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Energy Management Systems of Grid-Connected Active Buildings

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Abstract

An active building has some potential flexible resources which can be utilized to provide the grid with required energy and flexibility. These flexible resources are building devices whose working power and/or time is flexible and can be modified based on the grid's needs. In this regard, the energy management system is responsible for scheduling these appliances based on the main objective of the building. In addition, the energy management system needs to take into account the operational cost of each appliance, the limits imposed by the owner, and those associated with the grid. The mentioned objective and constraints are discussed in this chapter. Finally, the chapter reviews the existing algorithm utilized by the building's energy management system. The algorithms utilize rule-based, artificial intelligence-based, and optimization-based approaches to optimally schedule the flexible appliances of the building.

I. OVERVIEW

Increasing energy consumption in the world due to the industrialization of countries, population growth as well as the need for providing the required energy for consumers, have had negative environmental impacts such as global warming due to increase in CO_2 emission or other greenhouse gases stemming from fossil fuels [1][2]. Therefore, in recent years, energy management's issue has become more important in most of the countries. Energy management can be considered both in the generation and demand sides [3]. Initially, to overcome these problems, electrical network stakeholders were obsessed with demand-side management, in which their main focus was on energy management as well as increasing the utilization of renewable energy resources located on the generation side. However, since all the activities of the power system aim to provide the required power and energy for the consumers, and a great portion of power is consumed at consumer-level by different kind of buildings, including residential, commercial, industrial, etc. most of the waste in energy occurs in this side of power systems. This attracted the attention of systems' operators to spend more time and money on the energy management studies in the downstream networks [4]. Accordingly, energy management at the building level entered a new phase of the study. Energy consumption in buildings for cooling, heating, lighting, etc. account for a significant part of energy consumption. According to available statistics, this amount is about 40 % of total generation capacity which is also responsible for about 36 % of the total emission [5]. The share of energy consumption in buildings is about 20.1% of the total delivered energy production consumed in the world that is expected to have an annual growth of 1.5% by 2040 [6][7]. The negative effects of this staggering increase of energy demand in communities are not limited to rising costs and pollution. It might also result in system-wide blackouts due to high energy demand during peak hours and the consequent reliability problems in the whole system. Hence, the energy management systems and their related considerations on the demand side especially in active (smart) buildings have become a crucial concept [8].

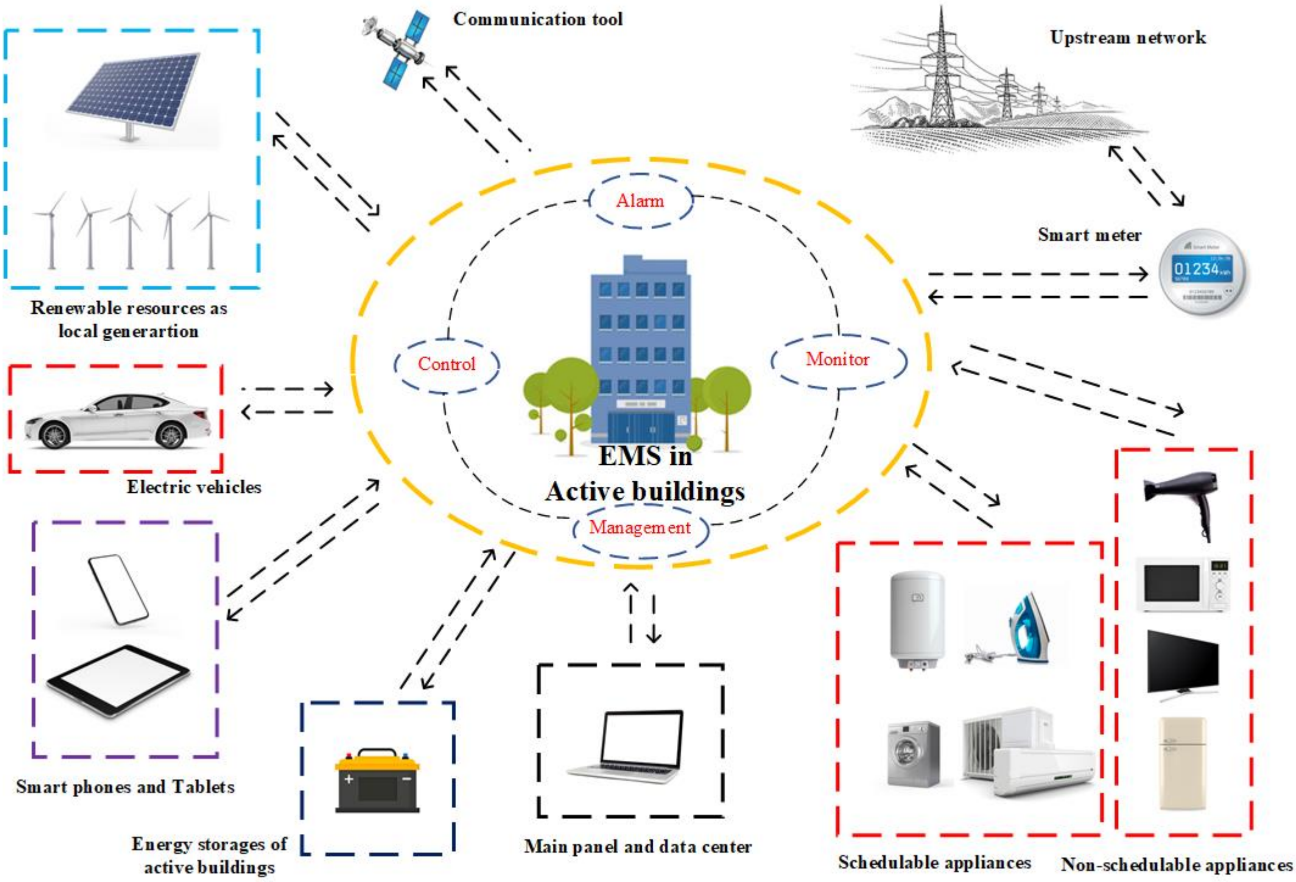

Fig.1 General scheme of energy management in grid-connected active buildings.

Grid-connected active buildings are those that not only utilize several renewable and non-renewable generation resources within themselves, but also perform energy management levels in conjunction with a variety of automation systems. Figure 1 shows an overview of a grid-connected active building. As shown in the figure, these buildings are also interacting and cooperating with the upstream power network. This interaction and cooperation will be done for specific purposes such as reducing the operating costs of the building and as result, reducing the costs imposed on the network due to increase in energy consumption. Moreover, other benefits of such buildings could be reducing pollution, peak shaving, increasing the reliability of the power network, improving the power quality and robustness of the power system, etc. [9][10]. Energy management in active buildings allows users to monitor and control the amount of energy consumed in different sectors at any time, and find out where they can reduce their costs and prevent energy waste. The automation system in these buildings should be designed and implemented in such a way that the minimum need for the presence of the occupant and the impacts of his/her behavior on decisions regarding energy-saving and management's issues. Building energy management system (BEMS) typically controls the heating, cooling, ventilation, air conditioning, lightening, etc. of the buildings [11]. Control, monitoring, and optimization of these systems in such buildings is done by various software based on intelligent algorithms as well as the internet of things (IoT) infrastructure, sensors, and equipment related to automation. Overall, these buildings have three important factors that distinguish them from other buildings [12]:

1- Automated control by various types of equipment.
2- Concatenation of tenant priority and feedback.
3- Adaptability and learning ability (based on intelligent algorithms behind the automation mechanism, it can adapt to the environment and lifestyle of people in order to reduce cost and increase social welfare).

Energy management in active buildings can be considered and evaluated from different points of view. However, in this chapter, we focused on the most important issues that these kinds of buildings are confronted with. These contents will be explained in the following sections. Several significant objective functions like cost minimization, peak shaving, flexibility services, as well as more than one objective, which are known as multi-objective function, will be presented in section 2. Constraints that these active buildings must consider, according to e.g. appliance constraints, thermal comfortness, and grid exchange limitation, have been expressed in section 3. Different modulation of the active building’s equations and solving approach for optimization problems will be explained in section 4. Finally, in section 5, the conclusion and summary of the whole chapter will be discussed.

II. OBJECTIVES OF AB’S ENERGY MANAGEMENT

In the energy management programs in grid-connected active buildings, various objective functions are considered. In most cases, this prioritization of objective functions is done according to the preferences of the occupants of the building. However, in some cases, these objective functions might be performed based on the needs of upstream network operators in order to achieve specific goals. In the following, we will discuss some of the most important objective functions related to energy management programs in grid-connected active buildings. The objective functions that have been considered in these systems, can be very diverse and extensive, for example, cost, peak shaving, and flexibility services, etc. are samples of these [1].

2.1 Cost Minimization

The Energy management for grid-connected active buildings can be expressed as both single-objective and multi-objective functions, this goal or goals can be considered from various aspects such as economic, technical, environmental, social, or a combination of two or more. Although a lot of research has been done on energy management in this type of buildings, it can be said that cost is one of the most important objective functions mentioned in most of the articles (of course in the presence of technical, economical, etc. constraints) [13]. The total cost in such buildings can be in the form of, the start-up cost of different equipment such as the cost of energy storages failure or battery deterioration, penalties or rewards for users due to following a specific consumption pattern [14][15], the total cost of building’s operation, maximizing profits of aggregators or residents, total cost and tax minimization caused by the emission of pollution, cost minimization of initial investment for construction such this buildings, also annual operating cost and life cycle cost, etc. [16][17]. For instance, in equation (1), a single objective function has been depicted, aim of this equation is to minimize the total bill’s cost of the residence and users, which is obtained by multiplying the energy price by the difference between the load profile and the energy sold by the active building to the upstream network [6].

$$Min\,(C_u)=\sum_{t=1}^{T}\left(P_u^n(t)-P_u^s(t)\right).\lambda\left(t,P_n(t)\right)$$

$\mathrm{C_u}$: Daily bill's cost
$\mathrm{P_u^n}$: Load profile of the building at time (t)
$\mathrm{P_u^s}$: Amount of power sold to the upstream network at time (t)
$\mathrm{P_n(t)}$: Energy price
(1)

As shown above, residents can sell their extra power which saved in energy storages in low demand hours and at peak load hours released the energy, the smaller the difference, the lower the cost of subscribers' bills can achieve, it should be noted that for this purposes constraints must also be met, so this difference cannot be less than one limit by considering different constraints, because the demand should be supplied in the first stage and then the surplus power might be sold to the network by user’s decision.

2.2 Peak Shaving

The amount of load is not constant during a day and is constantly changing. Providing this load with high reliability is one of the concerns of operators. This is important especially during peak times, because in these cases there is double pressure on the network, and also increasing the generation capacity of resources is not cost-effective. Most of the time to overcome such problems, gas power plants, or in islanded regions or buildings, diesel generators can be used (they generated the surplus power for the response to the load increment of the network or building during peak time). Although the capital cost of such these systems may be seen as low, the operation and maintenance (O&M) cost by the past, imposes a lot of cost on the network and building management programs. For this reason, peak shaving programs seem to be important along with reducing the overall cost of the network and buildings, as well as increase the overall reliability and robustness of the system simultaneously [18][19].

Peak shaving is a strategy in which the load curve is flattened so that the load is transferred to the parts with less amount of load (valleys in load profile) during peak hours (peaks). This change is done by considering various factors such as users' urgent for equipment needed at the moment, schedulable and un-schedulable equipment, considering peak hours on different days of different seasons, applying reward and penalty programs, etc.

There have been many articles that have discussed this issue recently, and the strategies that these papers have used to achieve this goal include the following:

1- Utilizing energy storage system’s integration (ESS)

2- Using electric vehicles for power exchange (V2G & G2V modes)
3- Demand-side management programs (DSM)

As one example, by using storage devices, energy can be stored at low load zone (low price), and the required power can be discharged back to the grid or building during peak hours. Moreover, electric vehicles, based on the contract that can be agreed with their owners, provide their power to the network and the building during the peak load in order to compensate the required power in this way. On the other hand, demand-side management programs as the other strategies can be divided into two categories, as follows:

1- Reliability-based programs
2- Market-based programs

Reliability-based programs operate by utilizing economic incentives, which include offering low electricity prices or granting special credits to the responsive demands. This program is divided into three more detailed sub-categories as follows:

1- Direct load control programs (DLCP)
2- Interruptible programs (IP)
3- Curtailable load programs (CLP)

In Market-based programs, consumers voluntarily adjust their demand according to the economic offers given by the network operator, and in return, they can benefit from discounts on electricity prices or other incentive programs [20][21].

It is important to note that considering peak shaving as an objective function indirectly has other benefits as well, such as improving power quality, increasing system efficiency, reduction in total cost, etc. [22].

Grid-connected active buildings, as their name suggests, have the ability to communicate with the upstream network and can participate in peak shaving programs in continuous communication with the network operator, in order to correct the load curve by using renewable energy resources and storage devices located in the buildings. Furthermore, by using automated systems and the Internet of Things (IoT), they can receive signals from the operator, following demand response programs (DRP), and thus, in addition to modifying the load curve and helping to increase network reliability, also have benefits such as reducing their overall cost. In the following, for instance, an objective function that mainly focuses on peak shaving by using the charging station of electrical vehicles (EV) has been expressed. In this equation, peak shaving is achieved by minimizing the system's demand using the following objective function [23].

$$Min \sum_{h=h_{start}}^{h_{end}} Demand^{h} = Min \sum_{h=h_{start}}^{h_{end}} \sum_{k=1}^{n} P_{k,load}^{h}$$

h_{start} : Starting charging hours
h_{end} : Ending charging hours
$P_{k,load}^{h}$: Load demand of node k at hour h (2)

According to the above function, by considering and limiting the charging and discharging time for electric vehicles (EVs), it is possible to have proper control over the load regulator. For example, peaks can be flattened at a particular node in the network, so that if the load from the charging stations is limited and minimized (start and end times for EVs charging based on the operator's decision), demand's minimization and load curve flattening in that particular node of the system can be reached. By applying this program for nodes that face peak load obstacles, a proper peak shaving can be done at the entire power system.

2.3 Flexibility Services

With the development of electrical networks from traditional and centralized to modern and decentralized networks, new challenges and problems were faced by planners and operators. These challenges have been due to the dense presence of renewable energy and its intermittency and uncertainties, power exchange in different directions (from upstream to downstream and reverse), more energy consumption due to the advent of electrical appliances more than before (e.g. electrical vehicles, new home appliances), etc. Since the power generation is no longer limited to the upstream network, and generation equipment (e.g. energy storages, renewable energy resources such as PV systems, etc.) have also reached to the level of the distribution network [24], the general nature of the power network has undergone extensive changes both on the generation and on the consumer (demand) side. Therefore, with careful and detailed studies, the dense presence of this equipment in the distribution network can be used in a direction, that will help increase the overall efficiency of the power network [25].

Flexibility services refer to those actions, which can be defined as a stable power regulator at the power grid level at a specific moment and for a specific period of time from a particular part of the network.

It can be said that flexible service means the adaptability of demand with the generated power, especially in buildings or grids with the presence of renewable energy sources [26]. In other words, with the increasing growth of demand and consequently the increase in costs due to the supply of this power by the upstream network, it is possible to use the generation resources and other devices available at the demand side level (i.e. grid-connected active buildings) or by other methods like demand response programs so as to not only maintain system reliability, but also provide continuous power and reduce overall costs for all parties [27].

These services help to keep the power balance in the distribution network at an acceptable level, and also aims to keep the load curve relatively smooth at different times of the day.

Flexibility services basically have five general features, which are: 1) the direction of the exchanged power, 2) their electrical structure in the network, 3) temporary features according to the start-up time, 4) duration of its presence, 5) and finally its location in the power system [28].

Some distributed energy resources (DER) can be unidirectional like typical household loads like water heaters, dishwashers, etc. In contrast, some of them can exchange power in a bi-directional way like energy storages, electrical vehicles, etc.

It is important to pay attention to the network in which DER is used, to get the most out of these services. Some of the equipment are able to provide a lot of instantaneous power for a short period of time and cannot maintain their power level for a long time. In contrast, some of the other DERs can provide the power for longer periods, meaning that they can maintain their power at an acceptable level for a while.

Considering the time required to prepare and use this equipment is also important for the network, most distributed generation resources (DERs) such as storage devices, photovoltaic, electric vehicles (EVs), demand response programs (DRP), etc. that can quickly be ready for use. However, some equipment such as small-scale combined heat and power (CHP) needs more time to prepare and cannot deliver the required power to the network in order to help it for better performance at the moment.

Duration presence of such resources is another point. This means that for how long each unit can stay in touch and cooperate with the power system for flexibility service works, for example, electrical vehicles cannot participate in these programs at a specific period of time (i.e. their owners need them).

Finally, the location of the DERs can be important since the operator decides to use this type in congestion programs or to provide power for part of the network or maybe to improve the power quality and, etc. In other words, the location of the equipment in the power system affects how to use that particular equipment in a better and efficient way.

Moreover, as mentioned earlier, consumers can play an active role in flexibility services by using demand response programs (DRP), according to what is said in section 2.2.

In the following an equation that has shown this type of objective function has presented [25], which in this:

$$Min \sum_{f \in F}^{h \in H} F\left(C_i^f, P_i^f\right)$$

$$F\left(C_i^f, P_i^f\right)\text{:cost-function for flexibility f} \tag{3}$$

In this function, the goal is to minimize the cost of purchasing flexibility services provided by grid-connected active buildings and microgrids or maybe aggregators. In other words, the network, in order to reduce its initial costs and maintenance, as well as increase the overall efficiency of the system, requires them to participate in this matter, by accepting an appropriate ratio of costs. For this, based on optimal power flow (OPF) approach at each hour, considers different user's type of flexibility bids. By choosing the right one from those offers, it tries to provide flexibility services at the lowest cost. As well as, only distributed generations (DG) participate for flexibility services, which are considered tunable between the minimum and maximum amount that is assumed in the bids. It is to be noted that, in this planning, active and reactive power services for flexibility purposes can be supplied by users.

2.4 Multi-objective Function

As mentioned before, in the energy management system of grid-connected active buildings, power system operators usually seek to optimize and achieve more than one objective. Accordingly, several objective functions can be considered to achieve positive results also, to save time and money. In this case, the focus is on optimizing two or more objective functions, so that relative satisfaction is achieved. This creates a more desirable and complete plan for energy management in such buildings. There are some methods can solve a multi-objective problem by converting them into single objective functions, such as the weighting factor and lexicographic method, while others provide a set of optimal answers to the user according to priority or need, to choose among them, e.g. epsilon constraint and augmented epsilon constraint method. Some objective functions such as cost, environmental pollution, social welfare, power loss, etc. can be considered as well [29][30]. In below, a bi-objective function has been expressed, which are the home's total energy cost and load profile deviation that should be minimized simultaneously [31].

$$Min\ \ EC = \sum_{t \in T} \left(E_t^{total} \times \Omega_t \right)$$

$$Min\ \ LPD = \sum_{t \in T} \left| E_t^{total} - E^{mean,total} \right| \quad , \quad E^{mean,total} = \frac{\sum_{t \in T} E_t^{total}}{T}$$

$$\begin{aligned} &\mathrm{t: Index\ for\ time} \\ &\mathrm{T: Set\ of\ time\ intervals} \\ &\Omega_{\mathrm{t}}:\ \mathrm{electricity\ tariff} \\ &\mathrm{E_t^{total}: Energy\ consumption\ at\ time\ (t)} \end{aligned} \tag{4}$$

With respect to the functions which have been shown above, in this multi-objective problem, first, the total energy cost for homes should be minimized, and then in order to obtain the flattened load curve, the deviation in demand must be minimized too. It should be noted that in this multi-objective optimization problem, the energy cost for reaching to flattened load curve should not exceed the minimum operating cost of the first objective function, also according to the relationship of the second objective function, the amount of load should be shifted to the average daily consumption. (for reaching to latter aim).

III. CONSTRAINTS OF GRID-CONNECTED AB'S OPERATION

In the previous sections, the number of important objective functions in the energy management of grid-connected active buildings were discussed. In this section, some of the most important constraints that those objective functions should be optimized by considering these constraints. In other words, optimization is meaningful under defined constraints. These constraints can be economical, technical, social, welfare, etc. The objective functions are optimized under a set of constraints, depending on the type of building, as well as its facilities, generation resources, geographical condition, appliances, and limitations of them, these constraints may vary from one building to another [32].

3.1 Appliance's Constraints

There are many different electrical appliances in the buildings like refrigerator, oven, washing machine, hair-dryer, dishwasher, electric vehicle, television, lights, computers, air conditioner, etc. These appliances, depending on the application of each and the users' needs, can be used at different hours of the day [33]. The main constraints related to this type of device are related to the time period and as well as the priority that each appliance is required to be used. These appliances, from the load scheduling point of view, can be categorized based on two groups:

1- Controllable appliances (operation of these can be the scheduled duration of their work, e.g. washing machine, dishwasher, heating system, etc.).
2- Non-controllable appliances (operation of these cannot be scheduled, e.g. hair-dryer, refrigerator, etc. [34]).

There are many divisions based on different points of view in articles, so that a device can be placed in a specific group in an article, while in another article and according to the new division, has no place in that group. Researchers have not yet agreed on the exact grouping that can categorize the appliances, and just survey on them from different perspectives.

Various constraints on the performance of building appliances have been explored in the articles, including ensuring the continuous operation of appliances, coordination between appliances, so that when one appliance starts operating, another appliance must be worked at the same time or should be turned off. For instance, if the TV turns off, then the DVD player should also turn off. Turn on or off at the specified time is another constraint that has been considered in many types of research. Other constraints include the power consumption limit of each device, also time limitation that has allowable to use any device [35].

According to the above statements, another category can be obtained. In other words, appliances can be divided into six group and their constraints may be written and considered based on this grouping [36]. These types of groupings include:

1- Discrete type (Devices that fall into this category can be turned on and off without any restrictions like, hair-dryer).
2- One-stop type (Devices in this group can only be turned on and off once in a specified time period. In other words, they must operate continuously for a specified period of time like, dish-washer).
3- Multiple-stop type (Devices in this group can be turned on and off, M times in a specified period of time like, water pump).
4- Stepped type (Appliances that fall into this category have a variety of consumption patterns over the course of their operation and their energy consumption changes like washing-machine).
5- Cool-down type (Devices that fall into this category are not allowed to turn on immediately after being turned off and must be passed for a while like, some electric motors).

6- Sequential type (Devices in this group must start working after the end of the work of another device, in other words, to start working, they must wait for the end of the operation of another device like a dryer machine should works after washing machine).

In the following, an example of constraint related to the building's appliances is exhibited. This constraint shows the hot water temperature bounds specified by users [37].

$$\theta_n^{low} \leq \theta_n \leq \theta_n^{up} \qquad n = 1.......N$$

For instance:

$$\begin{cases} 132 \leq \theta_n \leq 150 & 13 \leq t_n \leq 17 \\ 142 \leq \theta_n \leq 160 & \text{otherwise} \end{cases} \tag{5}$$

In this constraint, the temperature of the hot water can be controlled by minimum and maximum limitation of boundaries, according to the user's decision based on various factors.

3.2 Thermal Comfortness

Aside from all that has been said about energy management and energy consumption at the grid-connected active building level, another important factor and constraint to consider is thermal comfortness. This means that all the buildings, in which people live or work should provide comfortable conditions in terms of temperature and heat. Thermal comfortness is a mental and individual condition that people feel satisfied with the environment's temperature, and this is assessed by the person themselves. In other words, this feeling of satisfaction varies from person to person, and an environment that seems ideal to one person may not be appropriate to another. For this reason, sufficient attention should be paid to this point in the operation of active buildings.

Factors that affect this feeling of satisfaction are divided into two categories: 1) environmental 2) individual. Environmental factors include ambient temperature, relative humidity, level of radiation, air movement in the environment, etc. Individual factors include things like each person's body metabolism, sickness, clothing style in the environment, and generally sense of personal satisfaction and taste [29][38].

There are various standards for determining the average comfort and convenience in buildings that can be referred and include them in the planning to greatly satisfy residents such as, ANSI/ASHRAE Standard 55, ISO 7730 [39]. In the following, a sample thermal comfortness constraint has been expressed [38]:

$$D(i,k)=\begin{cases}\dfrac{T_{opt}(i,k)-T_{in}(i,k)}{T_{opt}(i,k)-T_{\min}(i,k)} & if\ T_{in}(i,k)\le T_{opt}(i,k)\\[2ex] \dfrac{T_{in}(i,k)-T_{opt}(i,k)}{T_{\max}(i,k)-T_{opt}(i,k)} & if\ T_{in}(i,k)>T_{opt}(i,k)\end{cases}$$

T_{opt} (i,k) : Optimal temperature at each period of time
T_{in} (i,k) : Actual temperature
T_{min} (i,k) : Minimum acceptable temperatures
T_{max} (i,k) : Maximum acceptable temperatures (6)

Based on what is said and showed above, this constraint can control the environment temperature with respect to particular permanent service *i*, corresponding to a thermal zone, at each period *k*. Therefore, when the residents are in their buildings, the satisfaction can be obtained by the difference between the ideal temperature and the actual temperature. This ensures that, in the energy management planning of this type of buildings, the ambient temperature remains acceptable and satisfactory for the residents.

3.3 Grid Exchange Limitation

Grid-connected active buildings as the name implies has the ability to exchange power with the upstream network, which means that it can deliver power to the upstream network at times when has surplus power excess of demand, as opposed to, at times when is not able to supply the demands for some reason, it takes the required power from the upstream network.

These buildings connect to the upstream network by point of common coupling (PCC), this scheme and this type of connection (in other words, indirect connection by common and detachable buses) help and improve the protection and the reliability of the overall system. in case of failure in the operation of active buildings or vice versa (upstream network failure), failure isolation can be realized between the active building and the main grid.

As mentioned before, the presence of the grid in this type of buildings increases the reliability of buildings so that it is always possible to ensure continuous power supply without interruption. Moreover, by selling power to the network, it can make a profit for users and thus reduce its overall cost. The limitation of this exchangeable power depends on many factors like, the structure of the network, the place of building in the electrical network, total surplus power that can generate by different equipment in the building, minimum power required for vital equipment in the building, The amount of budget for construction of line (capacity of transmission line between active building and main grid), and the maximum acceptable cost for the operator and users (to build transmission line), etc. [40]. A grid exchange limitation constraint can be written as follows:

$$\left\{\begin{array}{lll} P^{Active\_Building-to-Main\ grid} & \leq P^{\max, Line} & \\ & & \\ P^{Active\_Building-to-Main\ grid} & \geq P^{\min, Line} & note: \text{This may or may not be considered} \end{array}\right\} \quad (7)$$

By considering the above constraint, it can be understood that there is a limitation for the amount of power which can be sell or buy to/from the upstream network. It is a very important point that operators should pay good attention to it, because ignoring this constraint can lead to the collapse of the intended planning. This maximum limitation as we pointed to depends on many factors, sometimes the exchanged power must be more than the specified amount, this does not apply to all buildings.

IV. MODELLING GRID-CONNECTED AB'S ENERGY MANAGEMENT

The responsibilities of an energy management system of the building include a range of tasks such as scheduling controllable appliances and devices, monitoring and forecasting the consumption of uncontrollable devices, forecasting the production of the building (e.g. solar production), and making bidding strategies on behalf of the building who wants to participate in local markets as an individual player. However, it is noticeable that the mentioned tasks are closely correlated with each other. For example, the optimal scheduling of controllable and flexible devices of the building is highly dependent on the occupant's preferences and comfort, the real-time and forecasted consumption power of other appliances, the production of the building, and the grid's real-time need. In addition, the scheduling process performed by the energy management system should be in line with the grid service that the building had promised to provide. However, the energy management system requires to take into account the main objective of the building as the main factor.

If the household promised to provide grid services and, for example, contribute to the peak-reduction services, the working time of controllable devices should be shifted to other off-peak timeslots. On the other hand, the occupant might also define a time range as a permissible timeslots for appliances' operation. If the predefined time range overlaps with the peak timeslots, the EMS may send a message to the occupant. The massage should warn the occupant about the consequences of using the appliances and remind them of their promises and the possible penalty costs of not adhering to them.

Accordingly, the building's occupant can decide whether using the device is worth the extra cost or not.

There might be some local markets, where the building can participate as a seller. Regarding this structure, the building can individually sell energy and flexibility to the grid or/and other participants [41]. In this way, the energy management system should make bidding strategies for the building. However, finding the optimal bidding strategies is a complicated process for the energy management system since it needs to analyze huge data and information on historical data, the behavior of other competitors, market prices and the market clearing process.

In general, an energy management system of the building can utilize various scheduling approaches and methods so as to better control the flexible devices. According to recent research, the scheduling algorithms can be categorized into rule-based, artificial intelligence-based, and optimization-based approaches. The following subsections introduce the mentioned methods.

4.1 Optimization-based Approaches

Optimization-based approaches aim to mathematically model the system and find the optimal schedule of the controllable devices in the building. In these approaches, the energy management system follows an objective which was defined by the occupant. According to this objective, the decision variables of the optimization problem are the optimal consumption and production power of controllable devices at each timeslot. In fact, the energy management system should determine the optimal working time and working power of flexible appliances. However, if the power of an appliance is not controllable, the decision variable regarding this device is a binary variable (ON/OFF signal) for each time slot.

In addition, the optimization problem has some constraints restricting the decision variables. The constraints are associated with the operation of each controllable appliance. Some of them consider the inherent characteristics of the devices (e.g. the capacity, maximum and minimum working power, etc.) while others can be those related to the occupants' comfort and preferences (e.g. the time span related to the operation of the devices specified by the customers).

The first step to define an optimization problem is to model controllable appliances mathematically. Based on these mathematical models, different optimization problems can be built. Here, are some examples [1]:

1- The first model is to define a linear programming (LP) problem. LP problems are always convex and easy to solve in polynomial-time. In these types of problems, the objective function and related constraints are defined to be linear affine functions. If the power consumed or produced by appliances is controllable and the other related functions are linear, it obtains an LP problem. In this situation, the variables should not be correlated with each other. However, as previously mentioned, most of the appliances consume constant power and are not controllable in terms of power. As a result, binary variables are required to implement the ON/OFF signals sent by the EMS. As a result, the problem is not LP anymore as it turns into a mixed-integer linear programming problem. However, one may relax integer variables to create an LP problem.

2- The energy management system may define a quadratic programming problem. Solving this type of problem is relatively simple. A problem that has a quadratic objective function and some linear constraints is an example. In this case, if the objective function is a positive definite function, the defined optimization problem can be simply solved in polynomial time. Otherwise, solving this problem would be harder. In addition, the model may have a convex objective function as well as some linear equality constraints and concave inequality constraints. This type of optimization problem is assured to be converged, leading to a unique solution.

3- The energy management system may model the dynamic of the appliances and devices, creating a dynamic programming problem. A dynamic programming problem is capable of solving large complex problems by splitting the main problem into several smaller sub-problems. The sub-problems are then recursively solved.

4- The scheduling problem may define as a mixed-integer linear programming problem in which the problem has a linear objective function along with some linear constraints. However, this problem consists of a mixture of continuous and integer decision variables [42].

5- There exist some practical algorithms that help to solve the problem. One of the effective methods is the branch-and-bound algorithm. This method relaxes the problem and creates some linear sub problems. Since most of the devices of a smart building operate with constant power, it would be more convenient for the energy management system to define mixed-integer programming problems. In this way, the energy management system can easily send the controllable appliances ON/OFF signals. These signals are modeled by binary decision variables. However, it is worth mentioning that integer variables may also make the problem complex which cannot be solved easily.

6- Defining a mixed-integer non-linear programming problem is not an appropriate form of scheduling since it is relatively difficult to solve. In other words, unlike a convex optimization, obtaining a unique solution is not guaranteed in this problem. However, in some studies, they transfer mixed-integer non-linear problems to mixed-integer linear programming ones through the use of linearization techniques [43].

4.2 Rule-based Approaches

Rule-based algorithms define rules for different conditions of behavioral systems. One of the popular rule-based algorithms which can be utilized in energy management systems is a Rete algorithm. By using Rete algorithm, the energy management system can control the consumption and production of the building via smart taps [44]. In this way, the flexible appliances of the building are distributed to the smart taps and go through the rule processing. Afterward, based on the priority defined by the occupant, the rule-based process defines some if/then rules [45].

For instance, the algorithm can define a rule to shift the operating time of high-priority flexible appliances from peak timeslots to off-peak timeslots providing that the building needs to provide peak-reduction services. The algorithm can also consider uncertainties associated with the dynamic prices and the consumption of uncontrollable devices of the building [46]. One of the disadvantages of the rule-based algorithm is that it fails to be extended to some advanced applications. In other words, the algorithm is unable to analyze large data when the energy management system confronts several tasks and a number of restrictions for the operation of appliances.

4.3 Artificial Intelligence and Machine Learning Approaches

An energy management system may utilize AI techniques to optimally schedule the appliances of the smart building. In this way, controllers of appliances may use artificial neural network (ANN) algorithms and machine learning, the algorithms based on fuzzy logic control (FLC), and adaptive neural fuzzy inference system (ANFIS) so as to find the optimal schedule [47]. In these algorithms, the controller seeks to play the role of the human brain, imitate human thinking, and make optimal decisions.

Integrating ANN algorithms with energy management systems can empower the scheduling process of these systems. Non-linear decision making is the main application of these algorithms. In the process of decision making, the inputs data are processed and the algorithm tries to simulate human brains to obtain the decision variables [48]. The energy management system can also be equipped with machine learning algorithms. In this way, according to the relation between historical inputs and decision variables, the rules and behaviors are learned.

If FLC algorithms are utilized in the energy management system of a building, the input data should go through four steps, including fuzzification, defuzzification, rule base, as well as an inference engine. It is noticeable that FLC algorithm does not need any mathematical model to solve the scheduling problem, but it is still capable of obtaining a solution for non-linear and linear models [49][50]. In addition, in this model the behavior of customers, its preferences and comfort can be modeled using fuzzy parameters. In comparison, the ANFIS algorithm is a more complicated algorithm presenting several layers [51]. The algorithm can define a set of fuzzy if/then rules and its learning capability is able to approximate nonlinear functions.

V. SUMMARY AND CONCLUSION

Grid-connected active buildings are those that not only utilize several renewable and non-renewable generation resources within themselves but also perform energy management levels in conjunction with a variety of automation systems. Thus, the energy management system is the core of an active building that should schedule the controllable devices and resources of the building while following a certain objective. The objective of the energy management system can be decided by the occupant (e.g. cost minimization) or be determined by the grid (e.g. peak-shaving and providing flexibility service), or it can be a hybrid of the mentioned objectives. In addition, there exist some key constraints which should consider in the process of scheduling. The constraints may be related to the characteristics of the devices or appliances, those imposed by occupants in order to maintain their comfort level, and the restrictions associated with the external grid. Thus, the energy management system should take into account the mentioned limitation when scheduling controllable appliances. The responsibilities of an energy management system of the building include a range of tasks such as scheduling controllable appliances and devices, monitoring and forecasting the consumption of uncontrollable devices, forecasting the production of the building (e.g. solar production), and making bidding strategies on behalf of the building who wants to participate in local markets as an individual player. In order to fulfill these responsibilities, the energy management system should model the internal system in the building. In fact, it should schedule appliances optimally using scheduling algorithms. In general, the scheduling algorithms can be categorized into rule-based, artificial intelligence-based, and optimization-based approaches. Regarding rule-based algorithms, the energy management system defines several rules for different conditions while the artificial intelligence-based approaches aim to imitate the human brain to find the optimal decision variables. In optimization-based methods, the system defines a mathematical model of the building in order to find the optimum control variables. These control variables can be ON/OFF signals sent to the appliances or the optimal working power of the devices. However, the defined model needs to be convex so as to get the best results.

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