V_{batt}: Battery voltage (V)
U_0: Battery constant voltage (V)
R: Battery internal resistance (Ω)
K: Constant Polarization (Ω)
I: Battery current (A)
$I.t$: Actual battery charge (Ah)
I^*: Filtered current of the Battery (A)
Q: Battery capacity(Ah)
A: Exponentiel zone amplitude (V)
B: Exponential zone inverse time $(\text{Ah})^{-1}$
SOC_{min}: Acceptable lower limit of the battery SOC
SOC_{max}: Acceptable upper limit of the battery SOC
P_{min}: Minimum operating power of PEV (KW)
P_{max}: Maximum operating PEV power of PEV (KW)
μ_{PEV}: Efficiency of the vehicle (KW/Km)
$P_{travelling}$: essential power for traveling (KW)
$AD_{travelling}$: distance travelled by the PEV(Km)
U_{m-bat}: Modulated voltage of DC/DC converter(V)
U_{DC}: Voltage of the DC bus (V)
V_{Gd}, V_{Gq}: Direct and quadratic components of Grid voltages (V)
i_{td}, i_{tq}: d and q line currents (A)
PEV_i: PEV identity number
PEV_{mod}: PEV model
T_{arr}: PEV arrival time to home
T_{dep}: PEV departure time from home
BAT_{type}: PEV battery type
BAT_{cap}: PEV battery capacity (KWh)
$P_{LH,n}$: Power demand of a home number "n"
$P_{LNH,h}$: Power demand of a neighbor home number "h"
$P_{RH,n}$: Power reference of a home number "n"
$P_{RNH,h}$: Power reference of a neighbor home number "h"
A_{PEVH}: Availability of the PEV connected at the considered home
A_{PEVNH}: Availability of the PEV connected at the neighbor home
SOC_{PEVH}: Initial energy of battery of the PEV connected at the considered home
SOC_{PEVNH}: Initial energy of battery of the PEV connected at the neighbor home
ΔP: Allowable power variation margin(W)
$P_{LH,n}$*: Modified power demand of home number "n"
P_{PEVH}: PEV power of the PEV connected at the considered home
P_{PEVNH}: PEV power of the PEV connected at the neighbor home
P_{LHtot}*: Modified total power demand of all homes
n : Counter of home number, n i∊$[1, n_H]$
h: Counter of neighbor home number, h ∊$[1, n_{NH}]$
n_H: Total number of homes
n_{NH}: Total number of neighbor homes
n_{PEVH} : Total number of PEV of each studied home
n_{PEVNH}: Total number of PEV of neighbor homes