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A priority-based seven-layer strategy for energy management cooperation in a smart city integrated green technology

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HIGHLIGHTS

- A general seven-layer smart city energy management strategy structure based on the cooperation between smart homes is proposed.
- The key goals are flattening the smart homes power profiles and reducing their electricity bills.
- This strategy supports a free charging of electric vehicles.
- This energy management can be applied on any smart city equipped with a flexible number of renewable energy sources and plug-in electric vehicles.

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ABSTRACT

The notion of smart city is based on using both bidirectional power and data flows. For that, designing a persuasive control model for power flow becomes a big and crucial part in a smart city to optimize the power balance between production and consumption. So, a seven-layer smart city energy management strategy (SLSCEMS) for multiple home energy cooperation is presented in this paper. The optimised aims of this strategy are smoothing the smart homes power demand profiles, reducing the electricity bills (E.B), and gaining a total free charging of Plug-in Electric Vehicles (PEVs). This approach has been designed as hierarchic local and global layers. The first one is divided into three layers that aim to transfer the energy between each smart home and its own Renewable Energy sources (RES) and PEVs. The second one is split into four layers that aim to transfer the energy between each smart home and its PEVs, the neighboring homes and their RES, and the smart grid. All optimised layers are based on Particle Swarm Optimization (PSO) algorithm. The proposed strategy is evaluated in a city that contains one hundred homes classified into five categories, each category is designated by its power profile and its flexible number of RESs and PEVs. Simulation results show a decrease in the daily E.B of 26.24%, 2.42%, 60.33%, 29.51%, and 2.38% respectively of the five categories. So, these numerical results prove that the proposed SLSCEMS has considerable efficiency.

1. Introduction

The world has known a variety of technologies that interact with the grid which results in an inevitable increase in energy demand. This increase reduces reliability and safety and disrupts power quality [1]. For this reason, fossil fuels continue to dominate the world energy supply and become more expensive and the issue of climate change has become increasingly important [2,3]. In fact, continued heavy reliance on fossil fuels has led to a dramatic increase in global carbon dioxide emissions despite significant technological-driven improvements in energy efficiency [4]. Today, the global energy challenge is to meet energy needs without harming the environment by reducing reliance on polluting fossil fuels. Moreover, it must also be economically, viable, and reliable.

Generating electric power from Renewable Energy sources (RES) presents the hoped big portion for emitting power into future microgrid systems [5,6]. Many researchers have been concentrating on the field of RES. In [7], a multi-objective daily energy management for networked microgrids composed of Photovoltaic Generators (PVGs) and Wind turbines (WTs) is proposed. The main idea of this model is to build a coalition and cooperation between microgrids, reduce its cost, greenhouse gas emissions, and decease system voltage drop. An energy management model for a smart locality is proposed in [8]. This locality consists of multiple consumers, RES, a central storage, and a smart grid.

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Nomenclature

Acronyms

PEV Plug-in electric vehicle
E. B Electricity-bill
RES Renewable energy sources
PSO Particle swarm optimization
EMS Energy management system
PVG Photovoltaic generator
SLSCEMS seven-layer smart city EMS

Indices

N_H number of homes
N_p number of periods
t Current period,t $\in \{1,2,\cdots,N_p\}$
i,j,k number of iterations,i $\in \{1,2,\cdots,N_H\}$
m number of iterations,j $\in \{1,2,\cdots,\mathrm{N}\}$
n number of iterations,j $\in \{1,2,\cdots,D\}$
C_i Category of home *i*
$P_{Hi_{in,t}}$ initial power of home *i*
P_{AV_i} average power of home *i*
$P_{Hi_{L1,t}}$ power of home *i* after layer 1
$P_{Hi_{L3,t}}$ power of home *i* after layer 3
$P_{Hi_{L4,t}}$ power of home *i* after layer 4
$P_{Hi_{L6,t}}$ power of home *i* after layer 6
$P_{RES_{MPPi,t}}$ maximum RES power of home *i*
$P_{RES,L1_{MPPi,t}}$ maximum RES power of home *i* after layer 1
$P_{RES,L2_{MPPi,t}}$ maximum RES power of home *i* after layer 2
$P_{RES,L4_{MPPi,t}}$ maximum RES power of home *i* after layer 4
$P_{RES,L5_{MPPi,t}}$ maximum RES power of home *i* after layer 5
$P_{city_{initial}}$ The entire initial city demand power
ref reference
$P_{l,ch}$ Minimum power injected by a PEV.
$P_{l,disch}$ Maximum power injected by a PEV
Pr_{Grid_t} Grid electricity price
$Pr_{Grid,av}$ Average grid electricity price
Pr_{city_t} City electricity price
$Pr_{city,av}$ Average city electricity price
RES_{Hi} Renewable energy sources power
$\mathrm{fitness}_L$ Local fitness function
$\mathrm{fitness}_G$ Global fitness function
$C.S_{PEVs}$ connexion state of PEVs
$\mathrm{E.B}_{initial}$ initial E.B
$\mathrm{E.B}_{final}$ Final E.B
ΔT, T Duration of time period/time period
$Q_{batt,PEVi}$ Battery capacity (Ah)
$P_{RES_{Hj}=>PEV_{Hi,ref,t}}$ Reference power transferred from RES home *j* to PEV home *i*
$P_{PEV_{Hj}<=>Hi_{ref,t}}$ Reference power transferred between home *i* and PEV home *j*
$P_{RES_{Hi}=>Grid_{ref,t}}$ Reference power transferred from RES home *i* to grid
$P_{PEV_{Hi}<=>Hi_{ref,t}}$ Reference power transferred between home *i* and PEV home i
$P_{RES_{Hj}=>Hi_{ref,t}}$ Reference power transferred from RES home *j* to home *i*
$P_{RES_{Hi}=>PEV_{Hi,ref,t}}$ Reference power transferred from RES home *i* to PEV home *i*
SOC_{max} Batteries maximum state of charge
$\mathrm{SOC}_{min,l}$ Batteries local minimum state of charge
$\mathrm{SOC}_{min,g}$ Batteries global minimum state of charge
$SOC_{PEV_{t-1}}$ actual values of PEVs batteries
$SOC_{PEVi_{L2,t}}$ actual values of PEVs batteries after layer 2
$SOC_{PEVi_{L3,t}}$ actual values of PEVs batteries after layer 3
$SOC_{PEVi_{L5,t}}$ actual values of PEVs batteries after layer 5
SOC_{PEVi_t} actual values of PEVs batteries after layer 6
H_{DECs} Rested hours number for PEVs disconnection
$P_{RES_{Hi}=>Hi_{ref,t}}$ Reference power transferred from RES home *i* to home *i*
$P_{city_{final}}$ The entire final city demand power

The central challenges of this paper are developing a bi-level optimisation based on energy sharing model and a RES pricing. The main objective of this strategy is lowering energy costs with saving user comfort. In [9], the research develops an efficient model of power operations management to obtain the energy optimization for energy efficacy in smart cities. The key point of this study is delivering a system that satisfies energy optimization of the energy costs in real-time using various natural sources. Considerably, several researchers have focused on two dominating RES which are the PVG and the WT. Nevertheless, these technologies have an intermittent characteristic that presents the main cause for limiting its growth [10]. For that, the need for green compliance and energy storage becomes a crucial issue.

Plug in electric vehicles (PEVs) can be considered as energy storage technology that functions as a flexible load and storage sources. This might have a serious impact on grid performances and power demand. Also, it presents the major part in decarbonising street transport. In [11], a smart city energy supervision system is proposed. The considered smart city is equipped with ten smart homes and each one is fitted with a viable number of PEV and a specific power daily profile. The objective of this study is to manage the charging and discharging of PEVs from/to its corresponding home and then flattening the smart city power demand. A multistage system for charging PEVs in a smart city is proposed in [12]. The first system idea is optimizing the optimal placement of power track which depends on city traffic data and PEV energy demand. And the second is investigating the best strategy for placing power tracks in the entire city.

Indeed, Power conversion in smart city with PEV plays a critical role as optimal charging and discharging. Despite that, much attention has been conducted to the coalition of PEVs with clean electricity generated from RESs due to the feasible disconnection of PEVs and its limited storage capacities. Furthermore, this coalition offers the topmost term potential for net-zero energy [13,14]. A hierarchical energy management strategy for many home energy hubs equipped with PVGs and PEVs connected to the neighborhood grid is developed in [15]. The main aims are increasing the monetary profit and flattening the peak of grid demand power. This proposed methodology based on the highest consumer excess power, the lowest possible price, and the state of charge (SOC) tariff plane. As the main trend of smart city energy management, in [16] the researchers have developed a real time pricing tariff to organise the demand response strategy. Additionally, a Multi-objective dragonfly model is used to reach both economic and technical objective functions considering the WT as the energy source and PEV as the energy storage. Another researcher in [17], has proposed a linear model to optimize the planning and operation of distributed RESs in order to achieve technical and economic objectives. In this study, the length and the traffic of the routes are designed basing on modes vehicle to subway and vehicle to grid. Nevertheless, none of these last three papers has focused on the combination of RESs and PEVs aiming to achieve well-designed and studied objectives. Yet, they didn't propose an energy management strategy that focuses on the achievement of many objectives of smart city simultaneously as smoothing the grid powers demand, PEVs free charging, and reducing the electricity bill (E.B) of each smart home.

To achieve this, this paper will provide a seven-layer smart city

Table 1
Taxonomy of energy management of a smart city considering the used technology, methodology, and objectives.

Ref.	Technology			Methodology and objective					
	PVG	WT	PEV	Self power model	Cooperative power model	Highest excess power	First/last disconnected PEV	Optimal powers references	Objectives
[7]	✓	✓	–	✓	–	–	–	–	• Reduce cost and decease system voltage drop. Case study: three same microgrids.
[8]	✓	–	–	✓	✓	–	–	–	• Reduce cost and peak load demand. Case study: two same smart homes.
[9]	✓	✓	–	–	–	–	–	–	• Reduce cost and efficient control of power operations management. Case study: one example in entire smart city.
[11]	–	–	✓	✓	–	–	–	–	• Flatten the power curve demand. Case study: ten different smart homes.
[12]	–	–	✓	–	–	–	–	✓	• Reducing cost by charging EV from a roadway powering system. Case study: one EV charged from a roadway powering system.
[15]	–	–	✓	✓	✓	✓	–	–	• Reduce cost and flatten the power curve demand. Case study: four homes aggregated into 2 same smart home and 2 same conventional home.
[16]	✓	✓	✓	✓	–	–	–	–	• Reduce cost and flatten the power curve demand. Case study: twenty same smart homes.
[17]	✓	✓	✓	–	–	–	–	✓	• Increasing the PEV profits by charging EVs from subways. Case study: four different EVs.
Proposed approach	✓	✓	✓	✓	✓	✓	✓	✓	• Flatten the power curve of different categories of smart homes, reduce cost and display all the optimal powers reference exchanged in the smart city. Case study: hundred homes aggregated into five different categories.

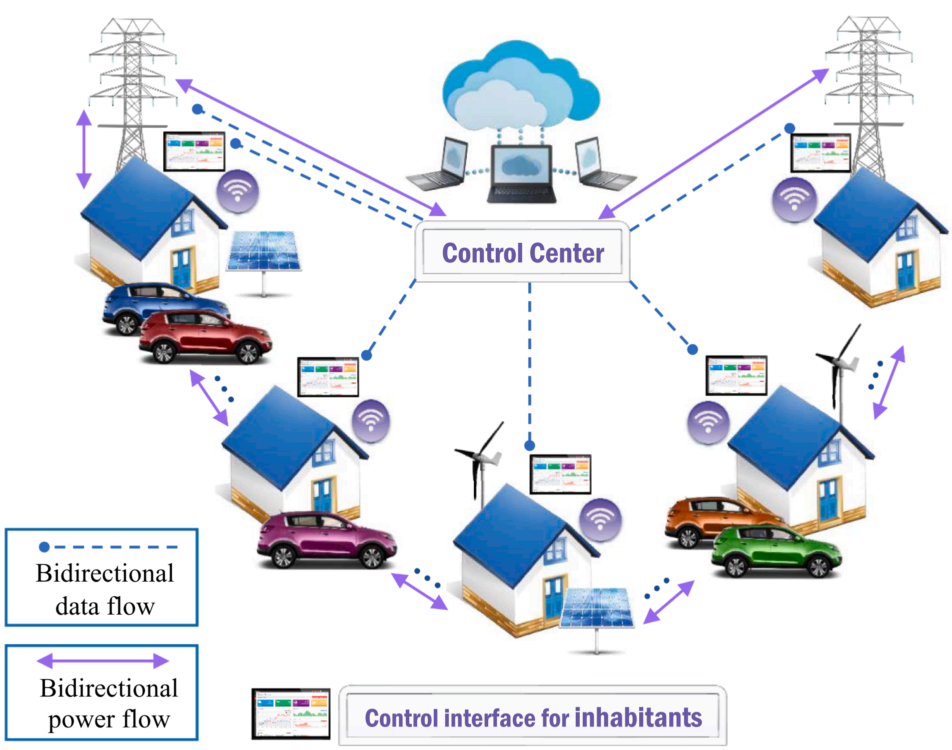

Fig. 1. Description of the studied smart city design.

energy management strategy (SLSCEMS) that is applicable to any smart city fitted with a flexible number of homes equipped with RESs and PEVs. The presented strategy has local and global layers. The first one is based on the self home control, unlike the second one which is generally based on the cooperation between neighbors and deeply on the RESs maximum excess power and the PEVs time disconnections. The key contributions of this work are to insure these present challenges simultaneously:

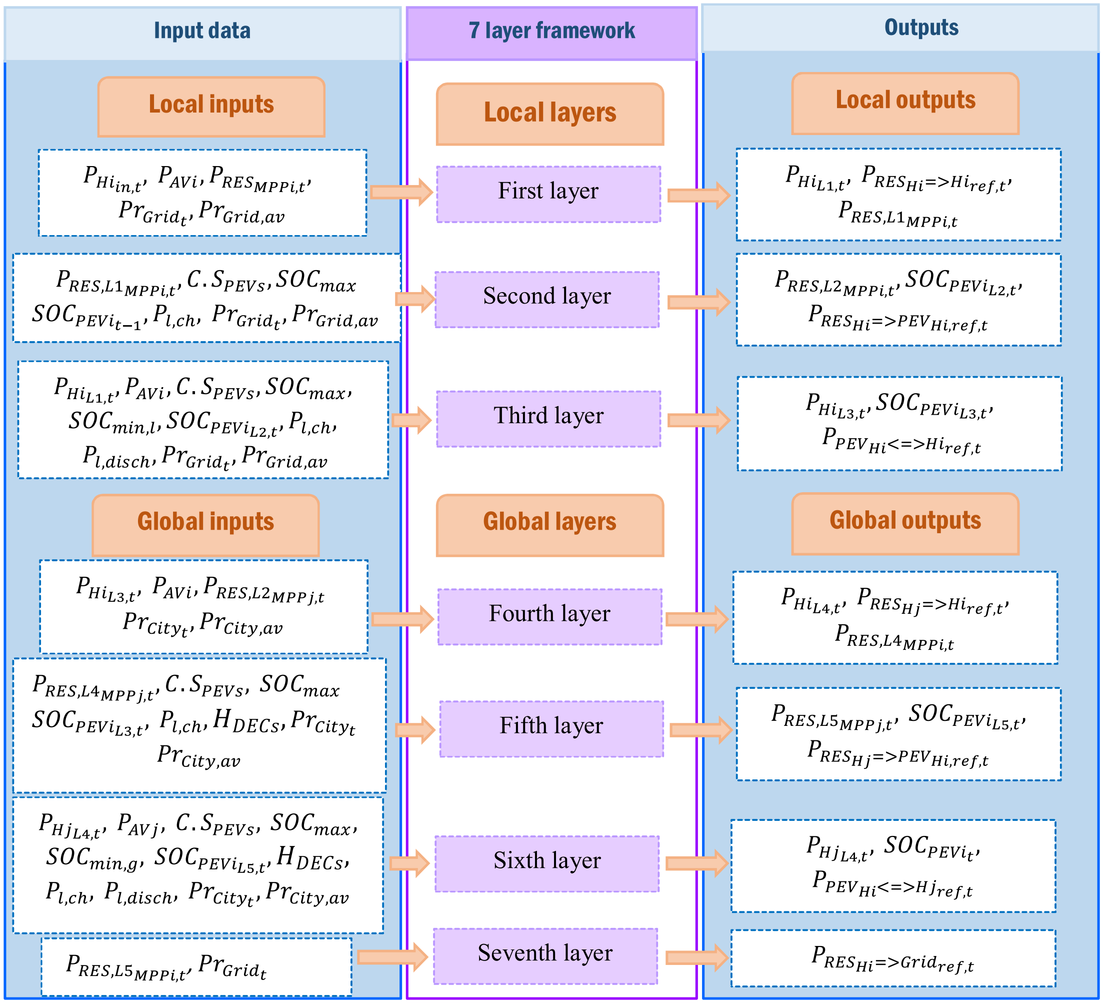

Fig. 2. General structure of the seven-layer smart city energy management strategy.

- Dealing with a flexible number of smart homes characterized by different power demand profile design and a flexible number of PEVs and RESs.
- Managing the RESs generated powers. Indeed, not only can inhabitants be delighted with high-quality energy, but also neighborhood and grid can enjoy the surplus RESs generated powers.
- Detecting the RESs highest excess powers to support the integration of green technology.
- Detecting the PEVs availabilities to participate in the smart city approach and checking their SOCs.
- Detecting the first/last connected/disconnected PEV to build a wise chargement/dischargement.
- Gaining a total free charging of PEVs.
- Obtaining the optimal powers reference exchanged between the different elements of the studied smart city using mathematical objective functions and constraints.
- Flattening the homes demand power profil by valleys filling and peaks shaving in order to enhance the smart city power grid quality and stability.
- Maximizing the financial benefit of inhabitants by building a grid and city special time tariffication.

These contributions can be summarized in this taxonomy table as follows (Table 1).

This proposed strategy is applied to hundred households aggregated into 5 different equivalent homes. Moreover, the obtained results highlight that the proposed strategy aims to improve the smart city power stability and avoid the stress on the whole smart grid, increase the finance profit of the inhabitants, and obtain a free charging of PEVs.

The rest of the paper is structured as follows: a general description of the studied smart city is presented in Section 2. In Section 3, the proposed SLSCEMS is described. The Simulation results, their descriptions and the conclusion of this paper are detailed in Section 4.

2. Proposed smart city design

The general schematic of the SLSCEMS is presented in Fig. 1. In this figure, several homes exist where each one could have more than one RES and more than one PEV.

RESs systems aim to generate clean electricity and all PEVs have the ability to charge and discharge as they can be either loads or storage sources. A lithium-ion battery for the PEVs is selected to continue this study due to its high power, energy density, nominal voltage, and number of charge and discharge cycles [18,19]. At grid side, a control center that communicates in two-way flows with the control interface fitted in each smart home. For that, each RES, PEV, and meter in the smart homes should be equipped with information technology-based communication to send/receive data to/from its corresponding control interface [20,21]. Furthermore, the smart city is characterized with a bidirectional power flow to form the coalition between all homes and grid. This is how the smartness of the electrical network comes into play.

3. Description of the SLSCEMS framework

As shown in Fig. 2, the proposed SLSCEMS is designed as a hierarchical framework divided into local and global layers. Also, the local layers contain three subsequent layers, and the global layers are fitted with four. All existing layers receive input data from other devices of the smart city or/and from the output of the preceding layers, then they display obligatory output data. This strategy was developed in the interest of flattening the smart homes power profiles, winning a total free charging of all PEVs, and maximizing the profit of inhabitants, likewise reinforcing the motivation of inhabitants to exploit green technologies. In this way, the city changes to a new energy decentralized system with low-carbon and rechargeable components that turn natural resources into services.

The seven layers are executed in an entire day (24 h) that is discretized into N_p periods with $N_p = 48$, and the period-time is presented by $\Delta T = 30min$.

3.1. Local layer framework

This step revolves around the transfer of energy locally. It aims to manage the energy generated by each RES and the energy conveyed between each home and its corresponding PEVs. Hence, the power profile of each smart home improves and gets flatter through its own RESs and electric vehicles. Thus, the batteries of the PEVs charge through their corresponding smart homes and RESs without exceeding its maximum state of charge SOC_{max}.

3.1.1. First layer

The key objective of the first layer is flattening the peak daily load profiles and then reducing the power purchased from the electric network. As such, each RES injects an amount of power to its corresponding home i until each power profile $P_{Hi_{in,t}}$ reaches its average power P_{AV_i}. In this top layer, some input should be sent: $P_{Hi_{in,t}}, P_{AVi}$, the maximum Power produced by the RES $P_{RES_{MPPi,t}}$, grid electricity price Pr_{Grid_t}, and grid average electricity price $Pr_{Grid,av}$ from both RESs and electricity market, as illustrated in Fig. 2. Next, the objective function formulated in (1), displays the optimal reference power $P_{RES_{Hi}=>Hi_{ref,t}}$ provided by each RES of home i to its corresponding home i, the obtained power profile $P_{Hi_{L1,t}}$, and the RESs excess power.

$P_{RES,L1_{MPPi,t}}$ are also obtained. It is important to clarify that N_H presents the number of smart homes, and also according to the chosen RESs side convention, the obtained $P_{RES_{Hi}=>Hi_{ref,t}}$ power is regarded as positive.

$$min \sum_{t=1}^{N_p} \sum_{i=1}^{N_H} (\frac{1}{T} (P_{Hi_{in,t}} - P_{RES_{Hi}=>Hi_{ref,t}} - P_{AV_i})^2) \tag{1}$$

Constraint:

$$0 \leq P_{RES_{Hi}=>Hi_{ref,t}} \leq P_{RES_{MPPi,t}} \forall i \in \{1, 2, \cdots, N_H\} \tag{2}$$

The corresponding constraint is presented by (2). This marked constraint shows the minimum and the maximum limits of the power injected by the RESs which are respectively 0 and $P_{RES_{MPPi,t}}$. To note that $P_{RES_{MPPi,t}}$ defines the maximum power produced by each RES.

3.1.2. Second layer

The objective of this second layer, is to charge each connected PEV of home i from the RES excess power of the same home. This mode is applied only when the price is significantly low. Then, the implementation of this second part of the proposed SLSCEMS necessitates the registration of: $P_{RES,L1_{MPPi,t}}$, PEV connection state $C.S_{PEVi}$, the battery maximum state of charge SOC_{max}, the present value of the PEV $SOC_{PEVi_{t-1}}$, the minimum power injected in a PEV $P_{l,ch}$, Pr_{Grid_t}, and $Pr_{Grid,av}$ from both PEVs and electricity market. Next, the purpose of the objective function written in (3), is generating the optimal references powers $P_{RES_{Hi}=>PEV_{Hi,ref,t}}$ provided by each RES to the PEV of the same home, the new RES excess power $P_{RES,L2_{MPPi,t}}$, and the new actual PEV state of charge $SOC_{PEVi_{L2,t}}$ are also obtained. If a smart home contains more that one PEV, the first connected PEV has the charging priority. According to the chosen PEVs side convention, the obtained $P_{RES_{Hi}=>PEV_{Hi,ref,t}}$ power is regarded as negative.

$$min \sum_{t=1}^{N_p} \sum_{i=1}^{N_H} (\frac{1}{T} \left(P_{RES,L2_{MPPi,t}} + P_{RES_{Hi}=>PEV_{Hi,ref,t}}\right)^2) \tag{3}$$

Four constraints should be respected as follows.

Constraint 1:

Batteries should avoid the over-charging in charging modes. So, the constraint shown in (4) defines the maximum rate SOC_{max} of all PEVs [22,23].

$$SOC_{PEV_{t-1}} - \frac{P_{RES_{Hi}=>PEV_{Hi,ref,t}} \times \eta \times \Delta t}{Q_{batt,PEV\,i}} \leq SOC_{max} \forall i \in \{1, 2, \cdots, N_H\} \tag{4}$$

$$0 < \eta < 1$$

Constraint 2:

One of the key goals is to achieve the inhabitants profit maximization. Hence, all RESs inject power for charging the PEVs only during low price hours as expressed in (5) [24].

$$P_{RES_{Hi}=>PEV_{Hi,ref,t}} \times \left(Pr_{Grid,av_t} - Pr_{Grid_t}\right) \langle 0 \forall i \in \{1, 2, \cdots, N_H\} \tag{5}$$

Constraint 3:

For the sake of preventing the battery overload, the topmost amount of power $P_{l,ch}$ absorbed by each PEV is satisfied by (6) [25].

$$P_{l,ch} - P_{RES_{Hi}=>PEV_{Hi,ref,t}} \leq 0 \forall i \in \{1, 2, \cdots, N_H\} \tag{6}$$

Constraint 4:

The constraint expressed in (7) presents the connection state of the PEV. Indeed, this mode of charge can be released only when the PEV of home i is connected to its domestic charging socket.

$$C.S_{PEV,Hi} > 0 \forall i \in \{1, 2, \cdots, N_H\} \tag{7}$$

3.1.3. Third layer

For more flattening the power profiles, PEVs charging and discharging management via and to its corresponding home is planned in this layer. So as to obtain a power profile that coincides with its average, PEVs discharge during peak hours, when the prices are higher. Instead, it charges during off-peak hours, when the prices are lower. For that, the input data of this layer are: $P_{Hi_{L1,t}}$, P_{AVi}, $C.S_{PEVs}$, SOC_{max}, the battery minimum state of charge SOC_{min}, $SOC_{PEVi_{L2,t}}$, , $P_{l,ch}$, the maximum power injected by a PEV $P_{l,disch}$, Pr_{Grid_t}, and $Pr_{Grid,av}$. The objective function presented in (8) is developed to generate the optimal reference power $P_{PEV_{Hi}<=>Hi_{ref,t}}$ injected or absorbed by each PEV, the new power profile $P_{Hi_{L3,t}}$, and the new actual state of charge $SOC_{PEVi_{L3,t}}$ are produced. The obtained $P_{PEV_{Hi}<=>Hi_{ref,t}}$ power is regarded as negative when the PEVs charge and positive when the PEVs discharge according to the chosen PEVs side convention.

$$min \sum_{t=1}^{N_p} \sum_{i=1}^{N_H} (\frac{1}{T} (P_{Hi_{L1,t}} - P_{PEV_{Hi}<=>Hi_{ref,t}} - P_{AV_i})^2) \tag{8}$$

Four constraints should be respected as follows.

Constraint 1:

Protecting batteries against overcharge and deep discharge is requisite incessantly. So, the minimum and the maximum batteries state of charge $SOC_{min,l}$ and SOC_{max} are defined in (9).

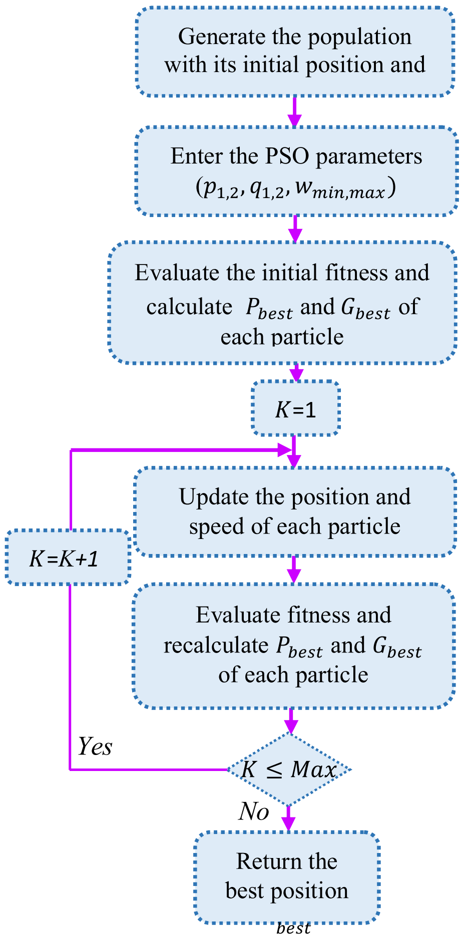

Fig. 3. PSO Algorithm Block Diagram.

$$SOC_{min,l} \le SOC_{PEVi_{L2,t}} - \frac{P_{PEV_{Hi<=>Hi_{ref,t}}} \times \eta \times \Delta t}{Q_{batt,PEV_i}} \le SOC_{max} \forall i \in \{1,2,\cdots,N_H\} \tag{9}$$

$$0 < \eta < 1$$

Constraint 2:

As explained, PEV charging action is promoted only when the prices are lower, meaningly when Pr_{Grid_t} is less than Pr_{Grid,av_t}. Conversely, PEV discharging action is promoted only when the prices are higher, meaningly when Pr_{Grid_t} is upper than Pr_{Grid,av_t} as expressed in (10).

$$min \sum_{t=1}^{N_p} P_{PEV_{Hi<=>Hi_{ref,t}}} \times \left(Pr_{Grid,av_t} - Pr_{Grid_t}\right) \forall i \in \{1,2,\cdots,N_H\} \tag{10}$$

Constraint 3:

Also, the transferred power to/from the PEVs should never be ver limited. So, the minimum and the maximum transferred powers are presented in (11).

$$P_{l,ch} \le P_{PEV_{Hi<=>Hi_{ref,t}}} \le P_{l,disch} \forall i \in \{1,2,\cdots,N_H\} \tag{11}$$

Constraint 4:

As defined in (12), this charging and discharging modes can be realized only during the connection of the PEV.

$$C.S_{PEV,Hi} > 0 \forall i \in \{1,2,\cdots,N_H\} \tag{12}$$

3.2. Global layer framework

To ensure more liveable smart city, more flattened powers profiles, and putting downward force on the E.B, this step is proposed. It concentrates on the transfer of energy globally, in which the power profile of each smart home improves through the RESs and PEVs of the neighboring homes. Thus, the batteries of the PEVs charge through smart homes and RESs of neighboring homes.

In the following, the homes are classified into two classes: the first class is indicated by home *i*. It presents the homes that are under regulation. The second class is indicated by home *j*. It presents the home that will do the regulation.

3.2.1. Fourth layer

The first class of homes possesses a lack of renewable energy production with a peak of consumption. The second class presents the homes that are characterized with an excess of renewable energy production with a regulated demand profile. Also, this layer seeks in transferring an amount of power produced by the neighbor home *j* RES to the home *i* until the power profile of this last coincides with its average power P_{AV_i}. Some input data should be registrated: $P_{Hi_{L3,t}}$, P_{AVi}, $P_{RES,L2_{MPPj,t}}$, city electricity price Pr_{City_t}, and city electricity price average $Pr_{City,av}$. Next, the objective function expressed in (13), shows the optimal reference power $P_{RES_{Hj=>Hi_{ref,t}}}$ offered by each RES of home *j* to home *i*, the obtained power profile $P_{Hi_{L4,t}}$, and the RESs excess power $P_{RES,L4_{MPPj,t}}$ are also produced. This layer led to better smooth the power profiles and to gain a lower cost thanks to the city lower price.

$$min \sum_{t=1}^{N_p} \sum_{i=1}^{N_H} \sum_{\substack{j=1 \\ j \ne i}}^{N_H} \left(\frac{1}{T}\left(P_{Hi_{L3,t}} - P_{RES_{Hj=>Hi_{ref,t}}} - P_{AV_i}\right)^2\right) \tag{13}$$

Two constraints should be observed as follows.

Constraint 1:

In the interest of building a green competition between neighborhood, this constraint is established. In fact, the priority among N_H homes that will provide the power, is the one that has the highest RES excess power as outlined in (14). The matric namely RESs contains the RES excess power of each home, so this data should be received by the SLSCEMS each ΔT period.

$$RESs = \left[P_{RES,L2_{MPP1,t}}, P_{RES,L2_{MPP2,t}}, \cdots, P_{RES,L2_{MPPj,t}}, \cdots, P_{RES,L2_{MPPN_H,t}}\right],$$

$$P_{RES,L2_{MPPj,t}} \ge P_{RES,L2_{MPPk,t}} \forall j,k \in \{1,2,\cdots,N_H\}/(i \ne j \ne k) \tag{14}$$

Constraint 2:

As marked in the first layer, the transferred power $\boldsymbol{P_{RES_{Hj=>Hi_{ref,t}}}}$ is limited by the minimum power which is zero and the maximum power which is $\boldsymbol{P_{RES,L2_{MPPj,t}}}$ as shown in (15).

$$0 \le \boldsymbol{P_{RES_{Hj=>Hi_{ref,t}}}} \le \boldsymbol{P_{RES,L2_{MPPj,t}}} \forall \boldsymbol{i}, \boldsymbol{j} \in \{1,2,\cdots,N_H\}/(\boldsymbol{i} \ne \boldsymbol{j}) \tag{15}$$

3.2.2. Fifth layer

To take more advantage of the RESs excess power, this layer is suggested. It aims to charge the PEV of home *i* via the excess power of the neighbor home *j*. For that, the input data of this layer are: $P_{RES,L4_{MPPj,t}}$, $C.S_{PEVs}$, SOC_{max}, $SOC_{PEVi_{L3,t}}$, P_{li-ch}, rested hours number for PEVs disconnection H_{DECs}, Pr_{City_t}, and $Pr_{City,av}$. Then, the objective function written in (16), displays the optimal reference power $P_{RES_{Hj=>PEV_{Hi,ref,t}}}$ injected by each RES of home *j* to PEV of home *i*, the new PEV state of charge $SOC_{PEVi_{L5,t}}$, and the RESs excess power $P_{RES,L5_{MPPj,t}}$ are also given.

$$min \sum_{t=1}^{N_p} \sum_{i=1}^{N_H} \sum_{\substack{j=1 \\ j \ne i}}^{N_H} \left(\frac{1}{T}\left(P_{RES,L4_{MPPj,t}} + P_{RES_{Hj=>PEV_{Hi,ref,t}}}\right)^2\right) \tag{16}$$

Five constraints should be observed as follows.

Constraint 1:

As cited in the constraints above, to protect batteries, the state of

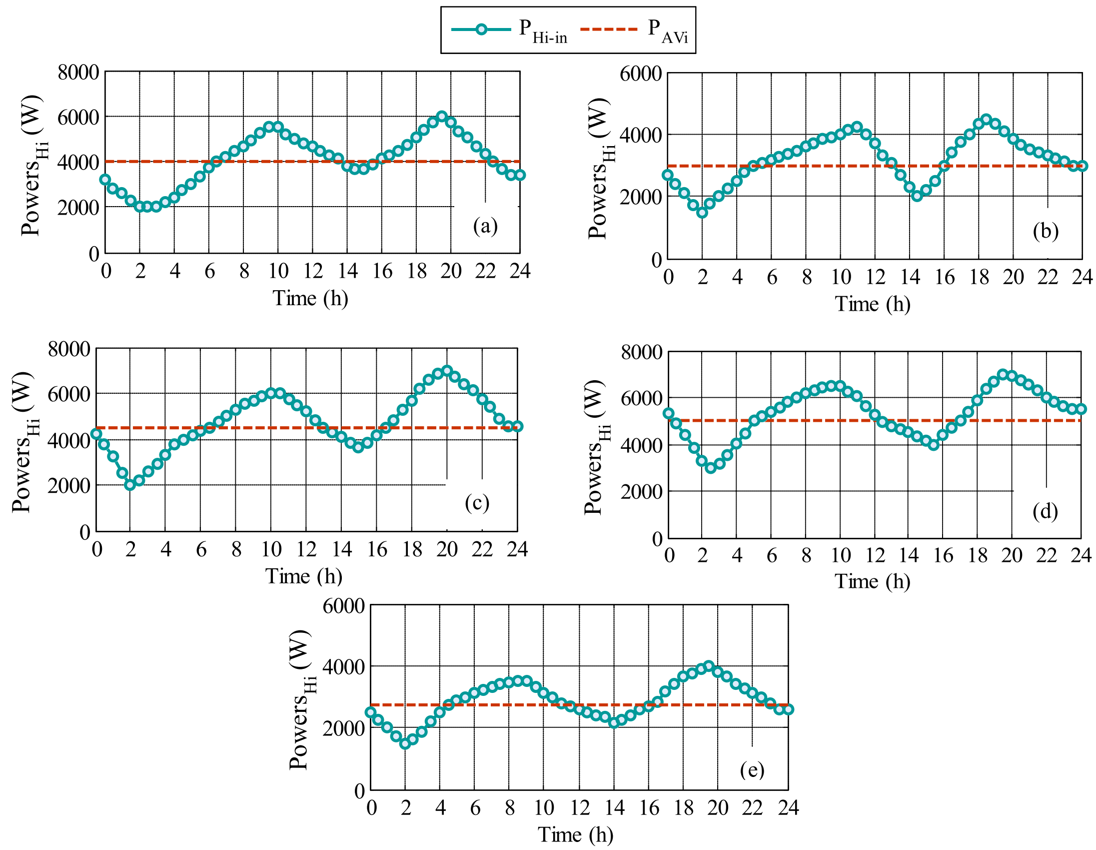

Fig. 4. Initial power profiles of the studied smart homes: (a) Home 1; (b) Home 2; (c) Home 3; (d) Home 4; (e) Home 5.

charge shouldn't exceed the maximum limit $\boldsymbol{SOC_{max}}$ as mentioned in (17).

$$SOC_{PEVi_{L3,t}} - \frac{P_{RES_{Hj=>PEV_{Hi,ref,t}}} \times \eta \times \Delta t}{Q_{batt,PEV\,i}} \leq SOC_{max} \forall i,j \in \{1,2,\cdots,N_H\}/(i \neq j) \tag{17}$$

$$0 < \eta < 1$$

Constraint 2:

As mentioned in layer 2, PEVs receive power from RESs only when the price is low as written in (18).

$$\sum_{t=1}^{N_p} P_{RES_{Hj=>PEV_{Hi,ref,t}}} \times \left(Pr_{City,av_t} - Pr_{City_t}\right) \langle 0 \forall i,j \in \{1,2,\cdots,N_H\}/(i \neq j) \tag{18}$$

Constraint 3:

The amount of power injected from the RES to the PEV in $\Delta \boldsymbol{T}$ period is restricted by a limited power $\boldsymbol{P_{l,ch}}$ as expressed in (19).

$$P_{l,ch} - P_{RES_{Hj=>PEV_{Hi,ref,t}}} \leq 0 \quad \forall i,j \in \{1,2,\cdots,N_H\}/(i \neq j) \tag{19}$$

Constraint 4:

In the proposed strategy, the power that will be purchased to charge the PEV of home *i,* is from the home that can provide more excess power as written in (20).

$$RESs = \left[P_{RES,L4_{MPP1,t}}, P_{RES,L2_{MPP2,t}}, \cdots, P_{RES,L2_{MPPj,t}}, \cdots, P_{RES,L2_{MPPN_H,t}}\right],$$

$$P_{RES,L2_{MPPj,t}} \geq P_{RES,L2_{MPPk,t}} \ \forall j,k \in \{1,2,\cdots,N_H\}/i \neq j \neq k \tag{20}$$

Constraints 5:

For PEV charging management, two constraints are outlined in (21) and (22). So, to implement the proposed strategy, two matrices namely $C.Ss$ and H_{DECs} will be formed basing on the information received by the SLSCEMS. The matric $C.Ss$ contains the connexion state of each PEV, thus if the PEV of the home i is connected, the data $C.S_{PEV,Hi_t}$ receives 1, else it receives 0. The matric H_{DECs} contains the rested hours number for PEVs disconnection. Thus, if $C.S_{PEV,Hi_t}$ is equal to one, the data H_{DECPEV,Hi_t} receives an integer which presents the rested hours number for the corresponding PEV disconnection, else it receives the string disc that refers to the word disconnected. In fact, the connected PEV that will disconnect first has the minimum number of H_{DECs}, so it has the priority to charge.

$$C.Ss = \left[C.S_{PEV,H1_t}, C.S_{PEV,H2_t}, \cdots, C.S_{PEV,Hi_t}, \cdots, C.S_{PEV,HN_{H_t}}\right],$$

$$H_{DECs} = \left[H_{DEC_{PEV,H1_t}}, H_{DEC\,PEV,H2_t}, \cdots, H_{DEC\,PEV,Hi_t}, \cdots, H_{DEC\,PEV,HN_{H_t}}\right],$$

$$C.S_{PEV,Hi} > 0 \tag{21}$$

$$H_{DEC\,PEV,Hi_t} \leq H_{DEC\,PEV,Hk_t} \forall i,k \in \{1,2,\cdots,N_H\}/(i \neq j \neq k) \tag{22}$$

3.2.3. Sixth layer

This layer aims at managing the transfer of power between home *i* and the PEV of its neighbor home *j.* The objective of this management is obtaining an adorable power profile that coincides with its average power P_{AV_i}. Here, the charge of the neighbor home *j* PEV from the smart home *i* is done only during the low-prices hours. Instead, the discharge of PEV is done only during high-prices hours. The registrated input data are: $P_{Hi_{L4,t}}$, P_{AVi}, $C.S_{PEVs}$, SOC_{max}, SOC_{min}, $SOC_{PEVj_{L5,t}}$, H_{DECs}, $P_{l,ch}$, $P_{l,disch}$, Pr_{City_t}, and $Pr_{City,av}$. The generated output SLSCEMS data are: the transferred power between home *i* and the PEV of its neighbor home *j.*

$P_{PEV_{Hj<=>Hi_{ref,t}}}$ as expressed in (23), the new power profile, the final state of charge SOC_{PEVi_t}.

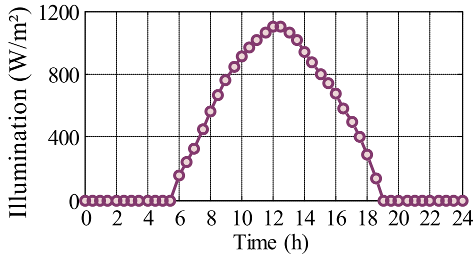

Fig. 5. Typical solar illumination.

$$min \sum_{t=1}^{N_p} \sum_{i=1}^{N_H} \sum_{\substack{j=1 \\ j \neq i}}^{N_H} \left(\frac{1}{T}\left(P_{Hi_{L4,t}} - P_{PEV_{Hj}<=>Hi_{ref,t}} - P_{AV_t}\right)^2\right) \tag{23}$$

Constraint 1:

Equation (24) defines the minimum state of charge $SOC_{min,g}$ to avoid the deep discharge. Furthermore, the level of $SOC_{min,g}$ is higher than $SOC_{min,l}$, because the priority for most discharge is for PEV owner. Also, the equation imposes the maximum state of charge to avoid the full charge.

$$SOC_{min,g} \leq SOC_{PEVj_{L5,t}} - \frac{P_{PEV_{Hi}<=>Hj_{ref,t}} \times \eta \times \Delta t}{Q_{batt,PEV\,j}} \leq SOC_{max}\,\forall i,j \in \{1,2,\cdots,N_H\}/(i \neq j) \tag{24}$$

$0 < \eta < 1$

Constraint 2:

Basing on the principle of supply and demand and increasing the reliability of energy storage systems, this layer is proposed. When the power demand is low, the price is generally low, so PEVs charge via neighborhood home. And when the power demand is high, the price is generally high to encourage inhabitants to delay electricity usage, so PEVs discharge to neighborhood home as expressed in (25).

$$min \sum_{t=1}^{N_p} P_{PEV_{Hj}<=>Hi_{ref,t}} \times \left(Pr_{City,av_t} - Pr_{City_t}\right)\forall i,j \in \{1,2,\cdots,N_H\}/(i \neq j) \tag{25}$$

Constraint 3:

As imposed in other constraints, the obtained power $P_{PEV_{Hi}<=>Hj_{ref,t}}$ is limited by the minimum power $P_{l,ch}$ and the maximum power $P_{l,disch}$ to preserve the PEV battery as shown in (26).

$$P_{l,ch} \leq P_{PEV_{Hj}<=>Hi_{ref,t}} \leq P_{l,disch}\forall i,j \in \{1,2,\cdots,N_H\}/(i \neq j) \tag{26}$$

Constraints 4:

For better management, this constraint is based on the two matrices $C.Ss$ and H_{DECs}. In fact, during the low-prices hours, the priority is to charge the connected PEVs that have the fewest number of H_{DECs} as expressed in (27) and (28). And during the high-prices hours, the priority is to discharge the connected PEVs that have the highest number of H_{DECs} as expressed in (29).

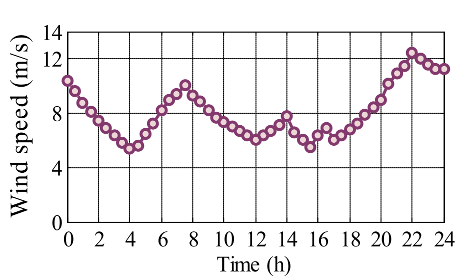

Fig. 6. Typical wind speed.

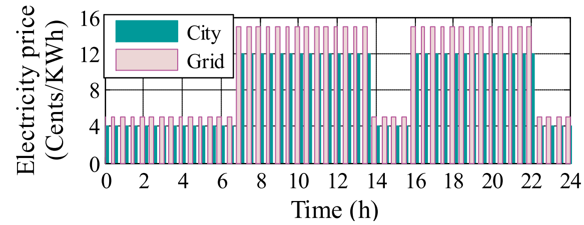

Fig. 7. Grid and city electricity prices.

$$\begin{aligned} C.Ss &= \left[C.S_{PEV,H1_t}, C.S_{PEV,H2_t}, \cdots, C.S_{PEV,Hj_t}, \cdots, C.S_{PEV,HN_{H_t}}\right], \\ H_{DECs} &= \left[H_{DEC_{PEV,H1_t}}, H_{DEC\,PEV,H2_t}, \cdots, H_{DEC\,PEV,Hj_t}, \cdots, H_{DEC\,PEV,HN_{H_t}}\right], \\ & C.S_{PEV,Hj} > 0 \end{aligned} \tag{27}$$

$$H_{DEC\,PEV,Hj_t} \leq H_{DEC\,PEV,Hk_t} \qquad \forall j,k \in \{1,2,\cdots,N_H\}/(i \neq j \neq k) \tag{28}$$

$$\mathrm{H}_{DEC_{PEV,Hj_t}} \geq H_{DEC_{PEV,Hk_t}} \qquad \forall j,k \in \{1,2,\cdots,N_H\}/(i \neq j \neq k) \tag{29}$$

3.2.4. Seventh layer

The last path that the RESs excess power can move is toward the grid. Whatever the price is, the rest of the power produced by each RES is transferred to the grid to guarantee its balance. Also, the data $P_{RES,L5_{MPPj,t}}$ and Pr_{Grid_t} should be received by the SLSCEMS to calculate the monitory profit. Then, the power $P_{RES_{Hi}<=>Grid_{ref,t}}$ is displayed as shown in (30) which should be positive as given in the constraint in (31).

$$min \sum_{t=1}^{N_p} \sum_{i=1}^{N_H} \left(\frac{1}{T}\left(P_{RES,L5_{MPPj,t}} - P_{RES_{Hi}=>Grid_{ref,t}}\right)^2\right) \tag{30}$$

Constraints:

$$P_{RES_{Hi}=>Grid_{ref,t}} \geq 0 \forall i \in \{1,2,\cdots,N_H\} \tag{31}$$

3.3. Implementation of the SLSCEMS

In the interest of getting an optimal short-run of the proposed strategy, the particle swarm optimization (PSO) strategy is used. This technique that is based on the social behaviour of bird clustering and fish schooling has a significant convergence rate [26]. In the PSO, a search space generates N particles, and each one is defined by its velocity V_m and its position X_m that represents a solution of the problem. The mth particle is presented by (32).

$$X_m = \left[X_{m,1}, X_{m,2}, \cdots, X_{m,n}, \cdots, X_{m,D}\right] \tag{32}$$

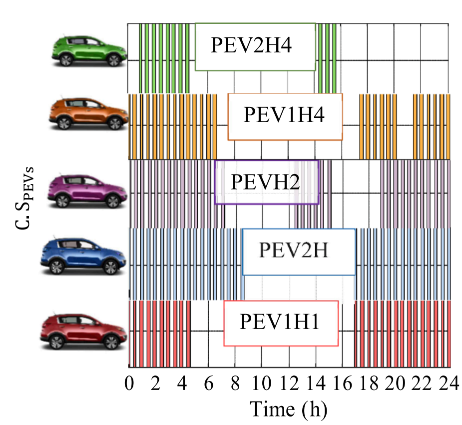

Fig. 8. PEV connection state for each home for one day cycle.

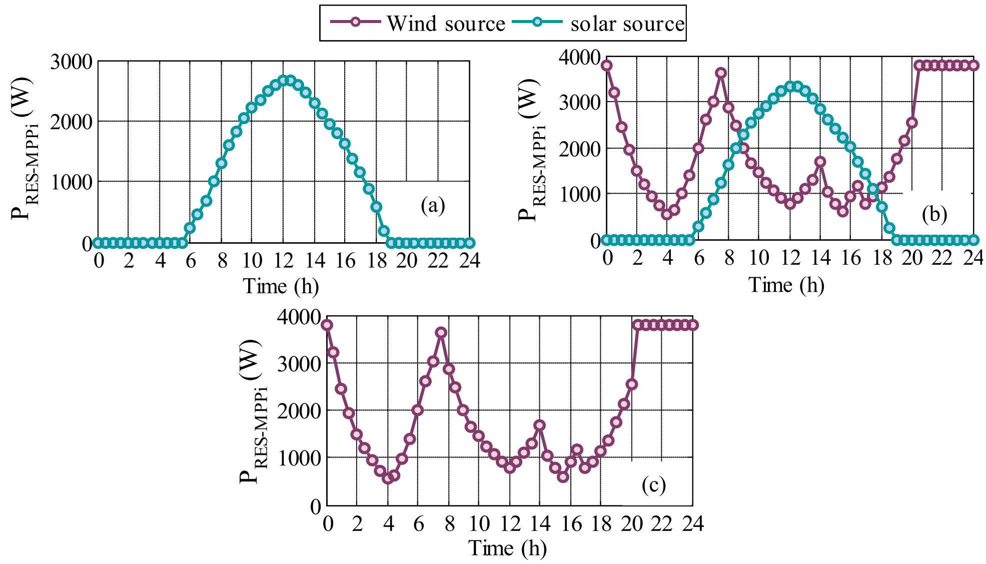

Fig. 9. Maximum power point of each renewable energy sources integrated in: (a) Home 1; (b) Home 3; (c) Home 4.

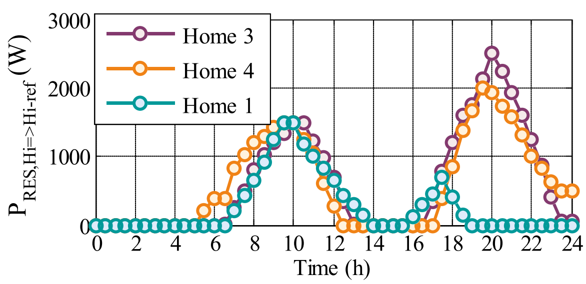

Fig. 10. Power transferred from renewable energy sources to its correspondent home (i).

Where n is a variable change from 1 to D, with D represents the swarm size. All particles are initialised randomly in a search space, whereas their initial position and obtained objectives values are memorised as their personal best solution. While, the position and the best objective value of the entire swarm are memorised as the global/social best solution. Then, the position and the velocity of each particle are updated using equations (33) and (34) until reaching Max iterations as depicted in Fig. 3. Thus, the personal bests and the global best are updated. From these equations, it is remarkable that the new positions of the particles are affected generally by three following terms: w which presents the inertia weight coefficient., $(c_1 \times \rho_1)$ which presents the personal best, and $(c_2 \times \rho_2)$ which presents the social best [27].

Meanwhile, a so-called fitness function evaluation f (X_m) is calculated and memorized to obtain the best personal and social solutions. In the end, the algorithm displays the best solution $Pbest_m$ attained by each particle, and the best overall solution $Gbest_m$ found by all particles [28,29].

$$V_{m,n}^{k+1} = w \times V_{m,n}^{k} + c_1 \times \rho_1 \times \left(Pbest_{m,n}^{k} - X_{m,n}^{k}\right) + c_2 \times \rho_2 \times \left(Gbest_{n}^{k} - X_{m,n}^{k}\right) \tag{33}$$

$$X_{m,n}^{k+1} = X_{m,n}^{k} + V_{m}^{k+1} \tag{34}$$

Where: c_1 and c_2 represent the personal and social acceleration coefficients, ρ_1 and ρ_2 are random numbers, and K is a variable change from 1 to Max, with Max represents the utmost number of iterations.

The local and global layers are implemented using PSO technique to estimate the optimal powers $P_{RES_{Hi}=>Hi_{ref,t}}$, $P_{RES_{Hi}=>PEV_{Hi,ref,t}}$, $P_{RES_{Hj}=>Hi_{ref,t}}$, $P_{RES_{Hj}=>PEV_{Hi,ref,t}}$, and $P_{RES_{Hi}=>Grid_{ref,t}}$ that should be imposed on the controller of each RES system of the corresponding home. In addition, the powers $P_{PEV_{Hi}<=>Hi_{ref,t}}$ and $P_{PEV_{Hj}<=>Hi_{ref,t}}$ are also optimized using PSO algorithm. These powers should be imposed on the controller of each PEV system to obtain the reference currents that must be injected into or by each PEV.

4. Results and discussion

To demonstrate the effectiveness of the proposed SCSCEMS, the Matlab/Simulink environment is selected for an entire day. The optimization strategy proposed in this paper will be tested at a city composed of a hundred home. These homes can be classified into five categories C_1, C_2, C_3, C_4, C_5.

- C_1: homes consisting of a PVG system and two PEVs.
- C_2: homes containing a PEV.
- C_3: homes containing a PVG system and a WT.
- C_4: homes consisting of a WT and two PEVs.

-C_5: homes neither comprising a RES nor a PEV.

In order to reduce calculation time and facilitate studies, these houses can be aggregated into 5 equivalent houses, as follows.

- First aggregated home: represents the equivalent of 25 homes of C_1.
- Second aggregated home: is the equivalent of 30 homes of C_2.
- Third aggregated home: is the equivalent of 10 homes of C_3.

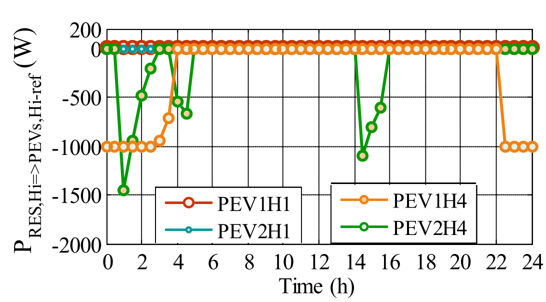

Fig. 11. Power transferred from renewable energy sources to its correspondent PEVs.

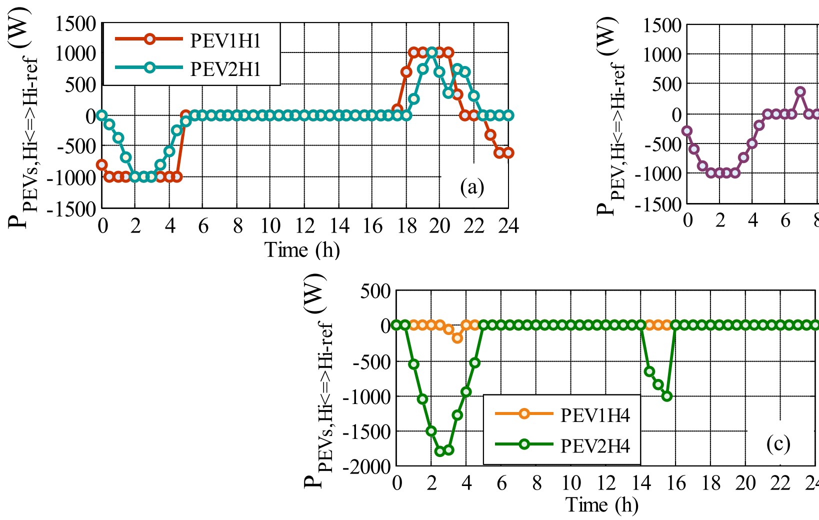

Fig. 12. Power transferred between homes (i) and its correspondent PEVs: (a) Home 1; (b) Home 2; (c) Home 4.

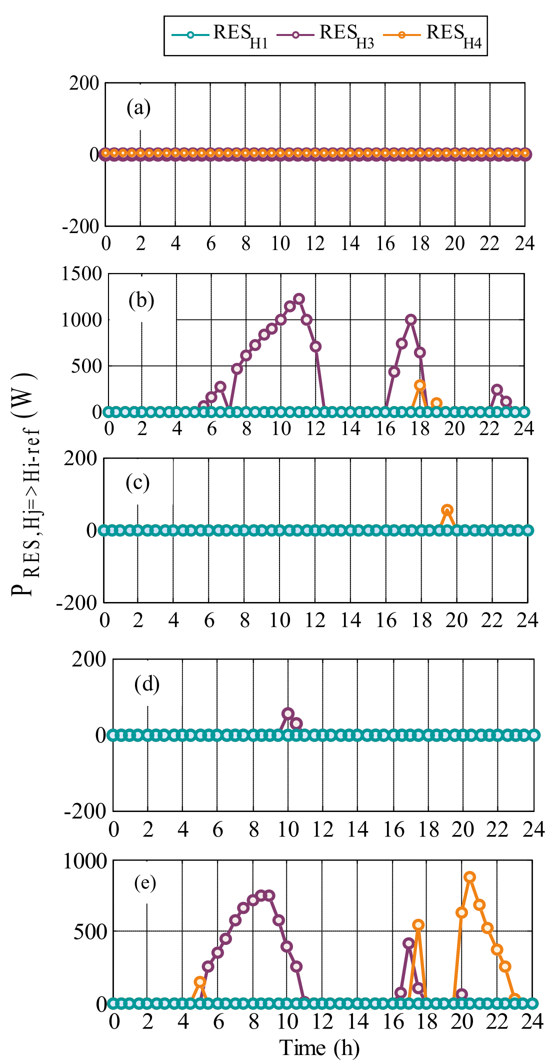

Fig. 13. Power transferred from neighbour homes RES (j) to home (i): (a) Home 1; (b) Home 2; (c) Home 3; (d) Home 4; (e) Home 5.

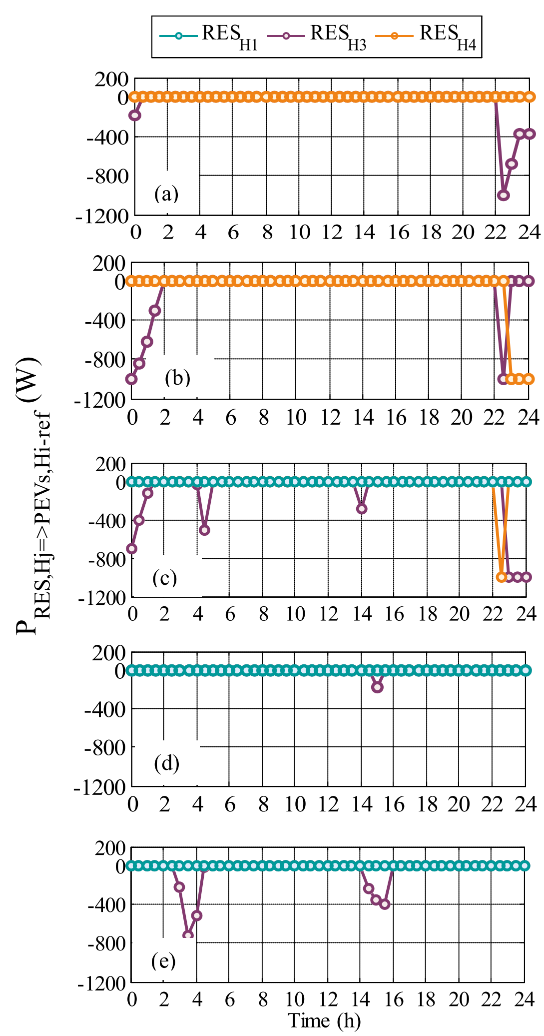

Fig. 14. Power transferred from neighbor homes RES (j) to PEVs homes (i): (a) PEV1H1; (b) PEV2H1; (c) PEVH2; (d) PEV1H4; (e) PEV2H4.

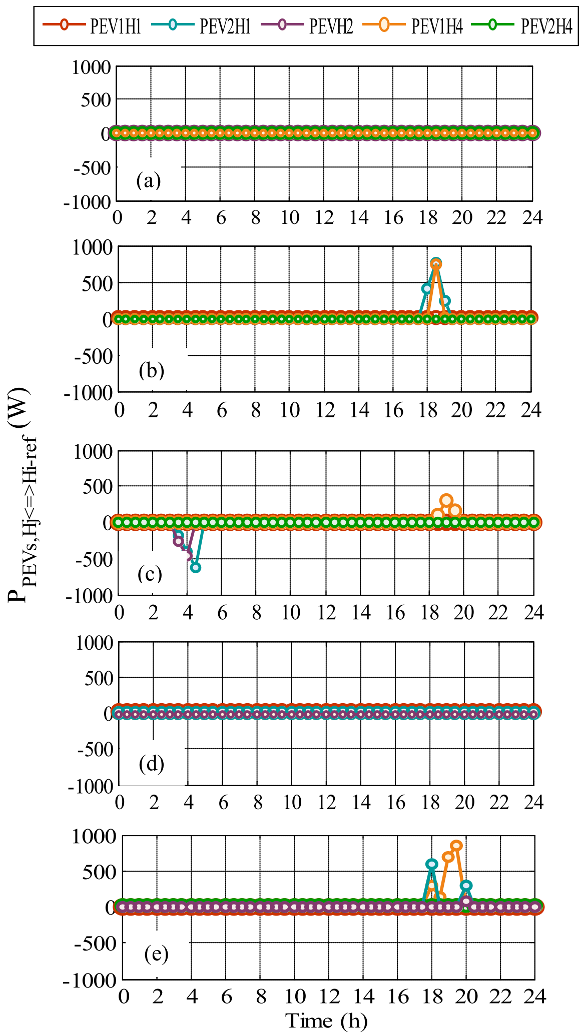

Fig. 15. Power transferred between neighbor homes PEVs (j) and homes (i): (a) Home 1; (b) Home 2; (c) Home 3; (d) Home 4; (e) Home 5.

- Fourth aggregated home: is the equivalent of 20 homes of C_4.
- Fifth aggregated home: is the equivalent of 15 homes of C_5

The system is simulated using data inputs as shown below, then the obtained results are presented and analysed.

4.1. Input data

4.1.1. Powers profile

Fig. 4 (a), (b), (c), and (d) shows the typical power profiles of the five studied smart homes. Two peaks of energy demand occur in each profile, generally in the morning and at night. These peaks have a big effect on the network augmentation power design. As it is remarkable, that each home profile is characterized by its power P_{AVi} which presents the average of the highest peak and the lowest drop power demand.

4.1.2. Illumination and wind speed

A typical daily curve of the illumination is shown in Fig. 5. The sunrise starts at 6am and the sunset finishes at 7 pm. A near-reality wind speed profile with intermittent cloud cover in the range of $5 - 13m/s$, is shown in Fig. 6.

4.1.3. Electricity price

Usage time tariffs requires that the price of electricity be proportionate to the power demand in various points as presented in Fig. 7 [30]. Generally, during peak demand hours the price is high. By contrast, during off-peak demand the price is low, notably in early morning and late night. Two prices are shown in the figure: the first one is grid price and the second is the city price as indicated in the SLSCEMS. The city electricity price is 20 % less than the grid electricity price. This is regarded as a desired condition for the choice of the best energy supplier.

4.1.4. Connection state of PEVs

As depicted in this case study, three categories of home contain PEV: C_1 owns two PEVs named PEVH1 and PEV2H1, C_2 has one PEV named PEVH2, and C_4 owns two PEVs named PEV1H4 and PEV2H4. The hours of departure and arrival of all PEV are shown in Fig. 8.

4.1.5. Renewable energy sources homes power

As outlined earlier, three categories of home comprise RES: C_1 has a PVG, C_3 has a PVG and a WT, and C_4 is fitted with a WT. Fig. 9 (a), (b), and (c) show the power profile produced by the RES of each home category. The power profile displayed by the wind source corresponded to the wind speed presented in the figure above. It is clear that when the wind profile exceeds 10.25 (m/s), the power produced by the WT does not exceed its maximum 3.8 (KW) in order to protect the WT against strong winds [31]. The power profile displayed by the solar source corresponded to the illumination presented in the figure above using the Perturb and Observe technique, as it is the most popular because of its speed and ease of usage [22,32]. It's remarkable that during sunlight hours, PVG generates power, but during darkness hours, PVG power is zero.

4.2. Local controller effects

4.2.1. First layer

Fig. 10 presents the result of the power $P_{RES_{Hi}=>Hi_{ref,t}}$ injected from each RES to its corresponding home. This power which is displayed from the first layer of the proposed strategy is applied only on the categories of home 1, 3, and 4. During RES power production and when the power profile rises above P_{AV_i}, the RES injects the optimal power into the home.

4.2.2. Second layer

Fig. 11 shows four-line curves of $P_{RES_{Hi}=>PEV_{Hi,ref,t}}$ which are displayed from the second layer. In fact, each PEV absorbs an amount of power from its corresponding RES excess power when the price is significantly lower.

This layer applied to the categories of home 1 that contain a PVG and two PEVs: PEV1H1 and PEV2H1. As it is remarkable, the value of $P_{RES_{H1}=>PEVs_{H1,ref,t}}$ is equal to zero along the day, and this can be summarized in three causes: no illumination during the PEV connexion, charged vehicle, and high price. Also, this layer is applied to the home 4 that contains a PVG, WT and two PEVs: PEV1H4 and PEV2H4.

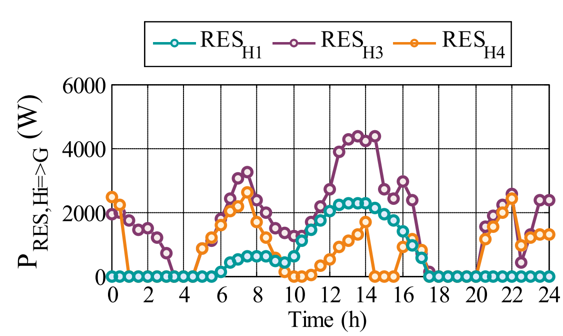

Fig. 16. Power transferred from homes to grid.

Table 2
Power flows injected from each home RES.

	(-) : Power flow wasn't transferred from RES home (i) to the home, PEV, and grid										
	(+) : Power flow transferred from RES home (i) to the home, PEV, and grid										
	Home 1	Home 2	Home 3	Home 4	Home 5	PEV1H1	PEV2H1	PEVH2	PEV1H4	PEV2H4	Grid
RES_{H1}	+	-	-	-	-	-	-	-	-	-	+
RES_{H3}	-	+	+	+	+	+	+	+	+	+	+
RES_{H4}	-	+	+	+	+	-	+	+	+	+	+

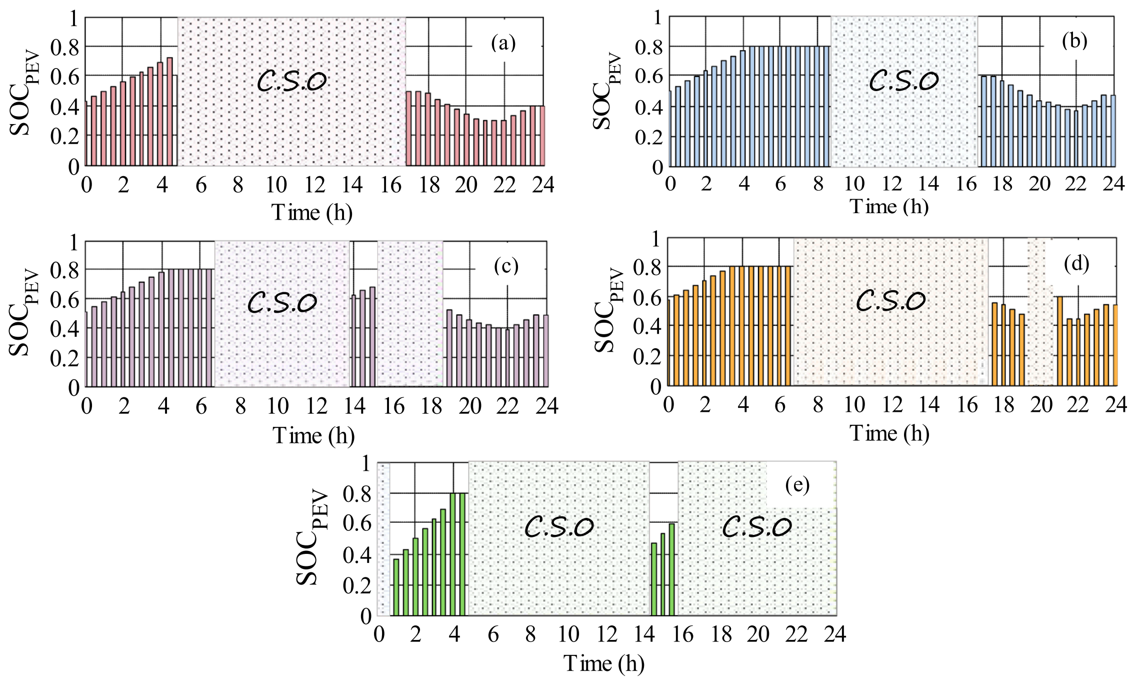

Fig. 17. State of charge of vehicles (a) PEV1H1; (b) PEV2H1; (c) PEVH2; (d) PEV1H4; (e) PEV2H4.

4.2.3. *Third layer*

Fig. 12 (a), (b), and (c) show each PEV power curve revealed from the third layer of the proposed SLSCEMS. This layer aims to support communication between PEVs and its corresponding homes basing on the power demand. Two essential operations are considered:

-Valley filling operation represented by negative powers: during off-peak demand hours, PEVs batteries absorb energy generated from the grid. They absorb the difference between the average power and the demand power of the house with respecting the layer constraints. In this phase, PEVs behave like charge related to the smart home.

- Peak shaving operation represented by positive powers: during peak demand hours, PEVs batteries inject energy to the home until that the home power profile coincides with its average power with respecting the layer constraints. In this phase, PEVs behave like as distributed energy resources.

4.3. *Global controller effects*

4.3.1. *Fourth layer*

As it is explained in the third part, home *j* represents the home that has an excess of RES power production, which can be home 1, 3, and 4. And home *i* is the neighbor home that hasn't or has an insufficiency in RES power with a demand power profile that surpasses its average power. Fig. 13 (a), (b), (c), (d), and (e), represent the three homes RESs participation to amend and flatten its neighbor home power profile. It's clear from Fig. 12.b and Fig. 12.c that home 2 and 5 are the main power receivers from their neighbor homes RES 3 and RES 4 as they have a lack in RES. In addition, home 3 is almost the first participant in injecting power as it has a huge RES excess power.

4.3.2. *Fifth layer*

Fig. 14 (a), (b), (c), (d), and (e) show the results of $P_{RES_{Hj}=>PEV_{Hi,ref,t}}$ obtained from the fifth layer. They represent the three homes RESs participation in charging its neighbor home PEVs. As it is remarkable, early morning and night present the large intervals for charging PEVs as they are their most time connections. As stated in this layer fourth constraint, the power is injected from homes RES 3 and RES 4 as it owns the highest excess power. In addition, the PEVs priorities charging action is realised confirming to the fifth layer, considering that the connected PEV that will disconnect first has the priority to charge. For instance, in [04 *h*00; 04hh30], the priority is to charge PEV2H4 with

Table 3
The intervened homes (including their RES) in charging and discharging the PEVs.

	(-): Home (i) didn't intervene in charging and discharging the PEV				
	(+): Home (i) intervenes in charging and discharging the PEV				
	Home 1	Home 2	Home 3	Home 4	Home 5
PEV1H1	+	-	-	-	-
PEV2H1	+	+	+	-	+
PEVH2	-	+	+	-	+
PEV1H4	-	+	+	+	+
PEV2H4	-	-	-	+	-

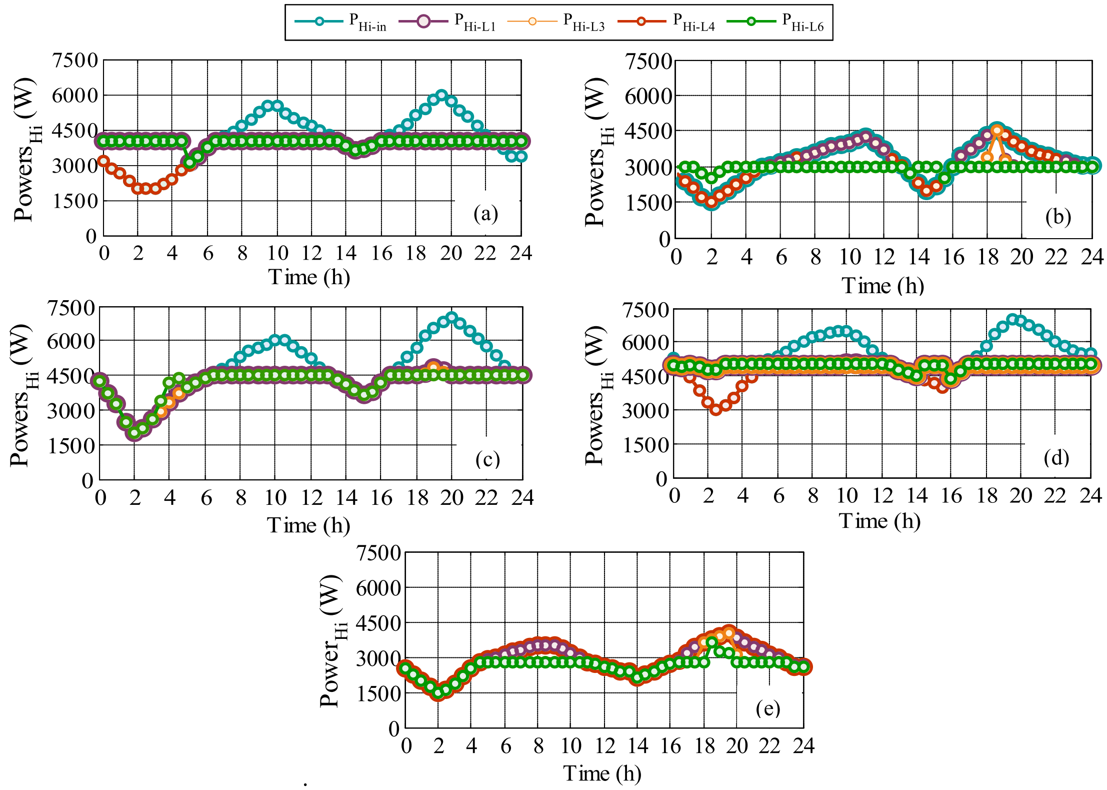

Fig. 18. Comparison between powers of: (a) Home 1; (b) Home 2; (c) Home 3; (d) Home 4; (e) Home 5.

514 W than PEVH2 with 32 W from home RES 3 as that PEV2H4 will disconnect firstly.

4.3.3. Sixth layer

Fig. 15 (a), (b), (c), (d), and (e) represent each PEV participation in flattening the smart neighbor homes. As it is illustrated in Fig. 15 (a) and (b), PEV1H1 and PEV1H4 get sufficiently charged/discharged from/to its corresponding home RES, home, and neighboring home RES. In addition, the PEVs charging and discharging actions are based on the priority notion as mentioned in section 3. For instance, in [18 *h*00; 18 h30] the PEVs that are connected are PEV1H1, PEV2H1, and PEV1H4 as depicted in Fig. 8. The priority is for PEV2H1 than to PEV1H4 to discharge to homes 2 and 5 as it will disconnect lastly.

4.3.4. Seventh layer

Fig. 16 show the excess power injected by each home RES into the grid throughout the day to balance necessarily its power.

4.4. General results of the proposed SLSCEMS

4.4.1. RESs power balance

Table 2 represents the power balance of each RES home. Generally, the energy of each RES is divided into three main parts: homes, PEVs, and grid. It's distinguishable that RES home 1 participates only to charge its corresponding home and its excess power is distributed to the network. However, both of RES home 3 and 4 have undergone multiple power flow direction distribution.

4.4.2. PEVs state of charge (SOC)

Fig. 17 (a), (b), (c), (d), and (e), enlighten the daily SOCs of PEVs. These results were obtained through executing layer 2, 3, 5, and 6 that are involved in scheduling a frequent charging and discharging for PEVs management. As exposed in all figures, state of charge evolution and regression throughout the time confirms the PEV charging and discharging operations.

4.4.3. PEVs charge/discharge actions

Table 3 represents each home (including their RESs) intervention in charging/discharging each PEV. Two main points can be distinguished from this table:

-Balancing RES power is necessary by charging PEVs: this is mode RES to PEV.

-Balancing intermittent RES by discharging PEVs to increase the availability of peak power demand: this is mode PEV to home.

4.4.4. Power profiles comparison

Fig. 18 (a), (b), (c), (d), and (e), show a comparison between each home power profiles. The blue curve presents the initial power profile, and the green curve presents the final obtained power profile. It's clear that from the purple curve, the power peaks have been flattened in home 1, 3, and 4 thanks to their RES. Also, the PEVs have an important role in

Table 4
The intervened layers in smoothing the demand homes profile.

(-): Layer (i) didn't intervene in smoothing the demand homes profile

(+): Layer (i) intervene in smoothing the demand homes profile

	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6	Layer 7
Home 1	+	-	+	-	-	-	-
Home 2	-	-	+	+	-	+	-
Home 3	+	-	-	-	-	+	-
Home 4	+	-	+	-	-	-	-
Home 5	-	-	-	+	-	-	-

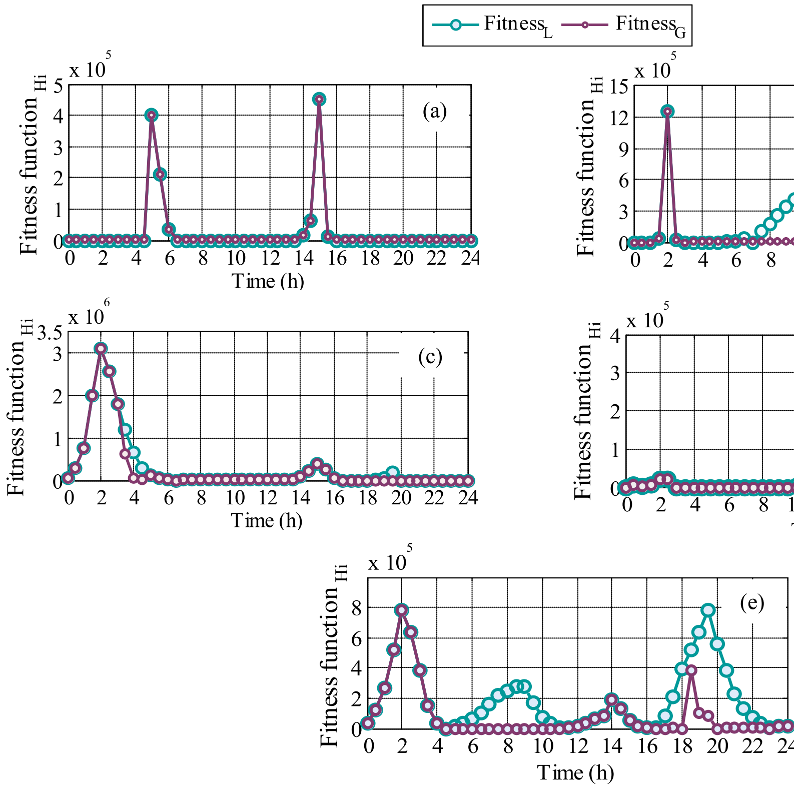

Fig. 19. Comparison between the initial and the final fitness of: (a) Home 1; (b) Home 2; (c) Home 3; (d) Home 4; (e) Home 5.

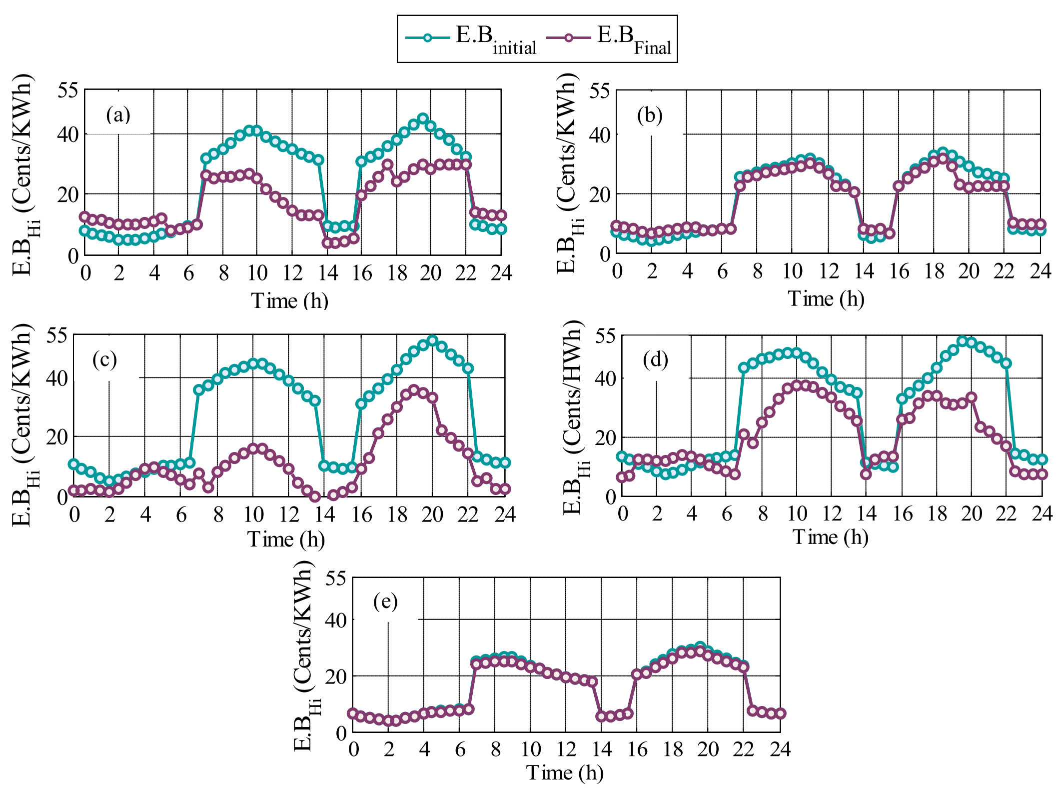

Fig. 20. Comparison between the initial and the final E.B of: (a) Home 1; (b) Home 2; (c) Home 3; (d) Home 4; (e) Home 5.

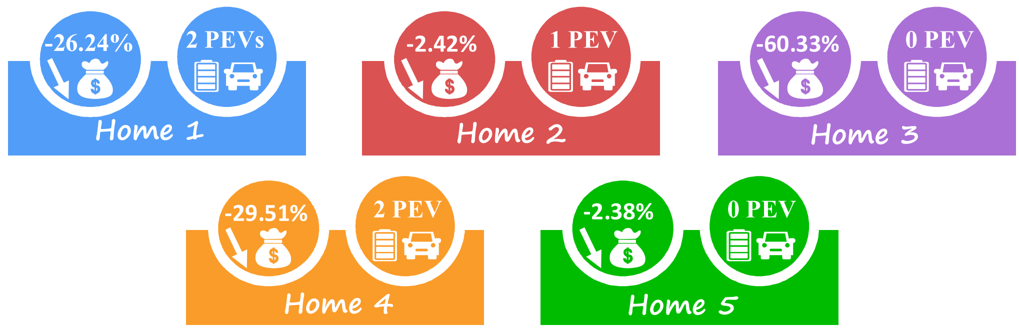

Fig. 21. The percentage of billing reduction and the number of PEVs that have undergone a completely free charging in each smart home.

smoothing the power profile presented by orange curve specifically in home 1, 2, and 4. And after applying layers 4 and 6 for flattening the neighbor home power profile, the daily power curves reach nearly their smoothness and achieve an acceptable result by superimposing on the average power curves. All that confirms the importance of an effective cooperative energy management between neighbor homes.

4.4.5. Smoothing the demand homes profile

Table 4 Shows a general summary that presents the layer that intervenes in smoothing each home power profile.

4.4.6. Fitness function

In Fig. 19 (a), (b), (c), (d), and (e), the blue curves and purple curves present the resulting fitness respectively after applying local and global layers. To explain, the objective of fitness function is assessing the quality of the acquired results. So, the lowest fitness value corresponds to the best position G_{best} discovered by the swarm. Obviously, the global fitness has been improved almost compared to the local fitness as it converges towards zero, that confirms the fulfilment of the optimal results.

4.4.7. Homes electricity bills

Fig. 20 (a), (b), (c), (d), and (e), present a comparison between the initial and final E. Bs of each smart home. As mentioned in the constraint above, the proposed SLSCEMS is responsible for managing charging and discharging PEVs actions according to the time electricity tariff. As shown, augmentations of the final electricity bill versus the initial electricity bill are distinguished because of the mechanism for PEV charging. Besides, E.B diminutions are also considered due to PEV discharging mechanism and the RES power injection. As a result, the inhabitant would enjoy a sizable financial saving.

Fig. 21 (a), (b), (c), (d), and (e) show each home inhabitant gain following the energy transition test. For the first smart home category, the final billing led to a reduction of 26.24 % compared to the initial cost including two PEVs free charging. The second home category verified a decrease of 2.42 % compared to the initial cost including one PEV free charging. For the third home category, the final billing verified a decrease of 60.33 % compared to the initial cost. For the fourth home category, the final billing led to a reduction of 29.51 % compared to the initial cost including two PEVs free charging. And finally for the fifth smart home category, the final billing led to a reduction of 2.38 % compared to the initial cost.

4.4.8. Smart city power profile

Fig. 22 Shows the amelioration of the whole studied smart city power demand curve for hundred smart homes. It’s apparent that from the final smart city power curve, two peak demands were better flattened, comparing to the initial one. Also, two off-peak demands are also improved. This demonstrates the effectiveness of the proposed SLSCEMS in obtaining a flattened power demand as much as enhancing grid performance.

5. Conclusion

The main focus of this paper is proposing an optimal control power exchange in a smart city that has a flexible number of homes. Each home is equipped with various types and numbers of RESs and PEVs. For this purpose, a SLSCEMS is suggested as a hierarchical framework designed with local and global layers. Local layers contain three subsequent layers that aim to flatten each smart home power profile and charge its PEV locally without neighbor home involvement. Instead, global layers comprise four subsequent layers that aim to more flatten each smart home power profile and charge its PEV globally depending on the neighbor home involvement. As such maximizing the financial benefit of inhabitants, enhancing the power grid quality and stability, and reducing air pollution using green technology are the main keys of the study. Numerical results, displayed from each layer correspond to optimal injected powers between different devices. The obtained results of the presented strategy show a flattened smart grid demand profile as well as minimizing its stress and avoid any blackout. Furthermore, the studied case shows that the first home category gains 26.24 % of its profit including two PEVs free charging, the second gains 2.42 % of its profit including one PEV free charging, the third enjoys a 60.33 % gain of its profit, the fourth enjoys a 29.51 % reduction of E.B with two PEVs free charging, and the last home category has a 2.38 % reduction of its E. B. It is safe to say, that the suggested solution has a proper performance in scheduling energy of smart city and can be applied in other smart cities that contain any number of smart homes, RESs, and PEVs.

CRediT authorship contribution statement

Marwa Ben Arab: Conceptualization, Formal analysis, Methodology, Software, Writing – original draft. **Mouna Rekik:** Conceptualization, Formal analysis, Methodology, Software, Writing – original draft. **Lotfi Krichen:** Methodology, Supervision, Validation, Writing – review & editing.

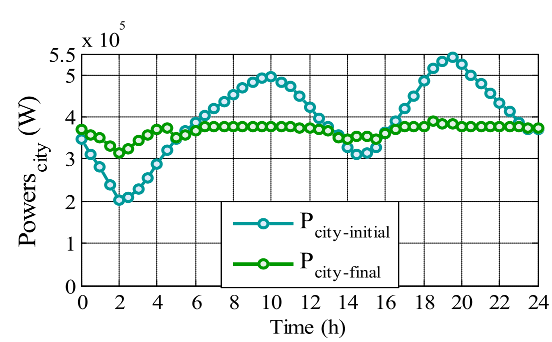

Fig. 22. Comparison between the initial and the final city power.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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