Smart homes: potentials and challenges

Rasha El-Azab*

Electrical Power and Machines Department, Faculty of Engineering at Helwan University, Cairo, Egypt

*Corresponding author. E-mail: r_m_elazab@yahoo.com

Abstract

Decentralized distributed clean-energy sources have become an essential need for smart grids to reduce the harmful effects of conventional power plants. Smart homes with a suitable sizing process and proper energy-management schemes can share in reducing the whole grid demand and even sell clean energy to the utility. Smart homes have been introduced recently as an alternative solution to classical power-system problems, such as the emissions of thermal plants and blackout hazards due to bulk plants/transmission outages. The appliances, sources and energy storage of smart homes should be coordinated with the requirements of homeowners via a suitable energy-management scheme. Energy-management systems are the main key to optimizing both home sources and the operation of loads to maximize home-economic benefits while keeping a comfortable lifestyle. The intermittent uncertain nature of smart homes may badly affect the whole grid performance. The prospective high penetration of smart homes on a smart power grid will introduce new, unusual scenarios in both generation and loading. In this paper, the main features and requirements of smart homes are defined. This review aims also to address recent proposed smart-home energy-management schemes. Moreover, smart-grid challenges with a high penetration of smart-home power are discussed.

Graphical Abstract

Keywords: smart homes; energy-management system; electrical tariff; smart-home infrastructure; load scheduling; power-quality control
Introduction

Smart homes provide comfortable, fully controlled and secure lifestyles to their occupants. Moreover, smart homes can save energy and money with the possibility of profiting from selling clean renewable energy to the grid. On the other hand, the probable decrease in total domestic energy loads encourages many governments to support promising smart-home technologies. Some countries have already put out many rules, laws and subsidy programmes to encourage the integration of smart homes, such as encouraging the optimization of the heating system, supporting building energy storage and/or deploying smart meters. For instance, the European Standard EN 15232 [1] and the Energy Performance of Buildings Directive 2010/31/ EU [2], which is in line with Directive 2009/72/EC as well as the Energy Road Map 2050 [3], encourage the integration of smart-home technologies to decrease power demand in residential areas.

To control the environment, a smart home is automated by controlling some appliances, such as those used for lighting and heating, based on different climatic conditions. Now, recent control schemes adapt many functions besides classical switching ones. They can monitor the internal environment and the activities of the home occupants. They also can independently take pre-programmed actions and operate devices in set predefined patterns, independently or according to the user’s requirements. Besides the ease of life, smart homes confirm efficient usage of electricity, lowering peak load, reducing energy bills and minimizing greenhouse-gas emissions [4, 5].

Smart homes can be studied from many points of view. The communication systems [6], social impacts [7], thermal characteristics [8], technologies and trends of smart homes [9] are reviewed individually. Moreover, the monitoring and modelling of smart-home appliances via smart meters are reviewed for accurate load forecasting, as in [10, 11]. Recently, power-grid authorities have modified residential electrical tariffs to encourage proper demand-side management by homeowners. Different from previous reviews, this paper introduces smart homes from the electrical/economic point of view. It also discusses smart-home energy-management systems (SHEMS) in two different modes, offline load scheduling and real-time management. The prospective impacts of unusual smart-home power profiles on future smart grids are also summarized.

After this introductory section, Section 1 describes the different definitions of smart homes within the last two decades. Smart-home communication schemes and other infrastructures of smart homes are discussed in Section 2. Section 3 discusses in more detail the existing functions of SHEMS, their pre-proposed optimization techniques and related technical/economical objective functions. The impacts of smart homes on modern grids are also discussed in Section 4. Finally, in Section 5, the main conclusions and contributions of the paper are highlighted.

1 Smart-home definition

The term ‘smart home’ has been commonly used for about two decades to describe houses with controlled energy schemes. This automation scheme confirms easier lifestyles for homeowners than normal un-automated homes, especially for elderly or disabled persons. Recently, the concept of ‘smart home’ has a wider description to include many applications of technologies in one place.

Sowah et al. [12] define smart homes as: ‘Houses that provide their occupants a comfortable, secure, and energy efficient environment with minimum possible costs regardless their occupants.’ The Smart Homes Association defines a smart home as: ‘The integration of technology and services through home networking for a better quality of living’ [13].

Makhadmeh et al. define them as: ‘Incorporated residential houses with smart technology to improve the comfort level of users (residents) by enhancing safety and healthcare and optimizing power consumption. Users can control and monitor smart-home appliances remotely through the home energy-management system (HEMS), which provides a remote monitoring system that uses telecommunication technology’ [14].

Smart homes can be defined as: any residential buildings using different communication schemes and optimization algorithms to predict, analyse, optimize and control its energy-consumption patterns according to preset users’ preferences to maximize home-economic benefits while preserving predefined conditions of a comfortable lifestyle.

Distributed clean energy generated by smart homes provides many benefits for prospective smart grids. Consequently, the effects of smart homes on future power grids should be extensively studied. In the near future, smart homes will play a major role as a power supplier in modern grids, not only as a power consumer.

2 Smart-home infrastructures

The general infrastructure of smart homes consists of control centres, resources of electricity, smart meters and communication tools, as shown in Fig. 1. Each component of the smart-home model will be discussed in the following subsections.

2.1 The control centre

The control centre provides home users with proper units to monitor and control different home appliances [15]. All real-time data are collected by SHEMS to optimize the demand/generation coordination and verify the predefined objectives. The main functions of the control centre can be summarized as follows [15]:
(i) collecting data from different meters, homeowners' commands and grid utility via a proper communication system;
(ii) providing proper monitoring and analysing of home-energy consumption for homeowners;
(iii) coordinating between different appliances and resources to satisfy the optimal solution for predefined objectives.

2.2 Smart meter
The smart meter receives a demand-response signal from power utilities as an input to the SHEMS system [16, 17]. Recently, advanced smart-metering infrastructures can monitor many home features such as electrical consumption, gas, water and heating [18].

2.3 Appliances
Smart-home loads can be divided according to their operating nature into two categories: schedulable and non-schedulable loads. Non-schedulable loads are operated occasionally according to the homeowner’s desires without any predictable operating patterns, such as printers, televisions and hairdryers, whereas schedulable loads have a predictable operating pattern that can be shifted or controlled via SHEMS, such as washing machines and air conditioners [19].

According to [19], controllable devices are also classified into interruptible and non-interruptible load according to the effect of supply interruption on their tasks. Electric vehicles (EVs) can be considered as an exceptional load [20, 21]. EVs have two operating modes: charging and discharging. Therefore, EVs are interruptible schedulable loads during the charging mode. Moreover, EV battery energy can also be discharged to supply power to the grid during critical events, which is known as vehicle-to-grid [22]. By SHEMS, EVs can participate in supplying loads during high-priced power periods. In low-priced power periods, EVs restore their energy from the grid [23, 24].

2.4 Resources of electricity
Solar and wind plants are the most mature renewable-energy sources in modern grids. Nowadays, many buildings have installed photovoltaic (PV) modules, thermal solar heaters or micro wind turbines. For smart homes, various functions can be supplied by solar energy besides generating electricity, such as a solar water heater (SWH), solar dryer and solar cooler [25]. Moreover, PV plants are cheap with low requirements of maintenance [26], whereas hot water produced by SWHs can be used in many home functions, such as washing and cooking, which increases the home-energy efficiency [27].

Energy storage may be considered as the cornerstone for any SHEMS. SHEMS are usually installed with energy-storage systems (ESSs) to manage their stored energy according to predefined objectives. Many energy-storage technologies are available in the power markets. Batteries and fuel cells are the most compatible energy-storage types of smart-home applications [28]. A fuel-cell structure is very similar to a battery. During the charging process, hydrogen fuel cells use electricity to produce hydrogen. Hydrogen feeds the fuel cell to create electricity during the discharging process. Fuel cells have relatively low efficiency compared to batteries. Fuel cells provide extra clean storage environments with the capability of storing extra hydrogen tanks. That perfectly matches isolated homes in remote areas [29].
Although wind energy is more economical for large-scale plants, it has a very limited market for micro wind turbines in homes. Typically, micro wind turbines require at least a wind speed of 2.7 m/s to generate minimum power, 25 m/s for rated power and 40 m/s for continuous generated power [30]. A micro wind turbine is relatively expensive, intermittent and needs special maintenance requirements and constraints compared to a solar plant [31].

Recently, biomass energy has been a promising renewable resource alternative for smart homes. Many pieces of research have recommended biomass energy for different types of buildings [32]. Heating is the main function of biomass in smart homes, as discussed in [33, 34]. In addition, a biomass-fuelled generation system is examined for many buildings [35, 36].

### 2.5 Communication schemes

Recently, communication systems are installed as built-in modules in smart homes. Both home users and grid operators will be able to monitor and control several home appliances in the near future to satisfy the optimum home-energy profile while preserving a comfortable lifestyle. Therefore, both wired and wireless communication schemes are utilized, which is known as a home area network (HAN), to cover remote-control signals as home occupants’ ones. Fig. 1 shows an example of a HAN that consists of Wi-Fi and cloud computing networks for both indoor and outdoor data exchange, respectively [37, 38].

Energy-management systems for homes require three main components: the computational embedded controllers, the local-area network communication middleware and the transmission control protocol/internet protocol (TCP/IP) communication for wide-area integration with the utility company using wide-area network communication [37].

According to home characteristics, many wired communication schemes can be selected, such as power-line communication (PLC), inter-integrated circuit (I2C) and serial peripheral interface or wireless technologies such as Zigbee, Wi-Fi, radio-frequency identification (RFID) and the Internet of Things (IoT) to develop HANs. A few of the most common techniques will be discussed briefly in the following subsections [38].

#### 2.5.1 PLC

PLC is a technique that uses power lines to transmit both power and data via the same cable to customers simultaneously. Such wired schemes provide fast communication with low interference of data. Moreover, PLC provides many communication terminals, as all power plugs can be used for data transferring. As all electrical home devices are connected by power cables, PLC can communicate with all these devices via the same cable.

PLC set-up has a low cost, as it uses pre-installed power cables with minimum hardware requirements. With a PLC communication scheme, home controllers can also be integrated easily with a high speed of data transfer. On the other hand, PLC has a high probability of data-signal attenuation. Furthermore, data signals suffer from electromagnetic interference of transmitted power signals.

#### 2.5.2 Zigbee

Zigbee is a wireless communication technique [37–46]. Zigbee follows the IEEE 802.15.4 standard as a radio-frequency wireless communication scheme. It does not require any licenses for limited zones such as homes [37]. Also, Zigbee is a low-power-consuming technique. Therefore, it is suitable for basic home appliances, such as lighting, alarm systems and air conditioners [39, 40]. Zigbee usually considers all home devices as slaves with a master coordinator/controller, which is known as a master–slave architecture.

Zigbee provides highly secured transferred data [38, 41] with high reliability and capacity [42]. It also has self-organizing capabilities [42]. Conversely, Zigbee is relatively expensive due to special hardware requirements with low data-transfer rates. Moreover, Zigbee is not compatible with many other protocols, such as internet-supported protocols and Wi-Fi.

#### 2.5.3 Wi-Fi technology

Wi-Fi is a wireless communication technique that follows the IEEE 802.11 standard. Wi-Fi provides high-rate data transfer that is compatible with many information-based devices such as computers, laptops, etc. [43, 44].

Wi-Fi is a highly secured scheme with many of the familiar internet capabilities and low data-transfer delays (<3 ms) [45]. On the contrary, it is a relatively high-power-consuming scheme compared to Zigbee schemes [45]. Also, home devices can affect transmitted data signals by their emitted electromagnetic fields [46]. Wi-Fi can also suffer from interference from other communication protocols such as Zigbee and Bluetooth [43].

#### 2.5.4 RFID

RFID is a wireless communication technique that conforms to the electronic product code protocol [47–52]. It can coincide with other communication schemes such as Wi-Fi and Zigbee. It can be utilized for a relatively wide-spread range of frequencies, from 120 kHz to 10 GHz. It also covers a wide range of distances, from 10 cm to 200 m [48]. Many researchers are investigating RFID home applications, such as energy-management systems [49], door locks [50] and lighting controls [51].

RFID operates on tags and reader-identification systems with a high data-transfer rate. Nevertheless, RFID has expensive chips with low bandwidth. The possibility of tag collision within the same zone decreases the accuracy of the RFID scheme.
2.5.5 IoT
This scheme connects home devices, users and grid operators via the internet to monitor and manage smart homes [6, 38, 53–65]. Consequently, the IoT and cloud computing have proven to be cheap, popular and easy services for smart homes. Moreover, IoT schemes are compatible with many other communication protocols, such as Zigbee, Bluetooth, etc., as listed in Table 1. Internet hacking is the main problem with IoT schemes. System security and privacy are critical challenges for such internet-based schemes.

3 Smart-home energy-management scheme
Today, building energy-management systems (BEMS) are utilized within residential, commercial, administration and industrial buildings. Moreover, the integration of variable renewable-energy sources with proper ESSs deployed in buildings represents an essential need for reliable, efficient BEMS.

For small-scale residential buildings or ‘homes’, BEMS should deal with variable uncertain load behaviours according to the home occupants’ desires and requirements, which is known as SHEMS. Throughout recent decades, many SHEMS have been presented and defined in many research studies.

In [66], SHEMS are defined as services that efficiently monitor and manage electricity generation, storage and consumption in smart houses. Nazabal et al. [67] include a collaborative exchange between smart homes and the utility as a main function of SHEMS. In [68], SHEMS are defined from the electrical-grid point of view as important tools that provide several benefits such as flattening the load curve, a reduction in peak demand and meeting the demand-side requirements.

Table 1: IoT protocols features

| Protocol          | Advantages                                                                 | Disadvantages                                                                 |
|-------------------|---------------------------------------------------------------------------|-------------------------------------------------------------------------------|
| 5G [59]           | Reliable with high speed and capable to manage a lot of devices simultaneously | Expensive with many problems related to security and privacy                  |
| Z-Wave [6, 38, 54–56] | Reliable, low data-transfer delay and without any interference with other communication schemes | Limited ranges and needs special networking requirements                      |
| 6LoWPAN [57]      | Low power consumer with large data-exchange capability                     | Complicated with low data-transfer rate                                       |
| Zigbee [58, 59]   | Low power consumer, simple and cheap                                       | Limited range and incompatible with other communication schemes              |
| Wireless HART [60–62] | Robust                                                                      | Insecure with low data-transfer rate                                          |
| Bluetooth [63]    | Low power consumer                                                         | Insecure with low data-transfer rate. It can be interfered with other IEEE 802.11 WLANs |
| Bluetooth Low Energy (BLE) [63] | Simple, cheap with very low power-consuming rate                          | Limited range and low amount of data handling                                |
| Narrowband IoT (NB-IoT) [64, 65] | Simple, cheap with very low power-consuming rate                          | Low speed with high data-transfer delay                                       |

3.1 Functions of SHEMS
Adaptive SHEMS are required to conserve power, especially with the increasing evolution in home loads. SHEMS should control both home appliances and available energy resources according to the real-time tariff and home user’s requirements [4]. Home-management schemes should provide an interface platform between home occupants and the home controller to readjust occasionally the load priority [5].

As shown in Fig. 2, the majority of smart-home centres can be summarized as having five main functions [5], as follows:

(i) Monitoring: provides home residents with visual instantaneous information about the consumed power of different appliances and the status of several home parameters such as temperature, lights, etc. Furthermore, it can guide users to available alternatives for saving energy according to the existing operating modes of different home appliances.

(ii) Logging: collects and saves data pertaining to the amount of electricity consumed by each appliance, generated out of energy-conservation states. This functionality includes analysing the demand response for real-time prices.

(iii) Control: both direct and remote-control schemes can be implemented in smart homes. Different home appliances are controlled directly by SHEMS to match the home users’ desires, whereas other management functions are controlled remotely via cell phones or laptops, such as logging and controlling the power consumption of interruptible devices.

(iv) Management: the main function of SHEMS. It concerns the coordination between installed energy sources such as PV modules, micro wind turbines, energy storage and home appliances to optimize the total system efficiency and/or increase economic benefits.
3.2 Economic analysis

Economic factors affecting home-management systems are classified into two classes. First, sizing costs include expanses of smart-home planning. Second, operating costs consist of bills of consumed energy. These costs depend mainly on the electrical tariff.

3.2.1 Sizing costs

These include capital, maintenance and replacement costs of smart-home infrastructures, such as PV systems, wind turbines, batteries/fuel cells and communication systems. In most previous SHEMS, such planning costs usually are not taken into consideration, as management schemes usually concern the daily operating costs only [69].

3.2.2 Operating costs

The electricity tariff is the main factor that gives an indication of the value of saving energy, according to the governmental authority; there are many types of tariffs, as follows [70–74]:

(i) Flat tariffs: the cost of consumed energy is constant regardless of the continuous change in the load. Load-rescheduling schemes do not affect the electricity bills in this scheme. Therefore, homeowners are not encouraged to rearrange their consumed energy, as they have no any economic benefits from managing the consumption of their appliances.

(ii) Block-rate tariffs: in this scheme, the monthly consumed energy price is classified into different categories. Each category has its own flat-rate price. Therefore, the main target of SHEMS is minimizing the total monthly consumed energy to avoid the risk of high-priced categories.

(iii) Seasonal tariffs: in this scheme, the total grid-demand load is changed significantly from one season to another. Therefore, the utility grid applies a high flat-rate tariff in high-demand seasons and vice versa. SHEMS should minimize the total consumption in such high-priced seasons and get the benefit of consumption in low-priced seasons.

(iv) Time-of-use (TOU) tariff: there are two or three pre-defined categories of tariffs daily in this scheme. First, a high-priced-hours tariff is applied during high-demand hours, which is known as a peak-hours tariff. Second, an off-peak-hours tariff is applied during low-demand hours with low prices for energy consumption. Sometimes, three levels of pricing are defined by the utility grid during the day, i.e. off-, middle- and high-peak costs, as discussed in [75]. SHEMS shift interrumpitable loads with low priority to off-peak hours to minimize the bill.
By using a proper optimal scheduling algorithm, electricity bills can be reduced by shifting loads from high-priced to low-priced intervals [77, 78]. Many techniques have been proposed for home load scheduling, as will be discussed in the following subsections:

(i) Rule-based scheduling: in this algorithm, all home appliances and resources are connected to smart data-collector taps. By processing the collected data, different appliances are scheduled according to their priorities and based on the if/then rule. Also, some high-priority loads are supplied by home renewable sources/storage to maintain their function during predicted peak hours [79, 80].

(ii) Artificial intelligence (AI): many AI controllers have been proposed for home load scheduling, such as artificial neural networks (ANNs), fuzzy logic (FL) and adaptive neural fuzzy inference systems (ANFISs). Table 2 compares between the three types of scheduling scheme based on AI.

### 3.3 Pre-proposed SHEMS

Different SHEMS may be classified according to four features: operational planning of load-scheduling techniques, system objective functions, optimization techniques and smart-home model characteristics, as will be discussed in the following subsections.

#### 3.3.1 Load-scheduling techniques

SHEMS concern the generation/load power balance to provide a comfortable lifestyle with the minimum possible costs. Scheduling loads according to their priority and the periods of renewable energy (solar, wind and EV state) can help in reducing the overall energy consumption daily. According to data collected by the management system, an initial load schedule is suggested daily to minimize the daily cost of consumed energy [76].

#### 3.3.2 Objective functions

(i) Single-objective techniques: in these schemes, only one criterion is minimized or maximized according to the home-user requirements. Several minimization objective functions were proposed, as follows:

- lifetime degradation [47–49];
- life-cycle costs [93];
- gas emissions [94–96];
- both active and reactive losses [97, 98].

On the other hand, some research defined other single maximizing objective functions, such as:

- net present value [96];
- economic profits [97, 98];
- increased system reliability: according to many well-known reliability indices, such as loss of power supply probability, loss of load probability and others [99, 100];
- generated power [101, 102];
- loadability [103];

(ii) Multi-objective techniques: homeowners may have several criteria to be optimized together. Multi-objective optimization (MOO) problems consider many functions simultaneously. MOO finds a proper coordination that moderately satisfies the considered objectives. In [102], SHEMS with MOO techniques are summarized. Table 3 lists some examples of such multi-objective functions.
into two categories: classical and AI-based techniques. Table 4 lists various SHEMS optimization techniques and their main features.

Classical methods, especially linear programming types, have been usually applied in the last decade for smart homes with limited objective functions and simple model characteristics of tariff and home appliances. Recently, AI-based techniques have been proposed to cover more complicated models of smart homes with multi-objective functions with high levels of comfortable lifestyles.

### 3.3.4 Home-model characteristics

The smart-home model differs significantly according to three factors: installed variable energy sources, applied tariff and EV deployment. PV systems have been applied for nearly all studied smart homes due to their low price, simplicity of installation, low maintenance requirements and easily predicted daily power profile. On the other hand, a few pieces of research have considered micro wind turbines in their home models, such as [120]. Wind turbines are limited by high-wind-speed zones that are usually located in rural areas. In addition, homeowners usually do not prefer wind turbines due to their high prices, mechanical maintenance requirements and the unpredictable variation in wind power.

Dynamic tariffs are applied in most smart-home research. Specifically, the TOU tariff is analysed in a lot of studies, such as [121, 122], whereas little research uses RTP, such as [123, 124]. EV is studied as an energy source in the parking period or vehicle-to-grid (V2G) mode. In [75, 125], EV in V2G mode reduces the electricity bill in peak hours, whereas, in [126–130], ESSs are managed only to reduce the electricity usage from the grid.

### 4 Technical challenges of smart homes

Many technical challenges arise for modern grids due to the increasing mutual exchange between smart homes and utility grids, especially power-quality control. Electric-power-quality studies usually confirm the acceptable behaviour of electrical sources such as voltage limits and harmonics analysis. Recently, smart power grids have diverse generation sources from different technologies that depend mainly on power electronics devices that increase the difficulty in power-quality control. Power-quality constraints should be taken into consideration for any energy-management systems to provide harmony between modern sources and loads.

On the other hand, power-quality issues should not form an additional obstacle against the integration of new technologies in modern grids. Therefore, both advanced communication schemes and AI-based techniques make modern grids ‘smart’ enough to cope with selective power-quality management. Smart homes exchange power with utility grids. With the prospective increase in such smart homes, the effect of their behaviour should be studied and controlled. Smart homes affect the grid-power quality in three different areas, as will be discussed in the following paragraphs [154–156].

### 4.1 Generating equipment

Integrated micro generation schemes in smart homes are mainly single-phase sources based on inverters with high switching frequencies that reach to many kHz. Low-order harmonics of such a generation type can usually be disregarded. However, with the expected continuous increase in such micro generators, the harmonics of low-voltage networks may shift into a range of higher frequencies, perhaps from 2 to 9 kHz [157]. Therefore, more research is needed to re-evaluate the appropriate limits for generation equipment in smart homes. Moreover, single-phase...
generation increases the risk of an unbalanced voltage in low-voltage grids. Therefore, negative-sequence voltage limits should be re-evaluated particularly for weak distribution networks. Also, a need for zero-sequence voltage limits may arise [154].

4.2 Home appliances

Modern home appliances depend mainly on electronic devices, such as newer LED lighting systems, EV battery chargers, etc., with relatively low fundamental current and high harmonic contents compared to traditional ones. According to many power-system analysers, many harmonics will increase significantly to risky levels, particularly fifth-harmonic voltage, with increase in such new electronic appliances [155].

4.3 Distribution network

In future grids, significant unusual operating scenarios may be possible with high penetration of domestic generation, especially with the possibility of an islanded (self-balanced) operation of smart homes. Short-circuit power will differ significantly during different operating conditions compared to classical grids. Moreover, low-voltage networks may suffer from damping-stability problems due to the continuous decrease in resistive loads, in conjunction with the increase in capacitive loads of electronic equipment. In addition, resonance problems may occur with low frequencies according to the continuous change in the nature of the load [156].

Although smart homes have bad impacts on utility grids, there are no charges applied from the grid authority to homeowners based on their buildings’ effects on grid-power quality. Therefore, home planners and SHEMS designers are usually concerned only with the economic benefits of their proposed schemes.

5 Conclusion

Smart homes, using new revolutions in communication systems and AI, provide residential houses with electrical power of a dual nature, i.e. as producer and consumer or ‘prosumer’. The energy-management system includes many components that mainly depend on a suitable communication scheme to coordinate between available sources, loads and users’ desire. Among many proposed communication systems, the IoT has many advantages

| Method           | Objectives                                                                 | Advantage                           | Drawbacks                             |
|------------------|-----------------------------------------------------------------------------|-------------------------------------|---------------------------------------|
| Classic          |                                                                              |                                     |                                       |
| Geometric        | Electricity consumption and minimizing bills                               | Simple                              | Difficult for users                   |
| programming      |                                                                              |                                     |                                       |
| Quadratic        | Optimal operation for battery and engine                                   | Fast                                | Limited real-time usage               |
| programming      |                                                                              |                                     |                                       |
| Convex           | Maximizing economic benefits with preserving comfortable lifestyle         | High efficiency with real-time operation capability | Complicated                           |
| programming      |                                                                              |                                     |                                       |
| Linear           | Battery-charging cost minimizing                                            | Real-time operation capability      | Valid for only one linear variable    |
| programming      |                                                                              |                                     |                                       |
| MILP             | Operating-cost minimizing                                                   | High accuracy                       | Sensitive to selected models          |
| [138, 139]       |                                                                              |                                     |                                       |
| MINLP            | Optimizing battery-charging/discharging processes                           | Simple modelling capability         | Slow with low accuracy                |
| [140–144]        |                                                                              |                                     |                                       |
| Markov decision  | Minimizing consumption with preserving comfortable lifestyle                | Good decision maker                 | Valid only for linear variable        |
| [145]            |                                                                              |                                     |                                       |
| Artificial       |                                                                              |                                     |                                       |
| intelligence     |                                                                              |                                     |                                       |
| ANN              | Simple load control                                                         | Suitable for forecasting            | Limited number of nodes               |
| Genetic algorithm|                                                                              |                                     |                                       |
| algorithm        | Minimizing emission and operating cost                                     | Easy                                | Long computational time               |
| Particle swarm   | Minimizing operating cost                                                   | Easy with limited required inputs   | Long computational time               |
| algorithm        |                                                                              |                                     | Complicated                           |
| Artificial bee   | Minimizing operating cost                                                   | Robust and flexible                 | Unreliable                           |
| colony           |                                                                              |                                     |                                       |
| Simulated        | Minimizing operating cost                                                   | Fast                                | Long computational time               |
| annealing        |                                                                              |                                     |                                       |
| Fuzzy            | Minimizing battery-charging/discharging processes and minimizing operating cost | Simple and flexible                 |                                       |
| Model predictive | Minimizing emission and operating cost                                      | Excellent predictive capabilities    | Expensive and complicated             |
| control          |                                                                              |                                     |                                       |
| [152]            | Maximizing energy trading                                                    | Flexible with disturbances          |                                       |
| Robust           |                                                                              |                                     |                                       |
| [153]            |                                                                              |                                     |                                       |

Table 4: Optimization techniques in SHEMS
and was chosen in many studies. Besides the popularity of the IoT, it does not need any special equipment installation and is compatible with many other communications protocols.

Many functions are applied by management systems such as monitoring and logging to facilitate a proper interaction between home occupants and the management scheme. Home security also should be confirmed via the management scheme by using different alarms corresponding to preset threats. Home users control different home appliances according their desires by SHEMS and via cell phones or manually.

The electricity tariff plays an important role in defining management-system characteristics. Tariffs vary from simple fixed flat rates to complicated variable dynamic ones according to the electrical-grid authority’s rules for residential loads. According to the tariff and selected objective functions, pre-proposed optimization techniques vary significantly from simple classical linear programming to sophisticated AI ones.

Modern electronic-based home appliances increase power-grid-quality problems, such as high harmonic contents, unbalanced loading and unpredictable short-circuit currents. On the other hand, power-grid authorities do not charge homeowners according to their buildings’ effects on the power quality. Therefore, all proposed energy-management systems are concerned mainly with the economic profits from reducing electricity consumption or even selling electrical power to the utility grids. In the future, price-based power-quality constraints should be defined by the grid authorities to confirm proper power exchange between both smart homes and grids. A possible future direction is behavior modeling of aggregated smart homes.smart cities in different operating scenarios to conclude probable power-grid scenarios for stability and quality.

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Conflict of Interest
None declared.

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