People's Democratic Republic of Algeria

Ministry of Higher Education and Scientific Research

University of Aout 20, 1955 Skikda
Faculty of Technology
Department of Mechanical Engineering

Ref : D012121004D

Thesis

Submitted to the Department of Mechanical Engineering in Partial Fulfillment

of the Requirement for PhD Degree (LMD) in Electromechanics

Specialty: Energy Systems

Presented by

BOUAKKAZ ABDERRAOUF

Theme

Energy pilotage of habitat with multi-sources of energy

Presented publicly on: 03/31/2021

Jury composed of:

Abderrezak METATLA	Full Professor	President	University of Skikda.
Salim HADDAD	Full Professor	Supervisor	University of Skikda.
Toufik REKIOUA	Full Professor	Examiner	University of Bejaia
El Madjid BERKOUK	Full Professor	Examiner	Polytechnic of Algiers.
Ridha KELAIAIA	MCA	Examiner	University of Skikda.
Antonio Jose GIL MENA	Full Professor	Guest	Polytechnic of Algeciras, Spain
Mario Luigi FERRARI	Full Professor	Guest	University of Genoa, Italy.

Skikda on 2020

République Algérienne Démocratique et Populaire

Ministère de l'Enseignement Supérieur et de la Recherche Scientifique

Université du 20 Août 1955 Skikda
Faculté de Technologie
Département De Génie Mécanique

Réf : D012121004D

Thèse

Soumis au Département de Génie Mécanique dans la Satisfaction Partielle de

l'Exigence d'un Dégrée Doctorat (LMD) en électromécanique

Spécialité : Systèmes Energétiques

Présenté par

BOUAKKAZ ABDERRAOUF

Thème

Pilotage énergétiques d’un habitat multi-sources d’énergies

Soutenue publiquement le : 31/03/2021

Jury composé de :

Abderrezak METATLA	Professeur	Présidant	Université de Skikda.
Salim HADDAD	Professeur	Encadreur	Université de Skikda.
Toufik REKIOUA	Professeur	Examinateur	Université de Bejaia
El Madjid BERKOUK	Professeur	Examinateur	Polytechnique d'Alger.
Ridha KELAIAIA	MCA	Examinateur	Université de Skikda.
Antonio Jose GIL MENA	Professeur	Invité	Polytechnique d'Algesiras, Espagne.
Mario Luigi FERRARI	Professeur	Invité	Université de Gênes, Italie.

Skikda en 2020

Acknowledgement

First of all I would thank almighty GOD for giving me the courage to carry out this project.

I would like to express my gratitude to my thesis supervisor professor Haddad Salim for his advice, encouragements and aids.

I am very appreciated to Dr. Antonio J. Gil Mena from high school of Polytechnic of Algeciras (university Cadiz, Span), and I would like to thanks him very much for his aids, advice and orientations and who helps me in research works during the difficult periods of thesis preparation.

Mr. Rafael Jiménez Castañeda department of electrical engineering (Puerto real, Cadiz, Spain), the person who supervised me in the Erasmus scholarship, also thanks for Mr. Juan Andrés Martin García in the department of electrical engineering (university Cadiz, Spain) for his advice.

I am very appreciated to Mr Mario Luigi Ferrari (Thermochemical power group: University of Genoa, Italy), the person who supervised me in PNE mobility and I would like to thank him for his advice, aides and orientations.

I would like also to thank the Ministry of High Education and Scientific Research of Algeria for providing me the financial support under the program of P.N.E to complete and finalize this project.

I send my thanks to

The President and members of the Jury who have agreed to evaluate this thesis.
All my teachers who taught me during the cycle of studies.
All administration staff at the University of Skikda.
All those who contributed from near or far to the realization of this project, for their advice, their precious help and their moral support.

Dedication

I dedicate this work to:

The dearest people in my life: my mother "Zohra" and my father "Hocine", for their love, care and encouragement.

My dear brothers.
My dear sisters.
The whole family from near and far.
My colleagues and my friends.

Abstract

The energy consumption at the housing level continues to increase in recent years, in particular with the proliferation of new cities with a high population concentration in Algeria; whose conventional energy produced the gazes, which responsible for greenhouse gas emissions. Faced with the resulting consequences, it is now essential, more than necessary, to reduce energy consumption at the housing level, and to increase energy sources based on new and renewable energy in order to replace conventional polluting energy sources. For this reason, it is necessary to determine an optimal strategy for efficient energy management while integrating new methods, approaches, design and renovation of the habitat.

To achieve this result, in the present work of thesis, we proposed a control mechanism with efficient energy management strategy that controls energy consumption in different time scales for a habitat powered by multiple sources based on renewable energies sources, to ensure the availability of energy for the user and rationalize the energy consumption with the possible minimum cost.

This mechanism of control allows scheduling the energy consumption based on data of weather forecast, the profile of energy demand as well as, a model of energy cost that considers the cost of both the energy used from grid and the battery for the optimal energy use. We also used the PSO optimization algorithm to schedule the energy consumption according to weather forecasts, cost and the provided data by the house occupant.

Keywords: Renewable energy, Habitat Multi sources, control, management, modelling, optimization.

Résumé

La consommation d'énergie au niveau de l'habitat continue d'augmenter ces dernières années, notamment avec la prolifération de nouvelles villes à forte concentration de population en Algérie; dont l'énergie conventionnelle produisait les gaz responsables des émissions de gaz à effet de serre. Face aux conséquences qui en découlent, il est désormais indispensable, plus que nécessaire, de réduire la consommation d'énergie au niveau de l'habitat, et d'augmenter les sources d'énergie basée sur les énergies nouvelles et renouvelables afin de remplacer les sources d'énergie conventionnelles polluantes. Pour cette raison, il est nécessaire de déterminer une stratégie optimale pour une gestion efficace de l'énergie tout en intégrant de nouvelles méthodes, approches, conception et rénovation de l'habitat.

Pour atteindre ce résultat, dans le présent travail de la thèse, nous avons proposé un mécanisme de contrôle avec une stratégie de mangement d'énergie efficace qui contrôle la consommation d'énergie à différentes échelles de temps pour un habitat alimenté par des sources multiples basées sur des sources d'énergies renouvelables, afin d'assurer la disponibilité de l'énergie pour l'utilisateur et rationaliser la consommation d'énergie avec le coût minimum possible.

Ce mécanisme de contrôle permet de planifier la consommation d'énergie en fonction des données de prévisions météorologiques, du profil de la demande d'énergie ainsi que d'un modèle de coût énergétique qui prend en compte le coût à la fois de l'énergie utilisée du réseau et de la batterie pour une utilisation optimale de l'énergie. Nous avons également utilisé l'algorithme d'optimisation PSO pour planifier la consommation d'énergie en fonction des prévisions météorologiques, du coût et des données fournies par l'occupant de la maison.

Mots-clés: Energie renouvelable, Habitat Multi sources, commande, pilotage, modélisation, optimisation.

ملخـــص

يستمر استهلاك الطاقة على مستوى الموائل في الزيادة في السنوات الأخيرة ، لا سيما مع انتشار المدن الجديدة ذات الكثافة السكانية العالية في الجزائر ؛ والتي تنتج طاقتها التقليدية الغازات المسؤولة عن الاحتباس الحراري. في مواجهة العواقب المترتبة على ذلك ، من الضروري الآن ، و أكثر من اللازم ، تقليل استهلاك الطاقة على مستوى الإسكان ، وزيادة مصادر الطاقة المعتمدة على الطاقة الجديدة والمتجددة من أجل استبدال مصادر الطاقة التقليدية الملوثة. لهذا السبب ، من الضروري تحديد استراتيجية مثالية لإدارة الطاقة بكفاءة مع دمج الأساليب الجديدة والنهج والتصميم وتجديد الموائل.

لتحقيق هذه النتيجة ، في العمل الحالي للأطروحة ، اقترحنا آلية تحكم مع استراتيجية إدارة الطاقة الفعالة التي تتحكم في استهلاك الطاقة في نطاقات زمنية مختلفة لموئل مدعوم من مصادر طاقة متعددة تعتمد على مصادر الطاقة المتجددة ، لضمان توافر الطاقة من أجل المستخدم وترشيد استهلاك الطاقة بأقل تكلفة ممكنة.

تسمح آلية التحكم هذه بجدولة استهلاك الطاقة بناءً على بيانات التنبؤ بالطقس ، وملف الطلب على الطاقة ، بالإضافة إلى نموذج لتكلفة الطاقة الذي يأخذ في الاعتبار تكلفة كل من الطاقة المستخدمة من الشبكة والبطارية للاستخدام الأمثل للطاقة . استخدمنا أيضًا خوارزمية تحسين PSO لجدولة استهلاك الطاقة وفقًا لتوقعات الطقس والتكلفة والبيانات المقدمة من قبل شاغل المنزل.

الكلمات المفتاحية: الطاقة المتجددة ، سكن ذات مصادر طاقة متعددة، التحكم ، قيادة ، النمذجة ، التحسين.

Conferences and Publications

1. Conferences

National conference

- **Abderraouf Bouakkaz** and Salim HADDAD. “Pilotage énergétiques d'un habitat multi-sources d'énergies”. Séminaire national sur les systèmes énergétiques hybrides. 29 - 30 Novembre 2015. Ghardaia – Algérie.

International conference

- **Abderraouf Bouakkaz** and Salim HADDAD. “Optimal Sizing and Simulation of PV System Production for Residential Building in Algeria”. The 4th International Seminar on New and Renewable Energies. 24 - 25 October 2016. Ghardaia – Algeria.
- **Abderraouf Bouakkaz**, Salim Haddad, Antonio J Gil Mena; “ Optimal Peak Power Shaving through Household Appliance Scheduling in off-grid Renewable Energy System”. In Proceedings - 2019 IEEE International Conference on Environment and Electrical Engineering and 2019 IEEE Industrial and Commercial Power Systems Europe, (EEEIC/I and CPS Europe) At: Genoa, Italy.
- **Abderraouf Bouakkaz**, Salim Haddad, Antonio J Gil Mena, Mario Luigi Ferrari ; “Scheduling of Energy Consumption in Stand-alone Energy Systems Considering the Battery Life Cycle”. In Proceedings - 2020 IEEE International Conference on Environment and Electrical Engineering and 2020 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe) At: Madrid, Spain.

2. Publications

Conference Proceedings

- **A. Bouakkaz**, S. Haddad and A. J. Gil Mena, "Optimal Peak Power Shaving Through Household Appliance Scheduling in off-grid Renewable Energy System," 2019 IEEE International Conference on Environment and Electrical Engineering and 2019 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe), Genova, Italy, 2019, pp. 1-6, doi: 10.1109/EEEIC.2019.8783662.
- **A. Bouakkaz**, A. J. Gil Mena, S. Haddad and M. L. Ferrari, "Scheduling of Energy Consumption in Stand-alone Energy Systems Considering the Battery Life Cycle," 2020 IEEE International Conference on Environment and Electrical Engineering and 2020 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe), Madrid, Spain, 2020, pp. 1-4, doi: 10.1109/EEEIC/ICPSEurope49358.2020.9160748.

International journals

- **A. Bouakkaz**, S. Haddad, J. A. Martín-García, A. J. Gil Mena, R. J. Castañeda; "Optimal Scheduling of Household Appliances in Off-Grid Hybrid Energy System using PSO Algorithm for Energy Saving", International Journal of Renewable Energy Research.,Vol.9, No.1, March, 2019. https://www.ijrer.org/ijrer/index.php/ijrer/article/view/8860.
- **A. Bouakkaz**, A. J. Gil Mena, S. Haddad, M. L. Ferrari; "Efficient energy scheduling considering cost reduction and energy saving in hybrid energy system with energy storage", Journal of Energy Storage, Vol 33, 2021, https://doi.org/10.1016/j.est.2020.101887
- A. J. Gil Mena, **A. Bouakkaz**, and S. Haddad; "Online Load Scheduling Strategy and Sizing Optimization for a Stand-Alone Hybrid System", SCE's J. Energy Eng., 2021, 147(1). https://doi.org/10.1061/(ASCE)EY.1943-7897.0000725.

Table of contents

List of Figures

List of Tables

List of Acronyms

AC: Alternative current;

ACU: Anticipative control unit;

ADSM: Active demand-side management;

ADS: Acquisition data system.

APRUE: National Agency for the Promotion and Rationalization of the Use of Energy;

BAS: Building automation systems;

BEMS: Building Energy Management System

CSP: Concentrating Solar Power;

CSS: Control and supervision system;

EMS: Energy management system;

ESS: Energy storage system;

EES: Electric energy storage;

HES: Hybrid energy system;

DC: Direct current;

DHW: Domestic hot water;

DLC: Direct Load Control;

DOD: Depth of discharge;

DSM: Demand-Side Management;

DR: Demand response;

HEMS: Home Energy Management System;

HES: Hybrid Energy System;

HMI: Human-machine interface;

HRES: Hybrid Renewable Energy System;

HVAC: Heating, ventilation and air conditioning;

IEA: International Energy Agency;

MAC: Model anticipative control;

MLP: Mixed Linear Programming;

MRC: Model reactive control.

Multi-SES: Multi-source energy system.

OECD: Organization for Economic Cooperation and Development

PV: Photovoltaic;

PSO: Particle swarm optimization;

RCU: Reactive control unite;

RESs: Renewable energy resources;

SH: Smart homes;

SG: Smart grid;

SOA: State of appliance.

SOC: State of charge.

SOO: State of occupant.

SOW: State of weather;

STE: Solar thermal energy;

TOU: Time of use.

WT: Wind turbine.

Introduction

Up to the present day, energy has been always considered as an indispensable resource for human activities, due to the diversity of energy use in various fields. Today, the energy is becoming more and more necessary for the daily uses (lighting, heating, feeding, moving around ...), but also for economic activities, trade, transport, agriculture, industry and communications, etc.

Globally, the residential sector accounts for 30 to 40% of energy consumption and is responsible for 30% of all greenhouse gas emissions. On the other hand, the residential sector presents the first sector for energy consumption in Algeria, and according to the report of the national agency for the promotion and rationalization of the use of energy (l'Agence nationale pour la Promotion et la Rationalisation de l'Utilisation de l'Energie: APRUE), indicates that the household energy consumption reached 19,808 tons of petroleum products in 2017, compared to 18,584 tons in the previous year (2016), with an increase of 6.6%. And more than 60% of electrical energy is consumed by households.

Moreover, the demand for electricity in the residential sector nonstop in increase and the demand is increasing day by day. For instance, in 2019, the national electrical system operators (OS: a subsidiary of the Sonelgaz group) have recorded a peak power demand for electricity (2h15 p.m.). This peak reached 15.044 MW, an increase of 10% compared to the peak in the year of 2018. This peak demand and the increase in energy consumption due to the use of several household appliances (heating, air conditioner, light, electric stove, television...) by many houses at the same time.

Unfortunately, the conventional energy sources are close to exhaustion, especially since these sources contribute to the increase in gas emissions, which lead to global warming. Consequently, the integration of clean and renewable energies such as solar and wind energy with including an energy storage system in buildings has become curial and essential.

Therefore, including more than energy sources and using storage systems besides the electrical grid in form hybrid system will contribute to reducing the peak power demand. Moreover, this will enhance the flexibility of the power network for energy operators, and reducing the energy consumption cost for householders. However, RESs (such as solar and wind energy) are intermittent sources where the period of energy production often does not coincide with the time of the power demand; this will make the control of power balance difficult and more complex. In addition, increasing energy storage capacity through using more batteries will increase the cost; as well as the problem of energy losses related to them.

In reality, the pilotage of energy in buildings through using efficient control strategies is one of the most convenient ways to reduce the increase of energy consumption (reduce peaks demand) as well as reduce the greenhouse gases. The pilotage of the energy designates all of the processes of control and command, which aims to reduce the energy consumption in the homes with assuring the availability of power supply with a minimum cost.

In this context, the presented work in this thesis, which is entitled "*Energy pilotage of habitat with multi-sources of energy*", aims to search on an efficient energy management strategy for a home equipped with a multi-source energy system (Multi-SES), in order to rationalize and reduce energy consumption, and minimize the costs. To achieve this objective, an energy management mechanism is proposed, which allows energy consumption in the home to be adjusted. This mechanism is able to ensure the power balance between the supply and demand, which takes into account the intermittent and random nature of the renewable energy sources, the comfort of the user as well as the economic and ecological constraints.

The work plan for this thesis is organized as follows:

The first chapter, which is entitled "*Energy overview: context and issues*", is devoted to analysing the global and national energy context, as well as presenting an overview for both the economic and the environmental issues related to the energy sector, in particular, energy in the homes.

To highlight the problems related to the energy demand and the impact of the residential sector in energy consumption, a chapter is entitled "*The residential sector: the main energy consumer*", is devoted to studying the impact of energy consumption in the residential sector, as well as studying the different loads, their profile of energy consumption and the behaviour of energy consumption in the home.

For better understand the energy management system in multi-source energy systems (Multi-SES), it necessary to study the general architecture of the multi-source energy systems, also, presenting the mains problems and issues for energy management in the hybrid systems, which is presented in the third chapter entitled: "*Multi-SES power production for homes*".

The fourth chapter "*Energy pilotage mechanisms for a home with a Multi-SES*", presents a review of the most research works developed for energy management systems in building, as well as the most strategies used to control the multi-source system in habitats, which is our objective in this thesis. This chapter also aims to propose an optimal strategy of control and supervision for managing the energy flow in the home in order to balance energy demand and supply with a decision algorithm able to deliver efficient management of energy consumption, reduce energy consumption cost and ensure the availability of energy all the time.

The last chapter entitled "*Implementation of the proposed control approach for a home with Multi-SES*", we present in this chapter an application case for the energy management system proposed in this research work.

Finally, we conclude by presenting the benefits of energy scheduling and the role of the energy storage system in maintaining the power balance between supply and demand. Moreover, how energy scheduling can also be used to optimize energy consumption and reducing peaks and costs. We also show that the optimal scheduling of energy consumption as well as the optimal using of batteries is an efficient strategy to reduce the cost of energy consumption, saving energy and avoiding the peak of power demand.

CHAPTER 1

Energy overview: context and issues

This chapter is devoted to analysing the energy context (energy production and consumption) and presenting an overview for both the economic and the environmental issues related to the energy sector. This analysis aims to clarify the complexity of the energy context which is considered as a worrying part of the transition in this time in particular regarding the environmental problems: climate change, the depletion of global energy reserves, etc. with specific attention paid to electrical energy, and in particular the use of the electricity in the residential sector which considered as first in energy consumption. Also, we will see the trend for the exploitation of renewable energy sources as future sources of energy for the next generations, as well as the main problems, and obstacles related to these energy sources.

1. Energy overview: context and issues

1.1. Energy context

With the beginning of the 21st century, the energy demand has increasingly increased due to population growth which reaches over 9 billion people. Consequently, as a result of the geographic expansion of population, the evolution of world demography, technological advances, and rapid development in countries with large populations such as China, India, and Brazil led to an intensive increase in energy consumption that was accompanied by an appearance of environmental impacts related to human energy activities: the shortage of primary energy sources, climate change, pollution, acid rain, etc. whereas, according to the latest statistics of the International Energy Agency (IEA) more than 1.1 billion people worldwide have not to access to electricity (Vinci et al., 2017). So on, the humanity is facing a difficult period at the energy level, the capacities of adaptation and innovation will be curial and decisive for the existence of human beings in an environment with a high level of development reached. Although making a reliable forecast on the evolution of energy production and consumption is extremely difficult considering the complexity of the energy context at the national and global levels, the energy demand is increasing continuously while production is in a complex transition phase with full of uncertainties. In this context, we will clarify that:

- How can the residential sector contribute to energy saving through the rationalization of final energy use, especially electrical energy?
- How to ensure energy supply at the local level by integrating other sources of energy?

1.1.1. Global energy context

As is mentioned above, the world experiences a sharp increase in energy consumption due to global population growth, which exceeds 9 billion people. Thus, if we look at the world's primary energy consumption since 1971, as shown by Figure.1. 1, we notice that it has not stopped of growing almost exponentially.

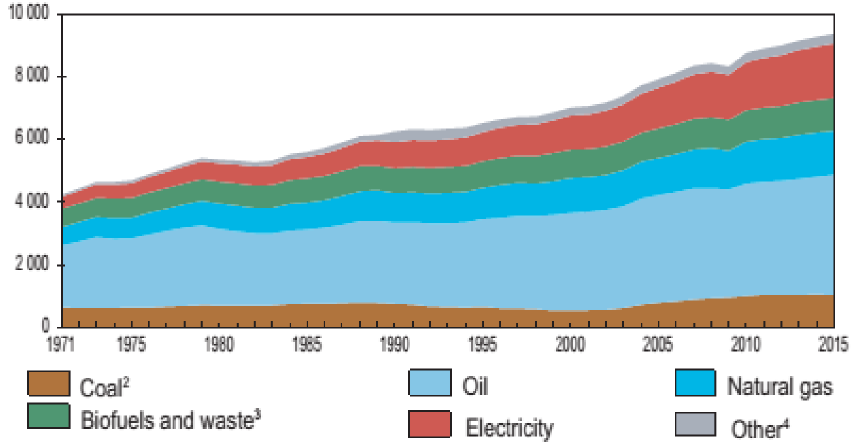


Figure.1. 1. Evolution of total final global primary energy consumption by source (IEA, 2018).

Based on the reference scenario by IEA, they estimate that the global energy consumption could strongly increase in the coming decades: it could drop from 549 billion MBtu (the "British Thermal Unit" is a unit of energy frequently used in the Anglo-Saxon world) in 2012 to 629 billion MBtu in 2020 and 815 billion MBtu in 2040, an increase of 48% in less than three decades. This increase comes mainly from developing countries, under the influence of their economic and demographic growth. In particular, it is believed that the Asian countries which not members of the Organization for Economic Cooperation and Development (OECD) including China and India are responsible for more than a half of the increase in the energy demand during this period. Africa's energy consumption can be double by 2040. However, it will remain very low during this horizon despite the strong demographic increasing on this continent; US energy demand will remain 2.4 times higher than in Africa in 2040 according to the IEA, with a population less than five times according to the latest data forecast.

Among all forms of energy, electrical energy is considered as the noblest and easiest to implement, and it is a blessing for everyone. The electricity used in many ways and in many sectors (industries, transports, agriculture, residential, commercial and public services, etc.). In the residential sector, the electricity gives us amenities in our life, we get many benefits such as lighting, cooking, conserving foods, cooling the room with air conditioner and heating the rooms using heaters and much more. This is why the proportion of electrical energy in the total energy consumed is constantly increasing as is depicted in Figure.1. 2.

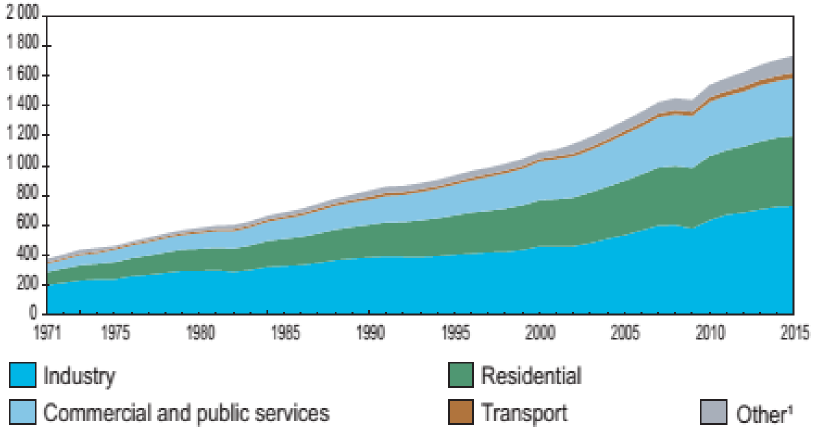


Figure.1. 2. Evolution of global electrical energy consumption by sector (IEA, 2018);

1.1.2. National energy context

Algeria is a country with a relatively enviable position in energy. The hydrocarbon reserves that own and the current levels of consumption necessary to cover its own energy needs allow it to remain serene for a certain time. However, the energy problem in Algeria is a problem that arises in terms of a strategy to value these resources for the country's development, the choice of real long-term energy policy and the immediate definition of a consistent energy consumption model that is covering the entire region in the short and medium-term by the investing in the new renewable energy sources, before the fateful date of the depletion of its strategic fossil resources.

The Algerian energy context is essentially characterized by an excessive dependence on hydrocarbons. However, hydrocarbons still play an essential role in the country's economy. According to 2016 statistics, the structure of primary energy production remains dominated in natural gas at 54%, followed by crude oil by with nearly 34%, as illustrated in the graph below:

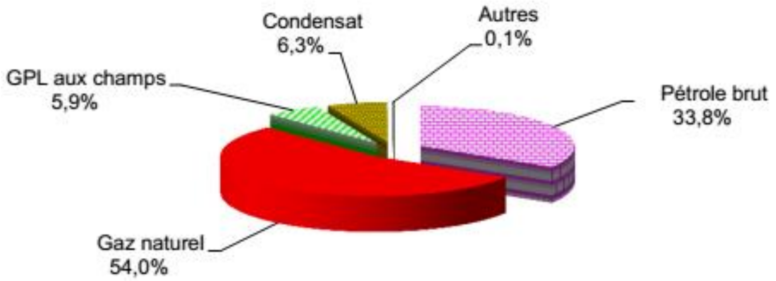


Figure.1. 3. Structure of primary energy production in 2016 (MEM, 2017).

1.1.2.1. Electricity production

Almost all of the electricity generation fleet in Algeria is owned by Sonelgaz company, the primary electricity production (including the hydraulic sector), exceeded 223 GWh. Thus, 2016 has known the commissioning of 13 photovoltaic power plants with a total capacity of almost 180 MW; which has brought increasing the solar and wind power generation in electricity production to almost 80%. The distribution of installed power by type and by the producer for the year 2016 is illustrated in the graphs below:

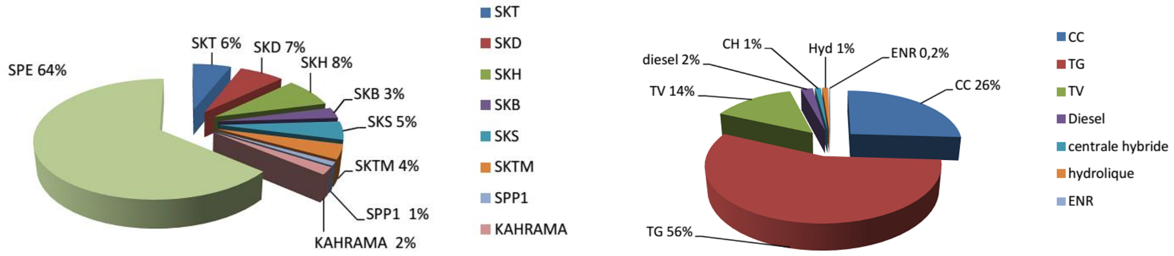


Figure.1. 4. Structure of electrical energy production in 2016. (Source: Sonelgaz key figures for 2015).

1.1.2.2. Electricity transport

The total length of the national electricity transport network, combined with all voltage levels (60 to 400 kV), that is managed by the administration of the electricity transport network (*Gestionnaire du Réseau de Transport de l'Electricité: GRTE*) equals 29,233 km at the end of 2017, i.e. 12,455 km achieved in 12 years such is presented in Figure.1.5.

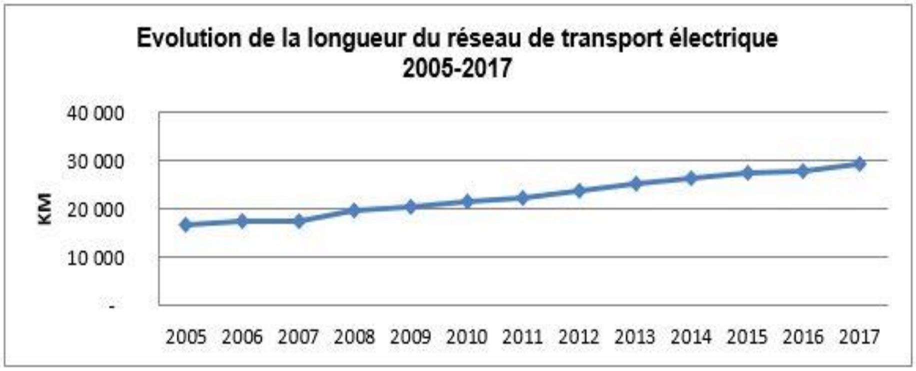


Figure.1. 5. Evolution of the length of the electric transport network between 2005 and 2017 (ME, 2020).

The structure of the national electricity network is divided into three systems, which is cited in the following points:

- The Interconnected National Network (INN)
- The Pole of In Salah - Adrar - Timimoune (PIAT)
- Isolated Southern Networks (ISN)

1.1.2.3. Electricity consumption

If we look at the electricity consumption in Algeria in recent years as shown in Figure.1.6, we observe that the consumption of electricity has increased significantly, reaching significant consumption peaks which increased from 26830 GWh in 2006 to 52289 GWh in 2016, with a ratio of 95%. This sharp increase in demand is a result of the change in consumer habits and the improvement of their life quality, as well as the impulse that was given to the economic and the industrial sectors.

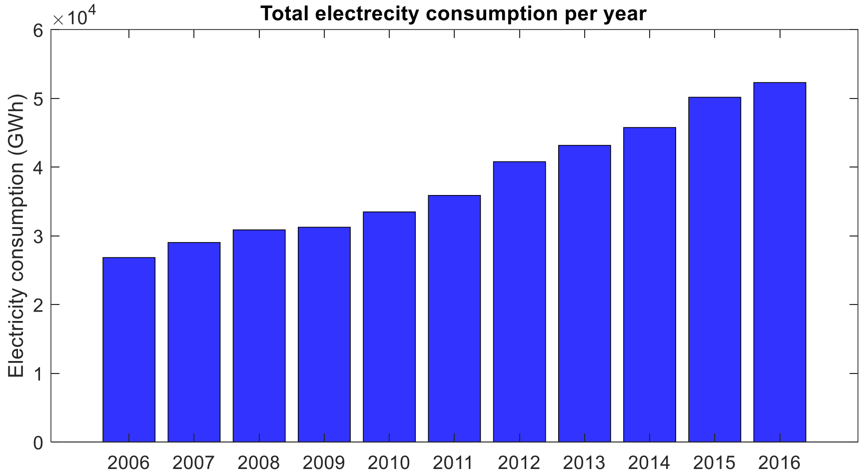


Figure.1. 6. The evolution of electricity consumption from 2006 – 2016.

1.1.3. Renewable energy in Algeria

Algeria is the country of sunshine, which has significant potential in renewable energies, with over 80% of its land occupied by the Sahara desert, makes it a pioneer in the field of solar energy (Com, 2020). Therefore, Algeria is resolutely embarking on the path of renewable energies in order to provide global and sustainable solutions to environmental challenges and the problems of preserving energy resources of fossil origin. Therefore, the Algerian government has launched several important projects for solar energy production (Era, 2015).

Solar energy constitutes the major axis of the program, which devotes an essential part of photovoltaic and thermal solar. Solar power is expected to reach more than 37% of national electricity production by 2030.

Despite a fairly weak potential, the program does not exclude wind power, which constitutes the second axis of development, which share could be around 3% of electricity production in 2030 (CDER, 2018).

Algeria also plans to install a few experimental units in order to test the different technologies in terms of biomass, geothermal energy and desalination of brackish water by the various renewable energy sources (Algeria, 2011).

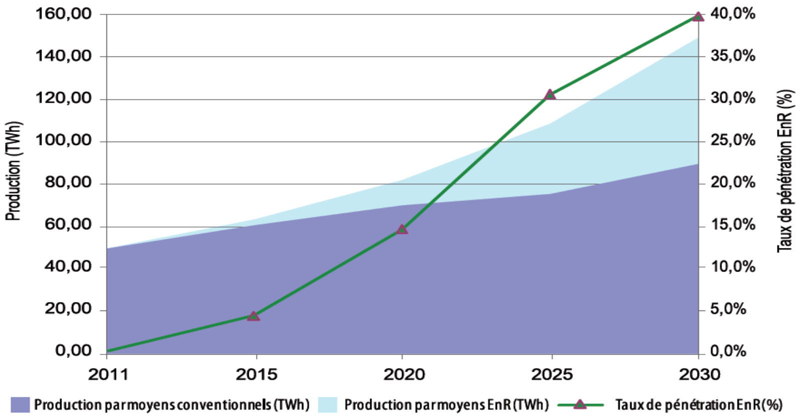


Figure.1. 7. Penetration of renewable energies in national production in TWh (Algeria, 2011).

1.1.3.1. Photovoltaic solar energy

Photovoltaic solar energy refers to energy recovered and transformed directly into electricity from sunlight by photovoltaic panels. It results from the direct conversion in a semiconductor of a photon into an electron. In addition to the advantages linked to the low maintenance cost of photovoltaic systems, this energy perfectly meets the needs of isolated sites; also, for whose connection to the electricity network is too expensive. Photovoltaic solar energy is a non-polluting energy source.

The strategy for energy in Algeria is based on accelerating the development of solar energy. The government plans to launch several photovoltaic projects with a total capacity of around 800 MWp by 2020. Other projects with a capacity of 200 MWp per year should be carried out over the period 2021-2030(Algeria, 2011).

1.1.3.2. Thermal solar energy

Thermal solar energy is the transformation of solar radiation into thermal energy. This transformation can be used directly (to heat a building for example) or indirectly obtain electrical energy by using power cycle systems (Rankine cycle and Brayton cycle). By using the heat transmitted by radiation rather than the radiation itself, these modes of energy transformation are distinguished from other forms of solar energy such as photovoltaic cells.

The direct radiation from the sun is concentrated by collectors on an exchanger where it is given up to a fluid, either vaporized directly or transporting the heat to a steam generator. All the systems have in common a certain number of organs such as a collector which concentrates the heat from the sun radiation, a liquid or a heat transfer gas which transports it to the point of extraction, an evaporator (heater), a condenser, a turbine and an alternator. Concentrating Solar Power (CSP), thermal solar can meet the demand for electricity day and night if it coupled to thermal storage means (such molten salt storage) or hybridized with other energies such as gas.

Algeria intends to develop its solar potential of energy, one of the most important in the world, by launching major projects in solar thermal. Two projects for concentrated thermal power plants including storage with a production capacity of 150 MW, in which 120 produced from gas and 30 from solar energy launched over the period 2011-2013. These projects will be added to the Hassi R'Mel hybrid power plant with a capacity of 150 MW, including 30 MW in solar. The 2021-2030 phase program provides for the installation of 500 MW per year until 2023, then 600 MW per year until 2030 (Algeria, 2011).

1.1.3.3. Wind energy

By definition, wind energy is energy produced by the kinetic energy of the wind. It is the result of the action of wind turbines that contains electric machines driven by the wind and whose function is to produce electricity. Turbine blades move in rotation by the force of the wind allows the production of mechanical energy that transformed into electrical energy through generators in any sufficiently windy place. The wind energy captured on the blades drives the rotor which, coupled to a generator that converts mechanical energy into electrical energy. The amount of energy produced by a wind turbine depends mainly on the wind speed but also the surface swept by the blades and the density of the air.

The Algerian program of wind energy predicts over 35 TWh per year of energy produced by wind turbines. However, almost half of the country experience significant wind speed. The country's first wind farm is being built at Adrar (south-west of Algeria) with an installed capacity of 10 MW with substantial funding from state-utility

Sonelgaz. Two more wind farms, each of 20 MW, are to be developed during 2014-2013. Studies will be led to detect suitable sites to realize the other projects during the period 2016-2030 for a power of about 1.7 GW(Algeria, 2011).

1.2. Energy production and consumption issues

In addition to the environmental issues so as global warming, we are faced with a challenge to manage and control energy demand. This challenge is mainly related to the issues of production and consumption of electrical energy. So better understand these issues, we must first address the general principles of problems related to energy consumption and production.

1.2.1. Peak power demand problems

The main challenge in operating the electricity grid is to maintain a constant electrical energy balance between the supply and demand. However, one of the major issues may the system of electricity operators face is the peak power demand. This peaks power demand generally results from the use of devices and equipment that consume a large amount of electric energy such in the applications of the industry sector and the residential sector. Regarding the building sector, using several household appliances (heating, air conditioner, light, electric stove, television…) by many houses at the same time can also lead to peak demand. The main parameters influencing in electricity consumption are mainly economic activity and meteorology.

For instance, the Algerian electricity operator (SONALGAZ[1]) has recorded in daily winter consumption for the year 2012 a historical record for electricity consumption for the winter period. This peak consumption was recorded in the evening at 8 p.m., as shown in Figure.1.8. Experts explained this peak of consumption and the increase in consumption due to the cold wave that has passed the country and which generated the maximum energy demand (PMA) of 8,305 MW is a significant development, from 7% compared to the same period last year (7,764 MW). This development represents 541 MW equivalent to the power of the power plant, such as that in Berroaughia (SKB).

---

[1] The national company of the production, transportation and distribution of the electricity and the gas.

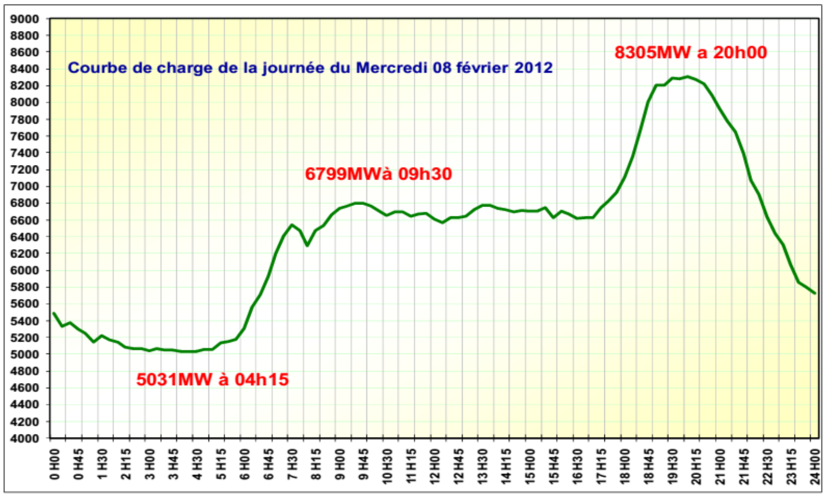


Figure.1. 8. daily electricity consumption curve (Sonelgaz, 2012).

1.2.2. Problems of the intermittency of RESs

Generally, renewable energy sources (RESs) are intermittent and variable energy production sources that are not permanently available. Some of these energy sources have regular and predictable variations like tidal power, and partially such as solar power, others are less regular like wind power.

The production of solar and wind energy illustrated in Figure.1.9 is subject to variations in availability due to the intermittent nature of these energy sources. Despite this limitation, the supply capacity must be maintained.

1.2.2.1. Variability

Renewable energy sources have a problem related to the variability of producing energy; this variability in production has an impact on the energy balance between supply and demand (Kunz et al., 2014). Wind does not always blow regularly, and sunlight can be obstructed by clouds. Wind and solar power are variable energy sources, which poses some unique challenges that must be addressed. Sometimes an entire region can experience periods of a day or sometimes even a week when winds or solar energy that is generally available on average are mostly absent. Wind power, in particular, is also variable over short time scales with gusts of wind producing peaks and troughs in power output which can cause voltage problems, due to the unevenness of power being put on the network.

1.2.2.2. Intermittency

Renewable energy sources have a common characteristic called intermittency. Intermittency means unplanned downtime or interruption in producing the power from power sources which caused by uncontrollable reasons. Therefore, the production of electricity from intermittent energy sources is inherently uncertain (Gersema and Wozabal, 2018). To delineate intermittent RESs, solar, wind and tidal energy are generally considered to be intermittent, while bioenergy, geothermal, and hydropower are non-intermittent renewable energy sources (Haupt, 2014).

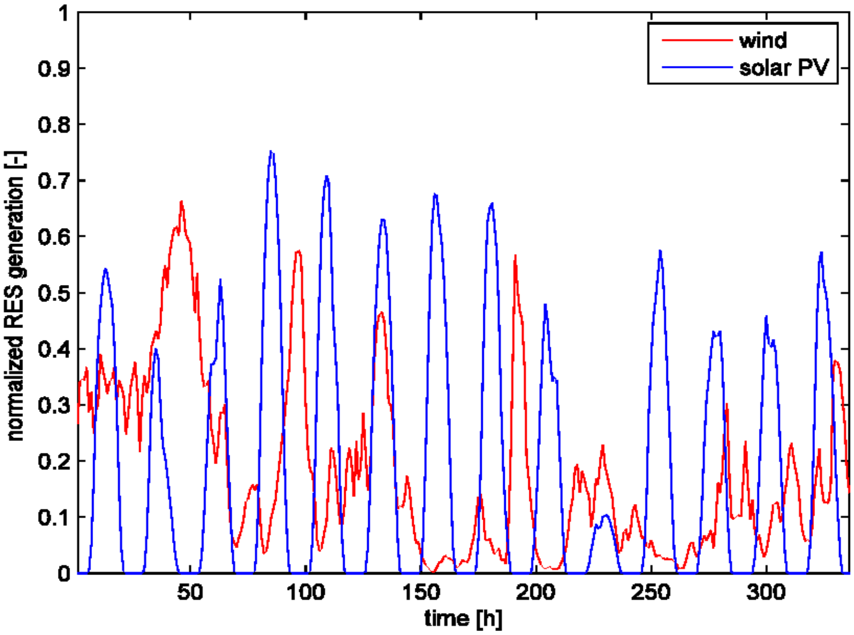


Figure.1. 9. Representation of intermittency problems of wind and solar energy (Delarue and Morris, 2015).

1.3. Conclusion

In this chapter, we have highlighted the global and national energy context, and the problems related to the consumption of electric energy such as the problems of peak consumption and their impact on the balance between production and consumption, also problems of intermittency related to renewable energies.

CHAPTER 2

The residential sector: the main energy consumer

The buildings sector in Algeria (residential and tertiary) consumes more than 40% of total energy. The development prospects for the housing sector will lead to an exponential increase in this energy consumption. The latter is considered to be the most significant source of energy savings and modulation with transport.

The present chapter is devoted to studying the impact of energy consumption in the residential sector, as well as studying the different load and their profile of energy consumption. Finally, to better understand the energy in the residential sector, we will give an analysis and modelling of energy behaviour for different loads used in homes.

2. The residential sector: the main energy consumer

2.1. The impact of building sector on energy demand

The study of the distribution of electric energy consumption by sector in Algeria indicates that the buildings sector is the most in which it is the biggest consumer of electric energy (Figure.2.1). The electricity consumption in the residential sector reached 807 KTep (tonnes of oil equivalent), representing 41% of total electricity consumption. Therefore, it represents the largest consumer of electrical energy at the national level(MEM, 2017).

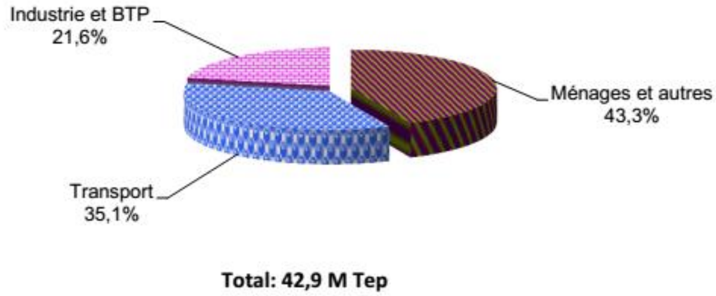


Figure.2. 1. Energy consumption by sector of activity in 2016 (MEM, 2017).

Therefore, the growth in the number of buildings is an explanatory factor for the increase in electricity consumption in the residential sector. According to the statistics, the increase in electricity consumption in the residential/tertiary sector is mainly due to the increase and the multiplication of the number of household appliances present in each household, especially for entertainment products (TV, DVD players, recorders, Hi-fi, decoders, telephony, game console, computers...). The main driving force behind this evolution is mainly due to the massive using of electric cooling and heating systems.

2.1.1. The home energy consumption

In a residential habitat, several electrical devices exist to offer different services for the occupant. However, each device differs from the other in terms of its nominal power, its type of use and its time of use (TOU) in the home, hence a difference in the impact of demand management actions depending on the electrical equipment chosen.

Therefore, the demand for electrical energy is the result of the consumption of electricity from different equipment by consumers. So, it is important to know the consumption and the load curve of each equipment to allow the best energy management to know how much energy can move/reduce and the power shaved/reduced by this equipment control with taking into account the comfort of the occupant.

2.1.2. Concept of service in homes

An energy service in a building designates the use of equipment over a period of time that transforms energy to meet specific user needs such as heating, cooling, lighting, etc. One service can be different from another by its flexibility. Indeed, service according to their behaviour and their flexibility can be classified into three categories; interruptible, shiftable and modifiable.

Interruptible: A service is said to be interruptible when the energy consumption of the service can be temporarily interrupted, such as the air conditioner, the refrigerator.

Shiftable: A service is shiftable if it can be scheduled freely within a given time window, such as washing machine, dishwasher.

Modifiable: A service can be modified if it offers the possibility of modifying its energy profile, for example, by reducing or increasing its energy consumption during a given period such as light, heater.

Also, service is qualified as a ***permanent service*** if its consumption/production energy covers the entire time range of the energy allocation plan; otherwise, the service is called ***temporary service***.

Another classification of service regarding the ability and accessibility of control, into ***controllable services*** with well-known temporal characteristics and energy profiles (consumption or production), and ***uncontrollable services*** in the event that no information on their temporal characteristics and energy profile is available.

The activities associated with these latter types of services are not planned by the energy management system, and their execution is totally dependent on the occupants. Uncontrollable services are numerous in terms of occurrence; however, they do not necessarily consume much energy.

2.2. Energy needs in the home

In general, the building consists of several energy and equipment functions. (Robert A., 2004) propose to classify the loads according to the function in the building in two main categories:

General functions: Correspond the majority of the energy consumption in the building, they characterized by their great energy consumption, it corresponds to the essential needs of the users, it constitutes the heating, air conditioning, lighting and water heating systems.

Specific functions: these functions correspond to specific or auxiliary user needs such as cooking, cold production and household appliance services.

The energy needs in buildings are distributed over three posts:

- Heat: heating, production of domestic hot water (DHW);
- Cold: cooling or cooling of premises, food preservation;
- Electricity: uses of electricity for (lighting, household appliances, audio-visual and various auxiliary devices such as burners, pumps, fans …).

According to the study performed by the National Agency for the Promotion and Rationalization of the Use of Energy (APRUE, 2016), the housing sector consumes more than 40% of the total national consumption of electricity. This study shows that heating consumption place the top of the list with (46%) of total consumption in the building sector, followed by cooking food (22%), hot water production (13%) and the electrical auxiliaries which present (19%). The daily distribution of energy consumption by type of equipment in a residential habitat presented in Figure.2.2.

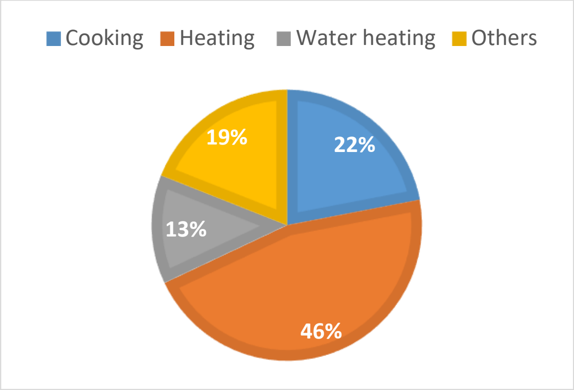


Figure.2. 2. Distribution of residential consumption by type of load in 2007 (APRUE, 2016).

Also, according to (Robert A., 2004), the periods of use the energy demand of the user can classify into four periods of which is varied as a function of time:

- Period of regular use;
- Reduced usage period;
- A reinforced period of use;
- Non-use period.

2.2.1. Heating, ventilation, and air conditioning (HVAC)

Heating, ventilation and air conditioning (HVAC) is a set of technical fields grouping together the state of bodies dealing with both thermal and aeration comfort. This qualifier applies to all types of buildings (residential, tertiary, industrial) and vehicles. The purpose of an HVAC system is to provide users with health and safety conditions that comply with current regulations, as well as a certain level of comfort.

The techniques used for the design and construction of an HVAC system make it possible to control in a building:

- The level of hygiene (CO2, pollutants, particles, odours, etc.);
- The level of safety (fire dampers in ventilation ducts, smoke extraction, etc.);
- Ambient temperature (in winter and summer);
- Hygrometry (humidity of the air);
- Air renewal in the closed place.

2.2.1.1. Thermal comfort

Thermal satisfaction is a basic human need of the twenty-first century. Therefore, many types of buildings are equipped with heating or cooling systems to control the indoor temperature. These systems allow occupants to adjust the temperature and sometimes the humidity level according to their needs (Mora and Bean, 2018).

Thermal comfort is a subjective quantity which depends on external conditions and also on the physiology of the use. In 1994, the international standard ISO 7730 (ISO, 1994) was designed from experimental studies validated mainly in the United States and Scandinavia. The ISO 7730 standard proposes human thermal sensation in the predictive sense, taking into account different aspects such as ambient temperature, relative humidity, airspeed, human metabolic effect or clothing effect.

In buildings, there are two different types of premises:

- Air-conditioned rooms are rooms and corridors, in which the temperature must be maintained at a level defined by one or more set points.
- Non-air-conditioned rooms are rooms and corridors in which the temperature is not controlled.

2.2.2. Ventilation

In residential and tertiary sector buildings, ventilation primarily meets the occupants' need for hygiene and health:

- A supply of fresh air for breathing;
- Elimination of indoor pollution linked to human presence and activities.

The ventilation system generally uses electrical energy; the installation and sizing of the system depend on the ventilation needs. Also, these needs vary according to the type of building.

2.2.3. Domestic hot water (DHW)

Domestic hot water (DHW) represents around 18% of total energy consumption in the residential sector in the USA and approximately of 14% in the European Union energy consumption(Pérez-Lombard et al., 2008). However, it is estimated that the daily consumption, whether it is low or high as the figures vary from 30 to 80 litres depending on the user. Generally, it is considered that an adult person consumes about 50 litres of hot water (at 45 °) per day or 1.75 litres/m² of living space. Also, the domestic hot water usage varies depending on the type of building, the number of occupants and hot water usage patterns.

Three main factors characterize hot water:

- The water requirement expressed either in litres per hour (litres/hour) or per day (litres/day), or in cubic meters per year (m3/year);
- The temperature level of heated water depends on the type of use: 40 °C for a sink, a bidet, a bathtub or a shower, 60 °C for a large sink, or a laundry room or a washing machine;
- The frequency of utilization, usually in the house, there are two main peak periods for using hot water: morning and evening and small consumptions in the middle of the day.

2.2.4. Lighting

Lighting brings all the means that allow the occupant to maintain the lighting conditions in his environment. All activities need bright conditions to avoid eye fatigue which is part of our visual comfort (Amasyali and El-gohary, 2016).

Electric light sources are responsible for the energy consumption of about 15% to 20% of the overall electricity production in the world. Hence, the average energy consumption of lighting in buildings is at least 15% of total energy consumption. It also represents more than 40% of national consumption (Zissis, 2016).

2.2.4.1. Visual comfort

Visual comfort is a subjective reaction to the amount and quality of light in a given space at a given time. Therefore, visual comfort depends on the ability to control the levels of light around us. Too little or too much light can lead a visual discomfort. The visual comfort can vary depending on the several factors: exposure time, type of light, eye colour and the age of the person (Saint-Gobain, 2020). Visual comfort includes a variety of aspects, such as:

- Aesthetic quality;
- Light quality;
- Light ambience;
- The level of brightness;
- No glare.

Unlike thermal comfort, visual comfort has been little studied in the literature. Many studies have been done on reducing lighting in offices during the day in particular. (Galasiu and Veitch, 2006) summarize the 60 research subjects concerning satisfaction in terms of luminosity in offices with natural sunlight. However, few norms or standards relate to visual comfort.

2.2.5. Household electrical functions

2.2.5.1. Food refrigeration

The purpose of domestic refrigeration production is generally to preserve food. The production of cold involves the presence of two categories of cooling devices: the refrigerator and the freezer. The trend in this category is to improve efficiency by imposing energy efficiency strategies. The report proposed in (Menanteau, 2007) presents a significant reduction in the energy consumed by the production of domestic cold thanks to the implementation of policies to improve energy efficiency.

2.2.5.2. Dish and clothes washing

A. Clothes washers

Washers and dryers are responsible for 10% of residential energy consumption, with most of the energy used for hot water used for washing. However, it is estimated that 85% to 90% of the energy is used to heat water, and about 10-15% of the energy is used in washing and controls process. Therefore, the reduction in energy consumption for clothes washing application would involve reduction in the hot water to be used (Dotton, 2020).

The power demand curve for an average washing process has three different operating phases: the water is first heated to the desired temperature by a heating system between 1800 and 2500W nominal power. When the desired temperature is reached, the cleaning process can be continued for a while, followed by several rinsing processes (Figure.2.3). This whole process can be controlled either by an electronic controller or by a mechanical clock (Timer). The process can take between 15 minutes and 3 hours.

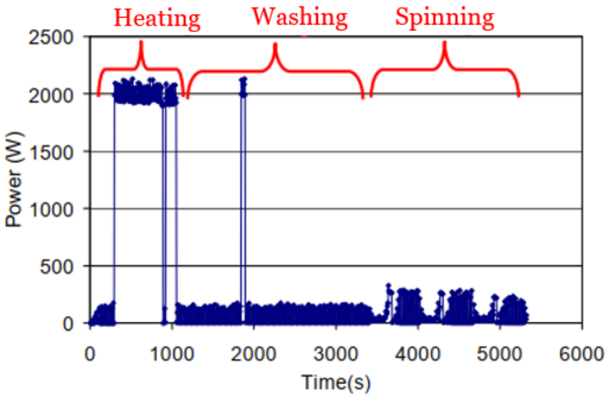


Figure.2. 3. Energy consumption profile of a washing machine (Rim MISSAOUI, 2012).

B. *Dish washer*

A dishwasher energy consumption is typically equivalent of 700–850 kWh of electricity annually. About 80 % of this energy is used to heat the water for washing the dishes (Dotton, 2020). According to a study conducted by GEA (Group for Efficient Appliances)(René B. J. Kemna, 1999), the operation of a dishwasher is characterized by 5 phases:

- Pre-rinse cold: the dishes are filled with cold water.
- Washing: the dishes are filled with water heated to the temperature chosen by the user (50/55 ° C, 60/65 ° C or 70/75 ° C) by an electric resistance with a power between 1800 and 2500 W. Rinse cold: the dishes are filled with cold water;
- Rinse hot: the water is warmed to a temperature a little above the washing temperature to prepare for the drying phase.
- Drying

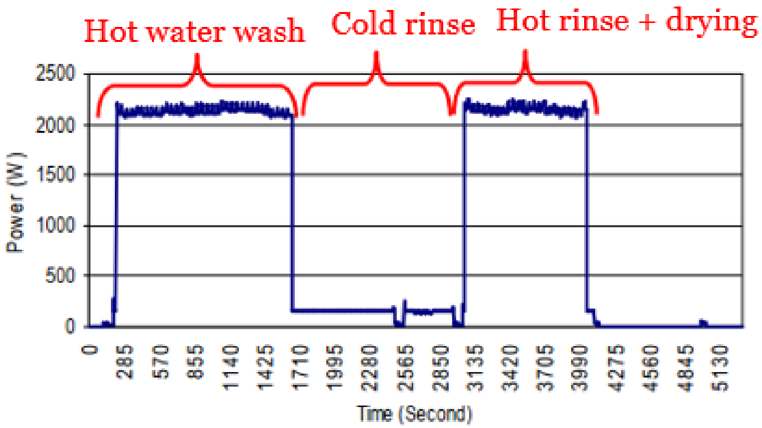


Figure.2. 4. Energy consumption profile of a dishwasher (Rim MISSAOUI, 2012).

2.2.5.3. Cooking

In Algeria, both gas and electricity are used by cooking appliances. However, cooking represents 22% of residential energy consumption (APRUE, 2016). An estimate of the usual consumption for collective cooking (Robert A., 2004) leads to an order of magnitude of 1 kWh per meal prepared; thus, the potential for energy savings remains significant. The study by (SIDLER, 1999) is based on all of database analyses of 517 appliances of 32 different types which cover the uses of electric cooking (hotplates, ovens, microwaves, coffee makers, kettles, etc.). It shows that 50% of the total energy of the cooking station is absorbed by the plates and 42% by the ovens (all types combined) and 99% of the powers called simultaneously by all electric cooking appliances are less than 3 kW.

2.2.5.4. Computer and entertainment equipment

The continuous increase in the applications of information and communication technology (ICT) services relevant to entertainment such as (TVs, computers, radios, music, and console games), communication (e.g. mobile phones) in the residential sector produces new energy demands. Entertainment devices account for about 15% of total energy demand in building, including wasted energy from devices on standby, which is estimated to contribute 6% of residential energy demand. For instance, in Europe, the household electricity consumption from small electronic appliances, including ICT, increased by 2.5 times in 2011 compared to 1990 (Pothitou et al., 2017).

2.3. Analyse the energy consumption profile.

To better understanding the energy consumption behaviour, it is necessary to analyse the annual and daily energy consumption profile of different uses on a residential scale and their contributions in periods of low energy availability on the electricity network.

An analysis of the average annual consumption curve in habitats (Figure.2.5) shows that it is possible to distinguish two main phases of energy consumption during the year:

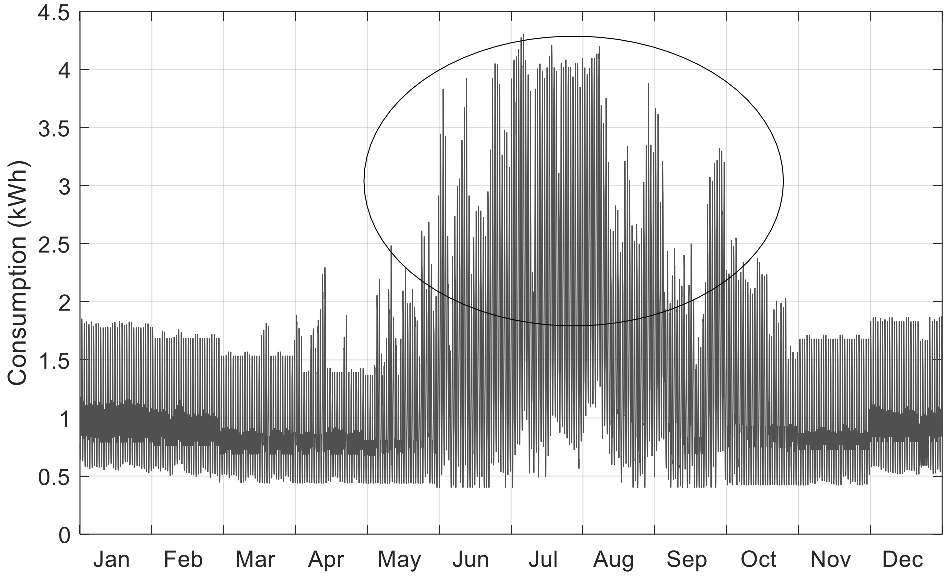


Figure.2. 5. The profile of annual electrical energy consumption for a home (Source: The National Renewable Energy Laboratory NREL).

Phase 1: presents the winter period of the year, characterized by its low consumption of electrical energy compared to the rest of the year.

Phase 2: this period can be considered as the summer period, where energy consumption is significantly high compared to the winter period. However, the consumption peaks can be twice higher than the winter consumption during the months of June, July and August. This increase in consumption is explained by the fact that during this period, temperatures are very high, which is accompanied by the intensive use of air conditioning systems that consume much energy.

The analysis of the daily electricity consumption curve of a habitat which carried out by (Amirat, 2005) shows that the electricity consumption profile has evolved according to four characteristic phases (See Figure.2.6):

- The first phase is between 12 a.m. and 6 a.m., corresponding to a period of low activity and during this period the demand for electrical energy is the lowest, the electrical consumption goes through a minimum;
- The second phase, which is between 8:00 a.m. and 12:00 p.m., corresponds to a period of activity for administrations and the industrial and service sectors during which electricity consumption increases, peaking around 9:00 a.m., then decreases;
- A third phase, which is approximately between 12:00 p.m. and 5:00 p.m., which corresponds to a slower period of activity due to lunch breaks and work interruptions in certain sectors of activity, during which electricity consumption is approximately an average and relatively stable level;
- A fourth phase, which runs from 5:00 p.m. to 0:00 a.m., which corresponds to the end of the activity period for administrations and the industrial sector and when people return to their homes. During this period, the demand for electrical energy is the highest. Electricity consumption increases sharply and then decreases again, with the peak consumption being around 7:30 p.m. - 8:00 p.m.

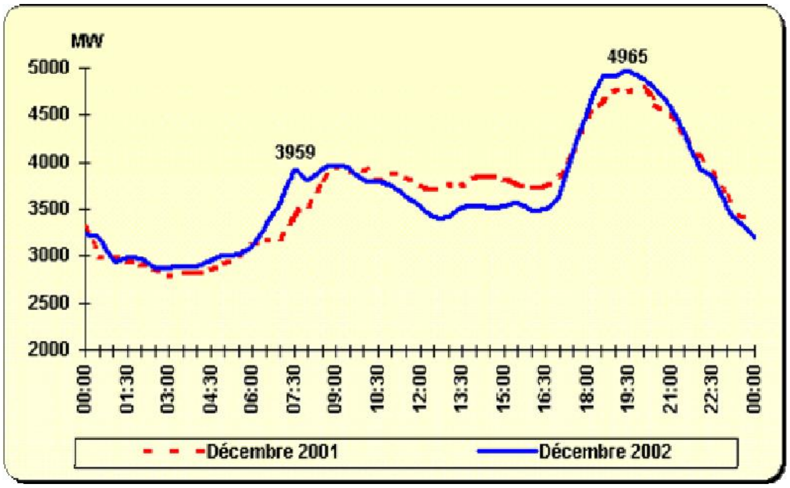


Figure.2. 6. Average annual electricity demand curves for a habitat (Source: Sonelgaz spa).

2.4. Modelling loads in the building

To develop an energy management system in buildings, it is necessary to studying the load behaviour and understand the energy consumption behaviour of users in the home. This section devoted to study the behaviour of electrical charges most used in the homes with some assumptions the main types of residential use.

Mathematical models provide a better understanding of the complexity of systems. On the other hand, it allows using standard techniques to deal with control problems of different nature and complexity. Therefore, through mathematical modelling, each problem is first transformed from the real world to the mathematical world.

Generally, the complexity of the control system is directly related to the complexity of the controlled system. However, in the analysis problem, it is common to validate the controller with precise models of the system under control before proceeding with the controller implementation.

Within the framework of energy management in the building, the objectives of the control design are:

- Ensure user comfort at the appropriate level;
- Offer flexibility in energy consumption to the electrical system;
- Optimal and efficient energy consumption;
- Streamline energy consumption and save energy.

2.4.1. Thermal behaviour of the building

In order to study the thermal behaviour in the house, we select a model of the power FlexHouse (Bacher and Bacher, 2010). The FlexHouse is designed as a large room that exchanging heat with the outside environment (Thavlov, 2008). This approach is useful for capturing the dominant dynamic heat of the house; thus, it makes it possible to estimate and predict the overall heat demand.

With such approach, the heating and cooling space are modelled as a single device, so that it is not possible to control the temperature in the rooms individually but to control the average temperature in all the rooms.

To show the dynamic heat of the house, three states are used: the first state is the temperature of the indoor air T_i, the second is the building envelope temperature T_{om}, and the third state is the temperature of the interior wall layers and floor T_{im}. The internal part of FlexHouse receives the energy of solar irradiance through the windows. Figure.2.7 shows the thermal circuit of a single room model (right) and a representation of the heat fluxes (left):

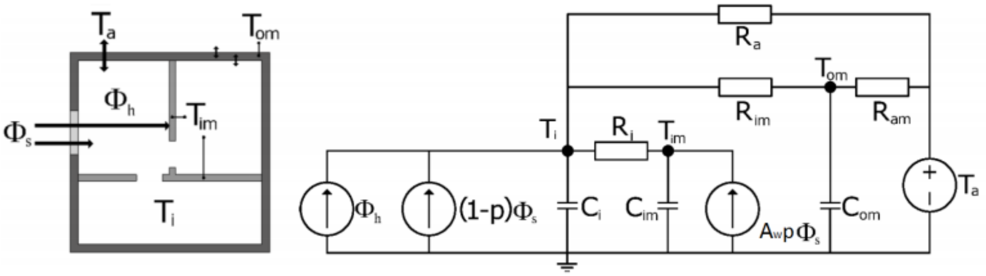


Figure.2. 7. Thermal circuit for the one-piece model of power FlexHouse (Costanzo, 2013).

Supposed that the exterior wall layer does not absorb the energy flow comes from solar radiation through windows ϕ_s so, this energy flow will distribute between the interior air and the interior wall layer. If it assumed P is a part of solar radiation energy flow, which directly effects on the temperature of the inner wall layer T_{im}, the quantity of energy flow due to solar radiation for both of interior wall layer is given by Equation (2.1). The indoor air is given by Equation (2.2):

$$Q_{im} = A_w P \phi_s \tag{2.1}$$

$$Q_i = A_w (1 - P) \phi_s \tag{2.2}$$

where Q_{im}, Q_i present the quantity of energy flow of interior wall layer and the indoor air. A_w is the windows area. Therefore, the differential equation for the temperature of the interior wall layer is given by the Equation (2.3):

$$C_{im} \frac{dT_{im}}{dt} = hA(T_i - T_{im}) + Q_{im} = \frac{1}{R_i}(T_i - T_{im}) + Q_{im} + R_{11,1} d\omega_1 \tag{2.3}$$

Where C_{im} is the total heat capacity of interior walls, R_i is the total thermal resistance between interior walls and interior air, $R_{11,1}$ is the diffusion term, which gives information allowing to locate the deficiencies of the model (Baadsgaard et al., 1997), finally, ω_1 is a Markov process representing the uncertainty of the model.

The envelope of the house exchanges heat by convection inside and outside the building is presented in the Equation (2.4):

$$C_{om}\frac{dT_{om}}{dt} = \frac{1}{R_{im}}(T_i - T_{om}) + \frac{1}{R_{am}}(T_a - T_{om}) + R_{22,2}d\omega_2 \tag{2.4}$$

Where C_{om} is the thermal capacity of the outer walls, T_{om} is the outer walls layer temperature, R_{im} and R_{am} are the thermal resistances from outer wall layer towards the indoor and outdoor and $R_{22,2}$ is the diffusion term.

The indoor air exchanges heat to the external ambient by ventilation and conduction through the windows. Moreover, there is a heat exchange by convection between the air and both inner and outer walls. Also, the indoor air receives thermal energy from solar radiationϕ_s and the electric space heaters ϕ_h. Therefore, the equation for the heat balance of the indoor air is equal to:

$$C_i\frac{dT_i}{dt} = \frac{1}{R_a}(T_{im} - T_i) + \frac{1}{R_{im}}(T_{om} - T_i) + Q_i + \phi_h + R_{33,1}d\omega_3 \tag{2.5}$$

Where C_i the total heat capacity of indoor air, R_a is the total resistance to heat flow to the outdoors, through windows and through ventilation, as well as the energy input from electric heaters. $R_{33,1}$, presents the diffusion term.

2.4.2. Modelling of refrigerator consumption

The interest is to control the refrigerator as a flexible unit of energy consumption, the operation of which can be shifted within the constraints of temperature and operation. If the refrigerator is not intended to be used as a smart load, in this case using validated models are useful to predict the energy consumption of the unit, in which these predict information is useful to manage the other flexible units (i.e. heat pumps for space heating), in order to reduce the load factor when peak hours demand. The objective is to obtain a model which links the power consumed by the compressor (input) and the external temperature (disturbances) to the temperature of the refrigeration chamber (controlled variable)(Costanzo et al., 2013).

Modelling and performance evaluation of household refrigerators have been already studied with different approaches such as dynamic simulation (Hermes and Melo, 2009), steady-state simulation (Hermes et al., 2009) and CFD models (Gupta et al., 2007). However, here we present the modelling of a vapour compression refrigeration system for residential applications using the grey box approach (Romijn et al., 2008).

A simplified schematic of a common single-stage vapour-compression refrigeration for household applications is presented in Figure.2.8.

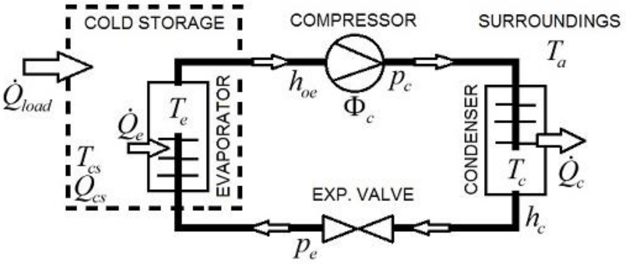


Figure.2. 8. Simplified single-stage vapour-compression refrigeration system (Costanzo, 2013).

This system model is presented by the following equations:

$$dQ_{cs} = m_{cs}C_{cs}dT_{cs} \tag{2.6}$$

$$Q_{load} = UA_{cs}(T_a - T_{cs}) \tag{2.7}$$

$$Q_e = m_r[h_{oe}(p_e) - h_{oc}(p_c)] \approx COP.\phi_c \tag{2.8}$$

$$m_r = N_c \alpha \rho_r(p_e) \tag{2.9}$$

where m_{cs} , C_{cs} , is the cold storage mass and specific heat. UA_{cs} is the overall heat transfer coefficient from the refrigeration chamber to the ambient. m_r , h_{oe} and h_{oc} are the refrigerant mass flow, the refrigerant evaporation and condensation enthalpies, while p_e and p_c are the evaporator and compressor pressures. N_c is the compressor revolution speed, α is a scaling coefficient that depends on the mechanical configuration of the compressor and ρ_r is the refrigerant viscosity. COP is the coefficient of performance which calculated as follow:

$$COP = \frac{thermal\ power}{electrical\ power} = \frac{Q_e}{\phi_c} \tag{2.10}$$

2.4.3. Modelling of a generic appliance

Any generic device that operation is directly managed by a local control system and where the power consumption is weakly influenced by the external ambient conditions, such as a television or a dryer, can be easily represented by its power consumption profile associated with a specific operating mode. In any case, the operation of the device is determined by the interaction with the users, who operate the device on time and choose the mode of operation. The use of finite state machines (FSM) is particularly practical for modelling such devices. Figure.2.9 shows a generic finite state machine for appliance modelling.

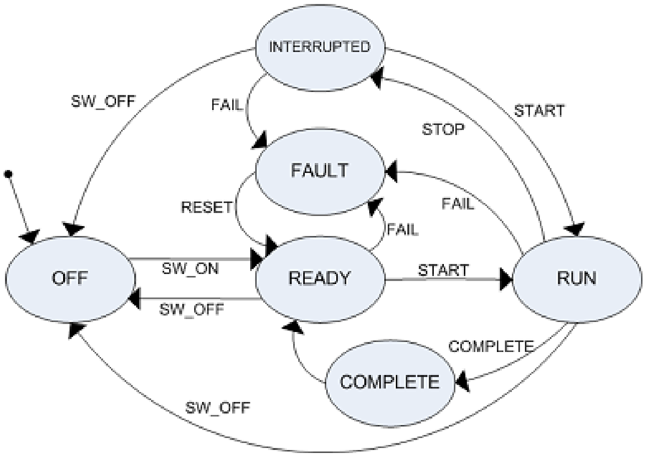


Figure.2. 9. FSM representation of generic appliance(Costanzo, 2013).

The status of appliance is presented by six states, and can be:

- **OFF:** the appliance is out of service (not enabled);
- **READY:** enabled asserted, appliance is ready to start service;
- **RUN:** enable asserted and start command received, appliance is on service and so consuming energy;
- **INTERRUPTED:** enable asserted and stop command received, the appliance is does not consume energy;

- **COMPLETE:** task completed and move to “READY" for being turned off or possible re-invoke;
- **FAULT:** fault detected in the appliance.

Each state of the FSM model is associated with the energy consumption profile (active/reactive) and other process parameters, such as elapsed time, the possibility of process pre-emption, time remaining, etc. This approach allows a couple of physical models with statistical models for use models, such as the time of use, the type of use, etc. For the implementation of these models type, it is necessary to map the states of the device operation and measuring the energy consumption associated with each one.

The operating programs, such as different cycles of a washing machine, are mapped based on the power consumption profile. At simulation time, the FSM model associates each state with the power consumption profile. Such a model can be implemented with the interface presented in Figure.2.10 (Savard, 2012)

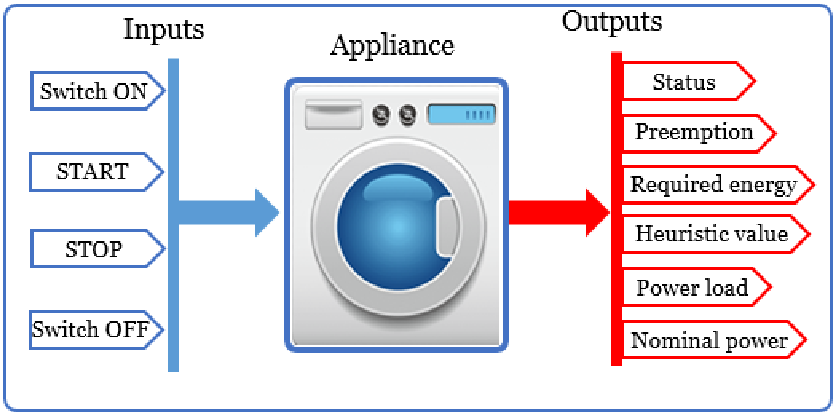


Figure.2. 10. FSM information interface (Costanzo, 2013).

The commands for the trigger inputs: "Switch ON" and "Switch OFF" come from the user interface and correspond to the user action of turning the power ON or OFF. The “START” and “STOP” triggers come either from the user or from the DSM system, depending on whether the device is intended to be used for flexible consumption or not.

2.5. Control the building's energy demand

The residential sector thus remains a rapidly growing sector even if the awareness-raising actions undertaken by the National Agency for the Promotion and Rationalization of the Use of Energy (APRUE) should contribute to gradually reducing the growth in consumption of energy from this sector. Considering the importance of consumption in the building sector, it is necessary to encourage the reduction and control of energy consumption in the residential and tertiary sector.

To move up the scale of thrifty housing and the energy efficiency in particular in the residential sector, APREU has launched many programs. For instance, the ECO-BAT program (APRUE, 2020) which aim to control the energy consumption in the building through building energy-efficient housing. The main objectives of the program are:

- Improving thermal comfort in homes and reducing energy consumption for heating and air conditioning;
- The mobilization of building stakeholders around the issue of energy efficiency;
- Carrying out a demonstrative action, proof of the feasibility of high-performance energy projects in Algeria;
- The consideration aspects of energy management in architectural design.

The development axes of energy efficiency concern

- Air conditioning and heating;
- Natural lighting using daylight using appropriate equipment, and the use of low consumption lamps low consumption appliances (use high energy performance household appliances);
- Thermal insulation;
- Energy management systems are making it possible not only to solve problems of adequacy, production and consumption of energy but also to reduce consumption by improving the adaptation of energy needs to uses.

2.6. Conclusion

In this chapter, we have seen that the building sector is in full evolution from the energy point of view with importance to multiply sources of electrical energy. Also, we have highlighted the need to control electrical energy in the building sector in the face of climate and energy challenges as this sector is considered the leading energy consumption sector.

Also, we have seen that the load curve analysis and the study the model behaviour of electrical loads are an integral part of the energy management system in buildings, and must be therefore taken into account for the study of energy management in buildings.

CHAPTER 3

Multi-SES power production for homes

As we have already seen in the first chapter, the renewable energy sources (RESs) pose a big issue of the energy production stability (fluctuation in the energy supply) which caused by the intermittency nature of these sources (variation in wind speed for wind turbines and absence of irradiation for the PV system, etc.). However, the multiplication and grouping of different renewable energy sources in the form of a hybrid system (multi-sources energy) can help to guarantee the availability of electrical energy and make the system more reliable and more effective.

The current chapter is devoted to studying the hybrid energy systems used in the residential power supply, as well as, presenting the mains problems and issues for energy management in the hybrid systems that present the main part for our work of this thesis.

3. Multi-SES power production for homes

3.1. Hybrid energy system

Definition

When the system contains two or more energy sources with different nature, the system is called a Hybrid system. By definition: Hybrid systems include all of the power supplies provided by the coupling of two (or more) sources of a different nature (Foggia, 2009). The hybrid system aims to ensure the best performance because it combines the advantages and the best operational characteristics of each source.

3.1.1. Hybridization of energy sources

Generally, the hybridization of energy sources is performed when the source of energy used in the system cannot meet the desired of all energy needs. Therefore, using another energy source (or more) can cover these needs and ensures the energy supply all the time and make the system more reliable. For instance, in some applications, hybrid fuel cell/battery systems combine the high power density of fuel cells with the high power density of batteries, so as to better respond to the variations of energy consumption.

In the case of renewable energy sources used for the residential sector, energy production is often variable and intermittent and it could not meet the demand for daily energy consumption. These limits of renewable energy sources can be avoided by using multiple energy sources in a form hybrid energy system which are based on the coupling of more than two energy sources as indicated in Figure.3.1 (Ex: grid, PV, diesel, batteries…).

The advantage of the hybrid system compared to a system contains only one source (i.e., wind or solar energy), depends on several fundamental factors: the form and the type of the load, the mode of the wind, the solar radiation, the cost, and the energy availability, fuel economy in the presence of one or more diesel generators, the relative costs of system components and other efficiency factors (CHALAL, 2013). So the hybridization allows:

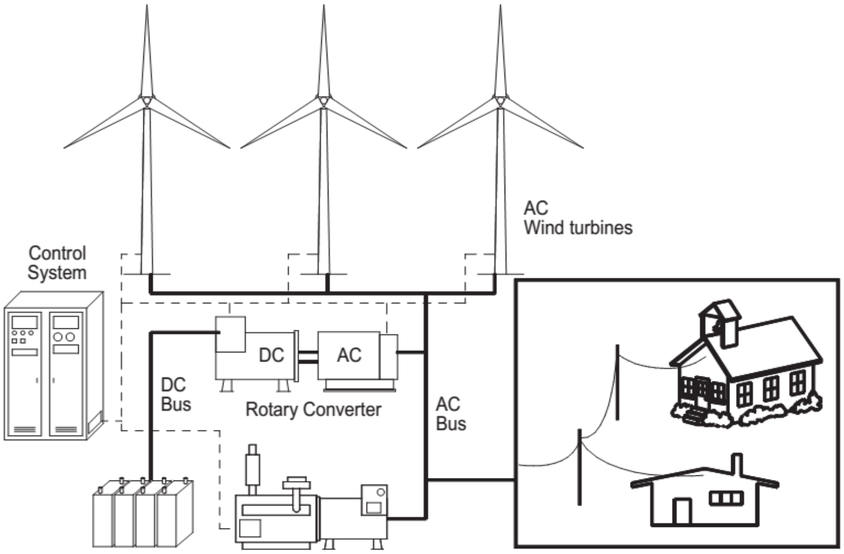


Figure.3. 1. Schematic of typical hybrid energy system with energy storage system (Baring-Gould and Corbus, 2006).

- Increasing the efficiency and reliability of the overall system, due to the multiplication and diversification of electricity generation source;
- Reducing energy storage capacity, especially in cases using a hybrid energy source with different renewable energy sources that present complementary behaviour;
- Minimization the operation and maintenance cost, Also, reducing the Levelized electricity cost through including renewable and non-fossil fuel sources, in particular when using hybrid energy system is based on optimum sizing techniques;
- Reducing the negative environmental impacts, through using environmental-friendly energy sources, especially in cases where the hybrid energy system not include any fossil fuel and based only on RESs.

3.2. Hybrid energy systems classification

The hybrid systems can be classified into several classifications according to the chosen criterion. The following are the most classifications widely used.

3.2.1. The mode of operation

Depending on the operating mode, the hybrid energy systems can be divided into two groups; one is a system connected to the electrical network (grid-connected system) and the other is a system operates in autonomous mode (Off-grid system / stand-alone system).

3.2.1.1. Grid-connected hybrid energy systems

In a grid-connected system, one or more of energy sources are connected side by side to the network (grid utility), this connection plays an essential role in the contribution of power balance and stability of the network. The including of renewable electricity sources makes possible to reduce the overload on the electrical network due to the high energy consumption, in particular during peak consumption periods where energy demand is high which has a negative impact on energy supply. As shown in Figure.3.2, a multi-source system contains a solar energy source connected to the electricity network with an energy storage system. In this case of these systems, the energy produced by the photovoltaic panels is directly consumed by the household appliances in the habitat; and so, the surplus of energy will be stored in the batteries for reused it later or be sold by injecting it into the network in the case the network provides the service of purchasing of renewable energy, where owners encourage them to buy this energy.

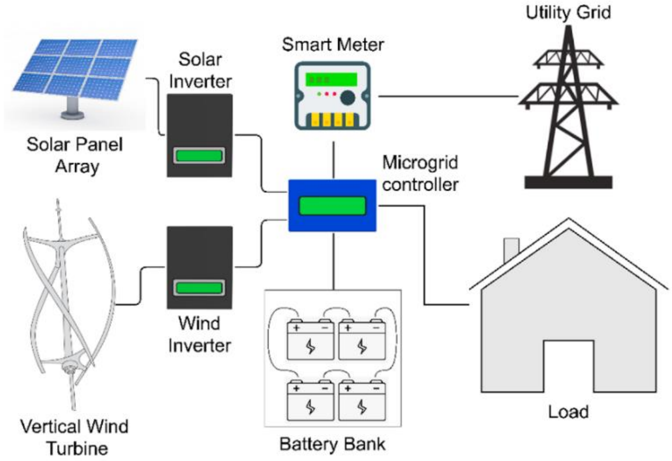


Figure.3. 2. Representation of a hybrid system connected to the grid (Shivam et al., 2020).

However, the users can use the energy from the grid when the price of electricity is low. On the other hands, they used the energy stored in the batteries during the day when the price is high especially during peak consumption periods, where the price is much higher than other periods, also possible to sell the stored energy when the price of electricity is high which provides again for the user.

3.2.1.2. Hybrid energy systems autonomous (Stand-alone)

In some case, it necessary to provide electricity for one or more consumers in isolated areas and far from the electricity network, where it is difficult to connect to the network because of the high costs or due to the difficulty of the geographical obstacles, In stand-alone systems often using more than one source to ensure the availability of power all the time.

In general, the stand-alone energy systems are located outside of any pricing environment. Given the need to energy balance between supply and demand at all times, the main objective is to seek to use as far as possible all of the energy produced from renewable sources and avoid the charge and discharge cycles in order to minimize conversion losses related to storage. Figure.3.3 shows a model of a stand-alone energy system contains a PV and wind generators associated with a storage system to ensure power supply at all times and for several days for covering the issue of the intermittent production of renewable energy sources.

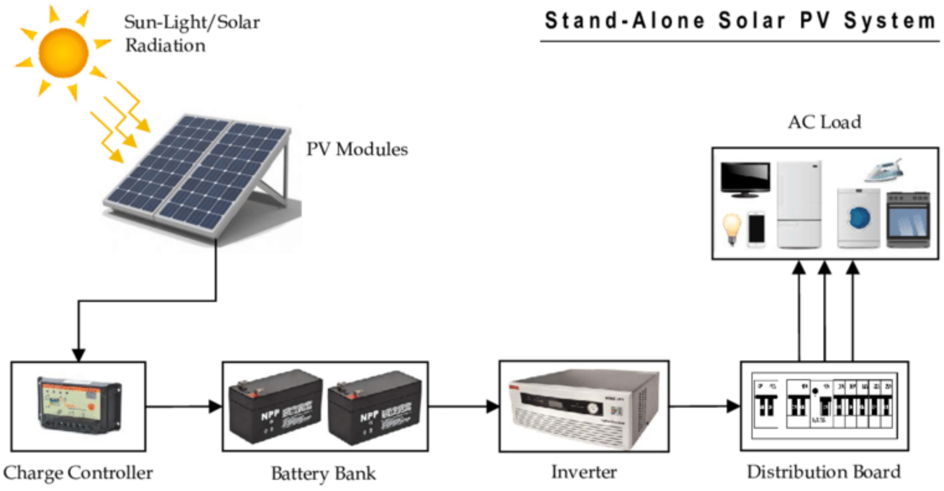


Figure.3. 3. Diagram of a stand-alone hybrid system (Ali et al., 2019).

3.2.2. The structure of the hybrid system

3.2.2.1. The presence of a conventional energy source

The use of a conventional source such as a diesel generator in the case of autonomous hybrid energy systems, or a gas micro-turbine, and in the case of a complete electrical network.

3.2.2.2. The presence of a storage device

The presence of a storage system in hybrid energy systems is considered an essential device in particular in the stand-alone systems for ensuring better satisfaction of electrical charges during periods of absence of a primary resource. Storage devices can be rechargeable batteries, electrolyzers with hydrogen tanks, flywheels, etc.

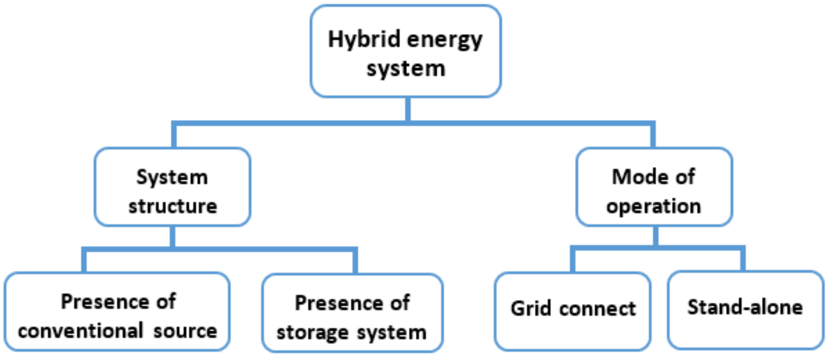


Figure.3. 4. Classification of hybrid energy systems.

3.3. Configurations of hybrid energy systems

In general, the hybrid electric power systems are configured according to the mode of bus coupling between the various devices in three modes of configuration; this configuration describes the mode of connection between the sources and the loads. However, the choice of such a hybrid bus configuration depends on the user. Therefore, there is no perfect configuration method and each mode of coupling has its advantages and disadvantages linked to each mode. The choice of coupling architecture will depend on several criteria; among them, we can cite:

- the situation of the site;
- The size of the system installation;

- The installed number of generator sources;
- The nature of the sources and charges.

The three configurations and their schematics are described below:

3.3.1. Direct current coupling (DC)

In the DC coupling mode, all the components connected to a DC bus. Direct current generators such as photovoltaic source are connected directly to the direct current bus through a regulator while rectifiers are used to connect the alternating current generators. The storage device is generally a battery which controlled and protected against overcharges and deep discharges by a charge regulator. For AC loads, an inverter is connected to the DC bus to convert DC to AC; however, DC loads can be connected directly.

In the case of a diesel generator, the connection can be direct (in the case of a DC generator) or through a rectifier (AC generator). The schematic of a hybrid system with a DC configuration is shown in Figure.3.5. In this configuration, the diesel generator can supply the load through the electronic converters or charge the battery. According to the hybrid system management strategy, the energy produced by the PV and WT system can directly supply the load or pass through the battery.

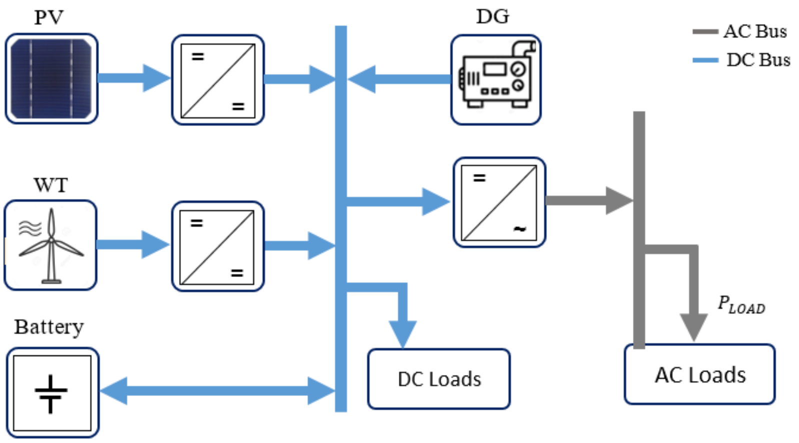


Figure.3. 5. DC bus configuration.

3.3.2. Alternative current coupling (AC)

In the AC coupling shown in Figure.3.6, all of the components are connected to an AC bus. The AC / AC converters must be inserted to allow synchronization of the AC power sources, and inverters inserted to connect the DC sources. If a battery is used as a storage device, a bidirectional static AC / DC converter is required. The AC loads are supplied directly by the AC bus, as also it is possible to supply the DC loads directly by the battery DC bus.

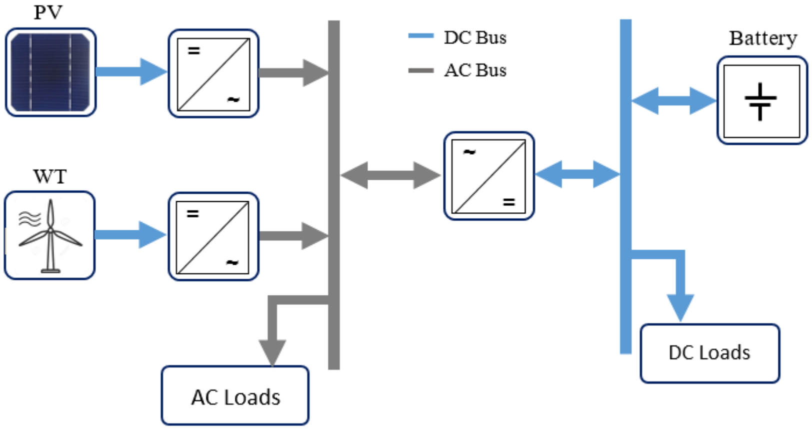


Figure.3. 6. AC bus configuration.

3.3.3. Mixed coupling (DC-AC)

In the DC / AC configuration presented in Figure.3.7, the energy will flow through different buses, one bus for circulating the alternating current (AC) and the other for the direct current (DC). If a battery is used as a storage device, a bidirectional AC/DC converter is required to connect the AC bus. However, the DC bus is connected directly to the storage system. The DC loads can be supplied through the AC/DC converter or directly from the DC bus. In contrast, the AC loads can be supplied directly from the AC generators or through DC/AC converter. On the AC bus, AC generators can be connected directly or via AC/AC converters to allow a good synchronization of the components.

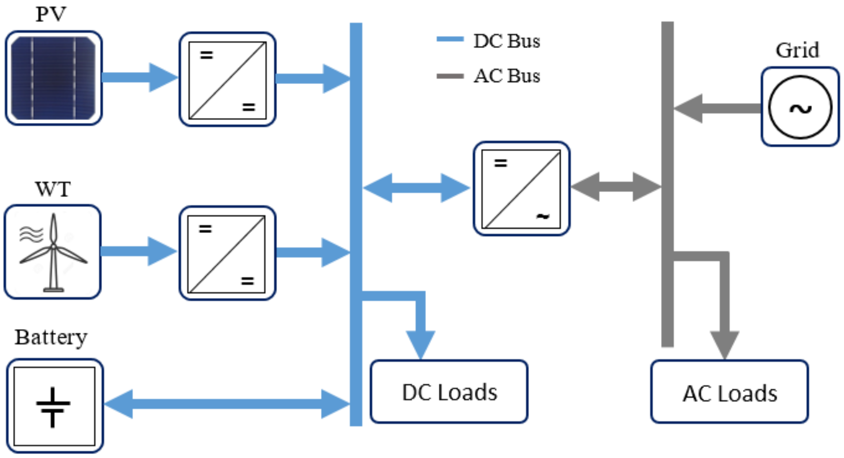


Figure.3. 7. Mixed configuration DC / AC.

3.4. Integration of hybrid energy systems in homes

Renewable energy integration in homes means of local energy production based on renewable sources. Thus, hybrid energy integration consists of using a combination of different energy sources, which may include at least one renewable energy source, in order to meet the maximum energy needs of the building with the best efficiency and more economical. (Ménézo, 2007), present the characteristics of a future building with technological solutions that make it possible to integrate energy production systems from renewable energy sources into the building: the heat pump replaces the heating system electric. They demonstrate the need for the development of decentralized electricity production in the building sector. Gradually, thanks to these local sources, the building is more and more autonomous in terms of energy, it becomes a more efficient energy producer for itself instead of being a simple consumer. As a result, energy production and consumption must be anticipated and coordinated according to the load on the building.

3.4.1. Photovoltaic power production

Photovoltaics are considered the main source of renewable energy from an electrical point of view for buildings. Indeed, solar photovoltaic electricity production systems are reliable, safe and very easy to implement. This technology is therefore well suited to meet the energy challenges of the 21st century and especially with regard to buildings. In these years, the integration of photovoltaic systems into buildings became a strong theme with two related dimensions: connection to the network and the constraints linked to integration into the urban environment. Photovoltaics connected to the grid and integrated into the building makes it possible to produce electricity at the point of consumption.

3.4.1.1. PV power production model

By definition, a photovoltaic (PV) generator converts the energy of photons (of light) into electricity. The photovoltaic effect is achieved by the photovoltaic cells corresponding to semiconductors, whose electronic structure has been modified (insertion of impurities). A PV generator is considered as current generator, in which the intensity depends mainly on the intensity of the incident light and the voltage imposed at the terminals of the module.

The output power of the PV generator (P_{pv}) at the maximum power point (MPP) can be calculated according to the solar radiation G (W/m²) and the ambient temperature T_{amb} (C °) as given in Equation (3.1):

$$P_{pv} = \left(P_{STC} \cdot \frac{G}{G_{STC}} \cdot \left(1 - \gamma\left(T_{cell} - T_{cell,STC}\right)\right)\right) \cdot N_s \cdot N_p \tag{3.1}$$

where:

P_{pv}: The output power of the PV in MPP,

N_s: The number of PV modules in series;

N_p: The number of PV modules in parallel,

P_{STC}: Rated power under standard test conditions (STC)

G_{STC}: Solar radiation in STC

$T_{cell,STC}$: The temperature of the cell in STC

γ: The temperature coefficient of PV cells in MPP,

T_{cell}: The temperature of the cell calculated by equation (3.2).

$$T_{cell} = T_{amb} + \frac{G}{G_{NOCT}} \cdot \left(NOCT - T_{amb,NOCT}\right) \tag{3.2}$$

where G_{NOCT} and $T_{amb}, NOCT$ are respectively the solar radiation and the ambient temperature at the nominal operating cell temperature (NOCT), NOCT is a constant. The STC and NOCT measurement conditions are obtained from the information in the technical data-sheet provided by the manufacturers.

3.4.2. Thermal solar energy

Thermal solar energy is the transformation of solar energy into thermal energy. It is a form of renewable, sustainable and environmentally friendly energy. STE recovered from sunlight using thermal solar collectors (Tian and Zhao, 2013). The general principle is to concentrate solar rays in one place to transform the solar radiation into thermal energy. This method of energy production can be used in small installations to heat buildings or domestic water (direct water heating) using solar water heaters, and in large power plants.

3.4.3. Wind power

Wind power is considered as one of the fastest-growing renewable energy technologies. Their usage is on the rise around the world, in part because costs are falling. Many parts of the world have strong winds, but sometimes the best places to generate wind power are far away. Offshore wind energy offers enormous potential (Irena, 2020).

Wind energy technologies can be classified regarding to utilization into two categories: macro wind turbines, which installed for large-scale power plant generation (Blazquez et al., 2005), such as wind farms, and micro wind turbines used for local power generation (Leary et al., 2012). Micro wind turbines are suitable for building scale application and are referred to as "building-integrated wind turbines". The main components that constitute a wind turbine are the blades, rotor, gearbox, and generator. Small wind turbines have initially been designed with a horizontal axis, also known as HAWT (Patent, 2000; Wright and Wood, 2004). To reduce the need for a tall tower and aesthetic reasons, Vertical Axis Wind Turbines (VAWT) (Aslam Bhutta et al., 2012) are becoming increasingly popular for integrated construction applications.

3.4.3.1. Wind power production model

By definition, a wind generator converts the kinetic energy of the wind into electrical energy through an electrical generator. There are many ways to simulate a wind power system, i.e. the power output of the wind turbine. The simplest models are defined by four characteristic parameters:

- the starting speed (v_c) which represents the value of the minimum speed for switching on the wind turbine and generates energy;
- the nominal speed (v_r) which represents the speed at which the wind turbine delivers nominal power;
- the wind speed limit (v_f) represents the maximum value of the speed for triggering the wind turbine (to protect the wind turbine from destroying it);
- Nominal output power (P_r).

According to the Pallabazzer model (Pallabazzer, 1995), the power of the wind turbine generator (P_{wt}) can be calculated as a function of the wind speed V (m/s) using the following formula:

$$P_{wt} = \begin{cases} 0 & , v < v_c \; or \; v > v_f \\ P_r \cdot \frac{v - v_c}{v_r - v_c}, & v_c \leq v \leq v_r \\ P_r & , \quad v_r \leq v \leq v_f \end{cases} \tag{3.3}$$

The characteristic curve of the wind turbine obtained by the Pallabazzer model presented in Figure.3.8 shows that for wind speeds less than v_c , the output power equal to zero. For wind speeds between v_c and v_r, the output power is obtained by the second expression in Equation (3.3), and for values greater than v_r to v_f, the efficiency is equal to v_f. This normalization will be extremely useful in determining the nominal power of the wind turbine.

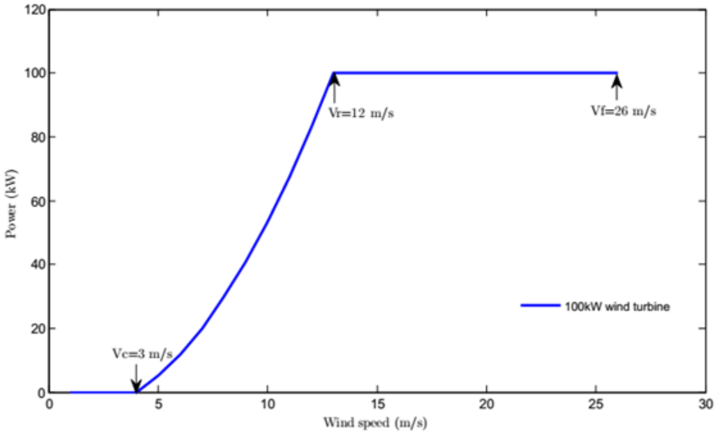


Figure.3. 8. Modelling of a 100 kW wind turbine (Gonçalves and Mesquita, 2010).

In addition, other parameters to take into account in the model, which is the height h of the hub of the wind turbine. The wind speed v at the height of h meters from the measured wind speed v_0 at a height h_0 can be estimated according to Equation (3.4). The exponent α is the coefficient of friction. The exponent α depends on the topography and the climatic conditions of the site (wind speed, the roughness of the terrain, the altitude above the ground, the temperature, the time of day and the time of year).

$$\frac{v}{v_0} = \left(\frac{h}{h_0}\right)^{\alpha} \qquad (3.4)$$

3.5. Energy storage system for HES

An energy storage system (ESS) is a unit device used to store electrical energy in order to be used when needed. Usually, it used as a power backup system to balance power and to give the system high quality, reliability and more flexibility (Hemmati and Saboori, 2017; Paul et al., 2014; Wang et al., 2013). For instance, in smart grids (SG) and smart homes (SH), ESS has a significant impact when supporting demand response programs (DR). On the one hand, in the case of grid-connected systems, it helps to reduce grid overload for power operators by reducing peak demand. On the other hand, it helps consumers in reducing the total cost of energy consumption. Also, it contributes to energy balance in the case of stand-alone power systems (e.g. EV and off-grid home)(Bert, D.F, 2012; Hossain et al., 2017; Kaldellis, 2010; Mazidi et al., 2018).

Electrical energy can be stored in various forms of energy, such as electrochemical energy, mechanical energy, thermal energy, electrostatic energy, etc. Therefore, there are many ESS technologies in use, and each technology has its own advantages and characteristics (Akinyele and Rayudu, 2014; Irena, 2015). An electrochemical storage system such as lead-acid batteries is the most common environmental system that provides fast and high energy capacity making it an ideal solution for homes connected to micro-grids with renewable energy systems(May et al., 2018; Wang et al., 2013).

3.5.1. Energy storage architectures

The electric energy storage (EES) systems are used in homogeneous or in hybrid form.

3.5.1.1. Homogeneous EES system

A homogeneous EES system consists of a single type of energy storage device. Since this homogeneity offers an easiest and simplest ways in implementation, controlling and maintenance. Figure 3.9 depicts the homogeneous architecture of an EES system composed of energy storage elements, an input and output power converter. Usually, multiple EES elements are clustered in order to increase power capacity. The input power converter performs the transduction of energy as well as, the power regulation from the power sources (e.g., power grid, PV panels, generators, etc.) to EES elements. The output power converter performs the energy transduction and the power regulation from the EES elements to loads (e.g., electric appliances, EV, etc.).

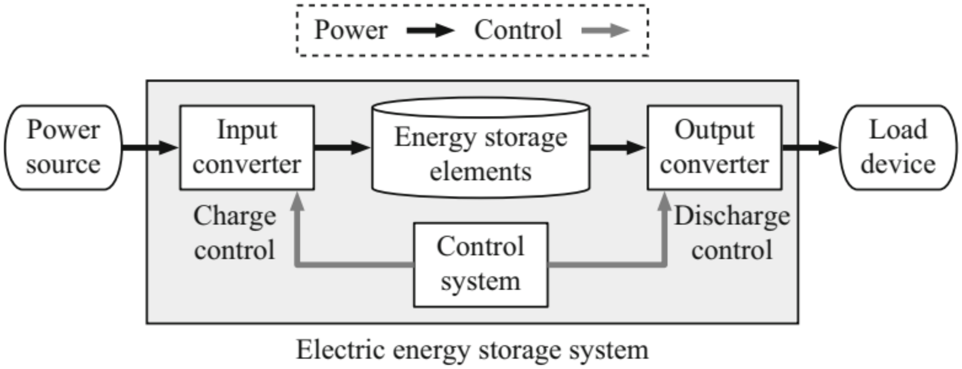
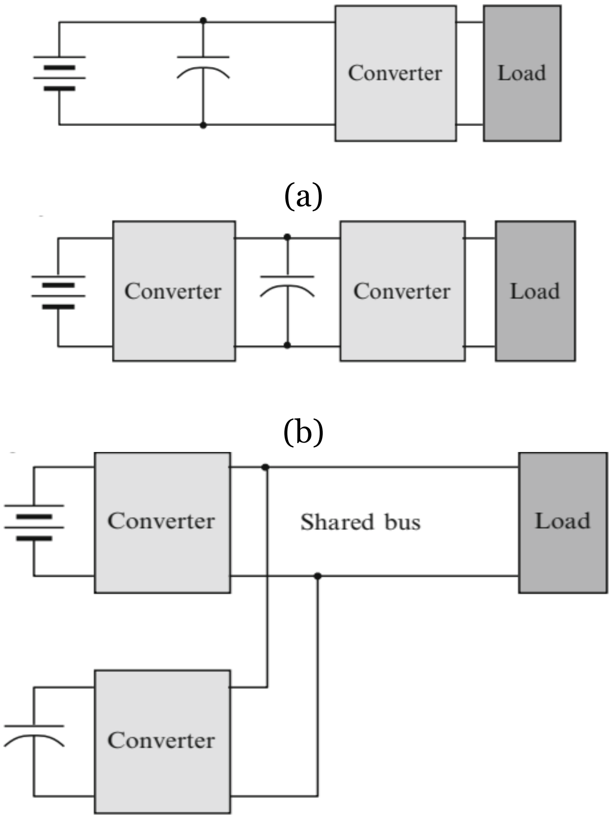


Figure.3. 9. Architecture of a typical homogeneous EES system (Kim and Chang, 2014).

3.5.1.2. Hybrid EES system

On the opposite of homogenous system architecture, the Hybrid energy storage (HES) system consists of more than one element of storage energy with different nature. Therefore, HES architecture is more complicated. Figure.3.10 shows different topologies of HES architectures. Some architectures are used for particular purposes, such as reducing the effective internal resistance through the parallel connection of supercapacitor and battery (Figure.3.10a) (Dougal et al., 2002), or buffering the current of the battery with supercapacitors using a power converter (Figure.3.10b) (Shin et al., 2012, 2011). Shared bus topology presented in Figure.3.10c considered a more general architecture that all the elements of energy storages are placed physically flat (Thounthong et al., 2011, 2009).



(a)

(b)

(c)

Figure.3. 10. Battery-supercapacitor hybridization topologies. (a) Passive parallel connection topology. (b) Cascade converters topology. (c) Shared bus topology (Kim and Chang, 2014).

3.5.2. Classification of ESS

ESSs are usually classified based on the form of their energy storage on four main categories: mechanical storage, thermal energy storage, electrical storage, and chemical storage.

3.5.2.1. Mechanical energy storage

The electrical energy can be stored through the conversion of electrical energy into mechanical energy in order to store it. Therefore, energy can be stored in water pumped to a higher elevation through pumped-storage methods (pumped hydro storage) (Al-hadhrami and Alam, 2015) or by moving solid matter to higher locations (gravity batteries). Other mechanical methods include compressed air energy storage (Garvey and Pimm, 2016) and flywheels that convert the electric energy into kinetic energy for using it when electrical demand peaks (Šonský and Tesař, 2019).

3.5.2.2. Electrical energy storage

A. *Superconducting magnetic energy storage (SMES)*

In Superconducting Magnetic Energy Storage (SMES) systems presented in Figure.3.11 (Kumar and Member, 2015) the energy stored in the magnetic field which is created by the flow of direct current through a superconducting coil. The superconducting coil must be cryogenically cooled to a temperature below its critical superconducting temperature (the material of the superconductor must be cooled enough to eliminate any resistance to current flow). The advantages of SMES systems are the ability of rapid response (They may be deeply discharged without any influence on their efficiency) and the impressive efficiency with a value of over 90%. However, SMES systems have some problems regarding the stability of the superconducting coil (sensitivity of the superconductor to temperature variation and the critical magnetic field).

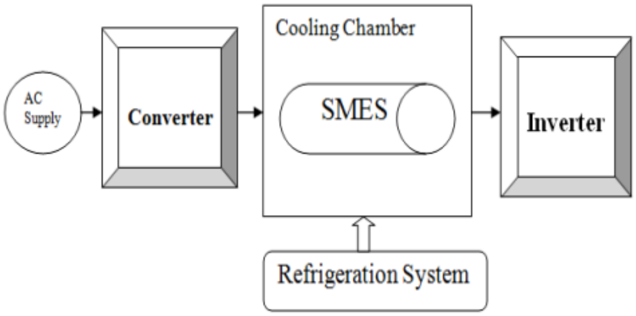


Figure.3. 11. Schematic of a superconductor magnetic storage (SMES)(Kim and Chang, 2014).

B. *Supercapacitors (SCs)*

The operational principle of supercapacitors (SCs) is based on the same principle of conventional capacitors. So on, they can offer direct storage of electricity at a high-speed rate (Wang, 2007). Supercapacitors have many advantages which include the fast charge and discharge rates, high power densities, low current leakage, a considerable service period, thousands of cycles per year at deep discharge without material degradation, operational stability within a wide range of temperatures and high energy efficiency. However, cost issues present a serious constraint for such systems while it is still among the lowest in energy storage.

3.5.2.3. Chemical energy storage

A. *Fuel cells and hydrogen energy storage (FC-HS)*

Electricity can be converted into hydrogen through electrolysis. And then, the hydrogen can be stored in pressurized containers, or solid metal hydrides, as well as, hydrogen can be stored in nanotubes with a very high density. On the other hand, hydrogen can be re-converted into electricity using fuel cells (Paul Breeze, 2018; Steilen and Jo, 2015).

Fuel cells have two electrodes surrounded by an electrolyte. Oxygen undergoes over one electrode, and hydrogen passes over the second, to generate electricity, water and heat.

In the operational principle, fuel cell work like a battery. However, a fuel cell does not require to be recharged; and the electricity is generated since the fuel is supplied to the cell. Consequently, the production of energy by the fuel cell is constrained by the size of the fuel tank. Therefore, the main disadvantage of this technology is the cycle efficiency that is estimated to be in the range of 30–40%. The losses are encountered during the production of the hydrogen, during the storage phase, and finally during the process of generating the electricity.

B. Battery energy storage

Batteries are the most common and widely used energy storage technology, due to their simplicity to employ, cost-effectiveness, and rapid response to input and output to/from the battery. There are many batteries technology, each with their own specific characteristics, covering a wide range of applications (renewable energy applications, electric vehicles…). These technologies include lead-acid batteries, nickel-cadmium (Ni-Cd) and sodium-sulphur (Na-S) batteries in addition to metal-air and lithium-ion (Li-ion) batteries, which have lately become very commercial (Irena, 2015; May et al., 2018).

Usually, batteries are determined by their capacity, the efficiency, depth of discharge, number of cycles, operating temperature, power density, and self-discharge. Every battery has a limited life depending on the type of the technology used; this life can be influenced by several factors such shallow cycles, intermittent use, deep of discharge, harsh environments, and non-comfortable conditions. Therefore, the intermittent uses of the battery due to the intermittency nature of renewable energy systems (REns) can affect the battery ageing and shorten their life cycle (Beltran et al., 2016; Riffonneau et al., 2008).

3.5.3. Energy storage system applications

Due to the great importance of EES systems, they have widely used in various applications (renewable energy applications, electric vehicles, cell phones, and much more). A comprehensive review of different EES system applications are presented in the references (Chen et al., 2009; Farhadi and Mohammed, 2015). However, in this section of the manuscript, the focus of this review is mainly limited to the applications related to the scope of the thesis subject.

3.5.3.1. Power grid applications

EES systems can be utilized in various power grid applications (Cho et al., 2013; Farhadi and Mohammed, 2015). They can be used as an energy management system in the grid through storing the energy in off-peak demand period and use it during the period with peak demand in order to arbitrage the price of electricity. Such applications can reduce peak load demand (peak shaving), or make the demand uniform over time (load levelling). The aim of these applications is mainly to reduce the cost of energy production through reducing the maximum capacity requirement in generation, transmission and distribution systems (Wayne C. Turner, 2004).

EES system can be used as a back-up power system in emergency service in grids, which supplies power when grid power production plants collapse or fall off-line, to ensure the provision of power without interruption. Also, ESS system has a very important role in the regulation of the system's frequency in order to maintain the power at fixed AC frequency (Cho et al., 2013).

EES systems can be used for residential purposes such as demand-side management strategy in order to help householder to reduce the total cost of energy consumption and ensure an energy supply stable (Barbato and Capone, 2014; Darcovich et al., 2010).

3.5.3.2. Renewable energy applications

The level of power generation of renewable energy sources such as solar and wind energy is largely determined by uncontrollable environmental factors. Therefore, the use of ESS systems often is mandatory in particular when considering stand-alone systems. They make the power generation of these sources efficient and more reliable (Gao, 2015; Taylor et al., 2017).

Consequently, using EES systems in renewable power generation application has two major benefits:

1. The EES system can contribute to the power balance between supply and demand by decreasing the temporal mismatch between the generated and demanded power. So, if load demand is less than the power generation, the surplus of power if not stored, so it is considered as wasted power. In contrast, storing this power surplus and using it in case the generated power cannot meet the load demand, allows reducing the waste of energy and saving the energy by fully utilizing of the power generation capability (Barote et al., 2008; Bernal-Agustín and Dufo-López, 2009; Chowdhury et al., 2011).
2. An EES system enhances the flexibility and stability of renewable sources which are characterized by the variability and intermittency of electricity generation. Thus, the production of electricity depends on environmental factors (such as irradiance, the wind speed ...), which lead to frequency variations (Bilodeau and Agbossou, 2006). EES systems can keep the frequency at the desired value thanks to rapid response to frequency variations.

3.5.3.3. Electric Vehicles applications

Today, electric vehicles (EVs) have become an active area for the application of battery-based EES systems. Hybrid EVs (HEVs), which used batteries in beside an internal combustion engine (ICE), to reduce fuel energy dependence. However, in an HEV, determining the power distribution between the batteries and the ICE is crucial. Therefore, several optimization techniques, such as dynamic programming and reinforcement learning can be used for this purpose (Lund and Salgi, 2009; Moura et al., 2011).

3.5.4. Battery power modelling

Currently, there are several types of batteries. We find lead batteries (Lead-acid), Nickel-Cadmium (Ni-Cd), Nickel Iron (Fe-Ni), Nickel-Zinc (Ni-Zn), Zn-Chlorine (Cl-Zn) and lithium batteries. More than 90% of the batteries available on the market are of the lead-acid batteries. Depending on the operating conditions, it is necessary to choose the most suitable battery. Lithium batteries, which cost four times that of lead-acid batteries, have some advantages over them. Such as their possibility of remaining for a long time in a low state of charge (long lifetime), the stability of the voltage supplied and their high efficiency. However, lead-acid batteries are the most commonly used in hybrid systems, for their low cost also, allow deep charge/discharge cycles up to 70-80%.

In this section, we present the mathematical model of the battery. However, since we are only interested in power management, we model the battery as a model of power exchange, nor do we focus on power conversion. This model is suitable for all types of batteries. In the mathematical model of battery presented in Figure.3.12, we consider the calculation of energy losses. These energy losses are composed of two sources: the own losses due to the battery efficiency plus the efficiency of the converter during charging and discharging process ($P_{B.loss}$), in addition, the losses due to self-discharge ($P_{B.self\_disc}$). Therefore, the equations to model the battery power balance and the energy battery are given by Equation. (3.5) and Equation. (3.6), respectively.

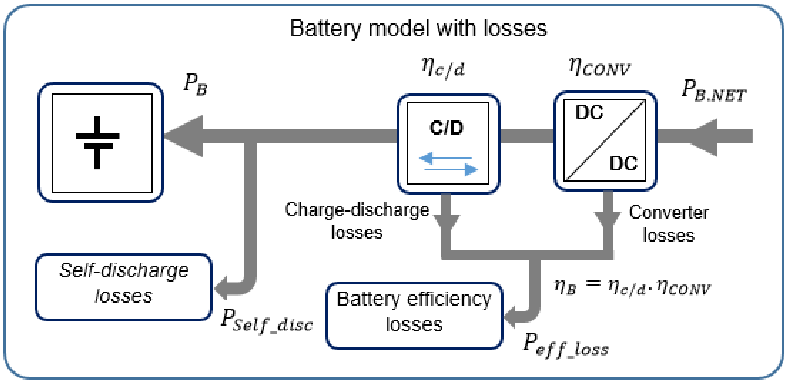


Figure.3. 12. Schematic of battery model with losses.

$$P_{B.NET}(t) = P_{B.loss}(t) + P_{B.self\_disc}(t) + P_B(t) \tag{3.5}$$

$$W_B(t+1) = W_B(t) + P_{B.NET}(t) \cdot \Delta t \tag{3.6}$$

where $P_{B.NET}$ is the net power from/to the battery each t (W), and P_B is the power from/to the battery at t (W), W_B is the energy of battery at t (Wh) while Δt is the time interval (h).

The Equation (3.7) shows the self-discharge energy losses of the battery, where $W_B(t-1)$, present the battery energy at a previous instant, and σ is the coefficient of self-discharge (%/h).

$$P_{B.self\_disc}(t) = W_B(t-1)\frac{\sigma}{100\,\Delta t} \tag{3.7}$$

Concerning the losses related to the battery efficiency, they were modelled using an efficiency coefficient η_B which includes the converter efficiency for both charging and discharging process. Moreover, the equations to model these losses depend on the direction of the power flow, that is, charging presented in Equation. (3.8) or discharging which given by in Equation. (3.9)

$$P_{B.loss}(t) = \left(P_B(t) + P_{B.self\_disc}(t)\right)\frac{1-\eta_B}{\eta_B} \tag{3.8}$$

$$P_{B.loss}(t) = -\left(P_B(t) + P_{B.self\_disc}(t)\right)\left(1-\eta_B\right) \tag{3.9}$$

3.5.5. Characteristics of BESS

The parameters generally used to characterize a battery are provided below:

Nominal capacity: this is the maximum number in ampere-hours (Ah) that can be extracted from the battery under predetermined discharge conditions.

The charge or discharge rate: this is the parameter which gives the ratio between the nominal capacity of a battery and the current at which it is charged (or discharged).

The state of charge: the SOC (State Of Charge) of battery is the ratio between the present capacity and the nominal capacity, it usually is between 0 and 1 (0 <SOC <1). If SOC = 1, the battery is fully charged, and if SOC = 0, the battery is fully discharged.

Power limitation: For the battery storage system, the power of charge and discharge is constrained by maximum charging and discharging power limitation due to the Kinetic battery model (Manwell and Jon, 1993). These constraints are formulated as follows:

$$P_B \leq P_B^{disc.max} \tag{3.10}$$

$$P_B \leq P_B^{ch.max} \tag{3.11}$$

3.5.6. Battery aging and life time

Battery life (also known as battery service period) is the period of battery operation that the battery can withstand before degrading. Usually, it is expressed in years, or the number of cycles, where one cycle is determined as the period of full charge and discharge. This life is determined by the operating conditions of the battery, which are mainly characterized by the number of charging and discharging cycles and the amplitude of these cycles (depth of discharge) as well as the distribution and frequency of these cycles.

On the other hand, the life of batteries is limited and depending on the type of technology used, and this life can be affected by several factors such as shallow cycles, intermittent use, deep of discharge, harsh environments, and non-comfortable conditions (temperature, humidity ...). Therefore, the intermittent uses of the battery due to the intermittency nature of renewable energy systems (RESs) can affect the battery ageing and shorten their life cycle (Beltran et al., 2016; Riffonneau et al., 2008).

Therefore, the efficiency of storage systems can be affected positively or negatively depends on whether or not the cycle is uniformly distributed over time. While the previously discussed aging mechanisms and stress factors also play an essential role in the life expectancy of the storage system (Ruetschi, 2004).

Battery manufacturers provide curves of the number of cycles to failure as a function of the depth of discharge (for a given temperature). The ageing of the battery is calculated according to the miner rule and using the cycle-failure curve provided by the battery manufacturers while the life expectancy is calculated according to the Equation. (3.12)

$$B_{aging} = \sum_{DoD=0}^{100\%} \frac{N_{cycle}(DoD)}{N_{cycle.max}(DoD)} \tag{3.12}$$

Where $N_{cycle}(DoD)$ is the number of cycles given at each DoD and $N_{cycle.max}(DoD)$ is the maximum number of cycles at DoD the battery can withstand before it degrades. Therefore, a battery aging equal to one indicates that the battery is exhausted. Finally, the battery life expectancy is calculated dividing the length of the simulated period by the battery aging such is presented in Equation (3.13).

$$B_{life} = \frac{N_{days}}{B_{aging}} \tag{3.13}$$

3.6. Problems related to the operation of M-SES

In the last few years, power and energy researchers and engineers have had to redesign traditional power systems to develop feasible solutions such as renewable energy-based distributed generation (DG) units, AC microgrids, Energy Storage Systems (ESS), and flexible AC transmission systems (FACTS), control methods, etc. But the afore-mentioned design measures have not taken place now as researchers have moved on to developing advanced control strategies. Interconnection of the distributed generating units in the electrical power system is essential for the continued use of RESs. With the increasing penetration of RES-based distributed energy resources, the distributed system has more difficulty maintaining the stability and security problems of the power system.

However, the issues related to the operation of hybrid energy systems can be distinguished according to different criteria: the application (stationary or transport), then the topology (autonomous system or connected to the network), finally the properties studied (dynamic response and load monitoring, profitability over the life cycle, average yield, real-time management). The interest of a hybrid system for a designer does not stop at the sizing of the system level according to the power needs but also concerns the overall efficiency and the performance in terms of dynamic response. Management strategies adapted to these systems must be proposed. So, in other words, the problem posed here is operational: it is a question of making the best economic use of production capacities already installed (the various generators); on the contrary, sizing problems. Although the control structure is much simpler than for electrical network operation, it must nevertheless be centralized; the economic optimization function corresponds to the higher level of control.

3.7. Conclusion

In this chapter, a brief description of hybrid energy systems has been presented. We have emphasized the importance and the need for the diversification of energy sources, in particular renewable energy sources as well as, the multiplication of sources by the combination of two or more energy sources in the form of a hybrid system, which makes the system more reliable and efficient.

We also presented the different coupling configurations of a hybrid energy system, as well as the model of the sources of a hybrid energy system (wind energy, photovoltaic energy and energy storage systems).

Finally, we considered the importance of integrating hybrid energy systems into habitats to cover thermal and electrical energy needs. Also, we presented most of the difficulties and problems facing the management of the energy in a habitat that contains a hybrid energy system. However, it is now necessary to work on the development of a control system making it possible to make the best use of the potential of the various renewable sources, by comprehensively managing the energy needs and the production capacity of a habitat.

CHAPTER 4

Energy pilotage mechanisms for a home with a Multi-SES

It is possibly better to control the energy in homes with multi-source of energy. Therefore, several research projects have been carried out to develop energy control and management systems, such as home energy management system (HOME). These systems can be installed in the buildings to help householders on the management and the control of energy production, consumption, and the storage of energy. This chapter is devoted to introducing the literature reviews and the state of the art of energy management mechanisms for the hybrid multi-source system in the building in order to better highlight the different strategies explored. In addition, an analysis and discussion of certain strategies and techniques used for the control mechanism of multi-source systems in the building will be carried out. Finally, we present our proposed approach for energy control strategy in the habitat, which is the aim of the work of this thesis.

4. Energy pilotage mechanisms for a home with Multi-SES

4.1. Energy pilotage in buildings

Definition: *Energy pilotage in buildings means all of the regulatory actions, and the decision-making processes triggered by events and changes in objectives under constraints according to a time scale implemented for judicious and efficient energy use (monitoring and controlling energy consumption), in order to save energy, minimize energy costs and reducing emissions without affecting the quality of life of occupants (ensuring the minimum comfort of occupants).*

4.1.2. The criteria of energy pilotage in buildings

The pilotage of energy is a complex operation, which depends on the interaction of two different flows, one is the power flow, and the other is the information flow. The pilotage function consists of managing the power flows, in other words, the management of power distribution according to user preferences and needs, also, the management of information flow which consist in managing the information in the system such as information on the energy sources, the storage system, the status electrical equipment, as well as the weather information…

The energy management and control strategy must meet several criteria which can be grouped into three categories:

4.1.2.1. The economic criterion

One of the most aspects that should be considered in energy management in homes is the cost minimization. Therefore, operating and maintenance cost must be minimized. The return on investment of the systems essentially depends on the cost energy purchased to make up for the shortages of power production and the investment made in the various multi-energy system such a solar and wind energy.

4.1.2.2. The comfort criterion

In order to ensure occupant comfort, the energy management function is to meet energy demand and secure the energy supply in any period of time.

4.1.2.3. The environmental criterion

This criterion ensures compliance with ecological constraints and the reduction of greenhouse gas emissions responsible for pollution.

4.2. A review of energy pilotage strategies in homes

Today, automated energy control has become a common practice. Many residential and non-residential buildings in the world have virtually automatic controllers with a computer as the central processor. These systems are known by energy management systems (EMS) or building automation systems (BAS)(Harris, 2012; Wayne C. Turner, 2004). However, the first utilization of EMS concept was started in the year 1979 where a functioning Energy management system was conceptualized in a paper entitled "Solar energy management system" written by (Men, 1979). After that, a proposed improvement of the performance in the system was added, specifically with the introduction of PCs in 1980 (Capehart et al., 1982). By the year 1986, an optimization algorithm was proposed to manage energy in order to reduce electrical costs by reducing demand as well as usage time (Rahman and Bhatnagar, 1986). Subsequently, new strategies were devised for controlling and managing of electronic machines, using a home automation communication network system (Wacks, 1991). In 1997, the introduction of the concept of energy management systems in buildings which have been presented in (Stum. K, Mosier. R, 1997). These systems consist of a set of equipment equipped with a microcontroller having the capacity of communication via standard protocols, a centralized control-command system and a human-machine interface (HMI) allowing to perform certain control optimization functions and energy consumption monitoring. Generally, these systems target commercial buildings to manage the consumption of air conditioning and lighting. In 2001, (Müller et al., 2001) proposed an innovative distributed energy management system based on data forecast (weather, generation and load), operations planning, online-optimization as well as generation control and load control. The function of the energy management system is short-term optimization in co-generation systems, incorporating generating units using renewable primary energy. The operations planning takes into account different generating source, energy storage system, demand-side management, contracts and co-generation. The online modules perform redistribution of generation and load schedules, generation control and load control.

Among the research work dedicated to energy management in buildings is the work of (Gergaud, 2002). He proposed a management strategy based on heuristic rules (export of local production; clipping or smoothing strategy for energy consumption; a scenario in autonomous operation; minimization of user dependence on the main grid). The proposed strategy aims to control a hybrid wind and photovoltaic production system connected to the grid and associated with energy storage by lead-acid accumulators for an individual housing Figure.4.1.

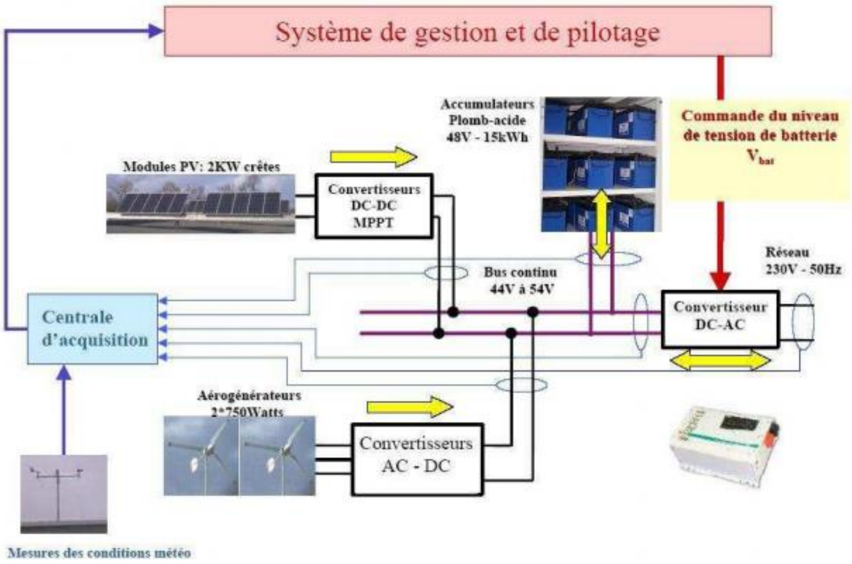


Figure.4. 1. Schematic of installation a hybrid energy system with energy storage (Gergaud, 2002)

In 2003, (Obayashi and Tokunaga, 2003) proposed a new building energy management system based on a multi-agent system (BEMAS). The multi-agent building energy management system is integrated into a control system to control the different subsystems in building such as electricity, air conditioning, prevention and security, etc.

BEMAS is characterized by:

- Flexible adaptation to changes in equipment or measures;

- Storage of data such as fault detection;
- Easy for the configuration;
- Interactive management with the user.

(Fardadi et al., 2005) studied a control system based on PID (Proportional, Integral, derivative) for the energy management of buildings using a neural network. The objective of this system is to control and monitor the parameters of the building environment (HVAC) in order to minimize energy consumption and cost.

The main BEMS proposed in the literature are:

- Distributed control of interior comfort conditions in the construction of an area/room;
- User interaction, accepting user comfort preferences and viewing energy consumption;
- Monitoring the performance of the whole system and adapting the control strategy.

(Virgone et al., 2006) proposed a conceptual tool for the control of multi-energy system for high energy performance building in order to define the best conditions for coupling energy supply and demand and estimate the resulting consumption.

(Duy-Long HA, 2007) proposed modelling of the optimization problems of the anticipatory layer in the form of a mixed linear program in order to control and manage the energy consumption. (Pham et al., 2008) is carrying out a study in the frame of the MULTISOL project, in the aims to develop an energy system for the building composed of a multi-source system and to realize a global energy management system to meet the technical optimization criteria such the user comfort and the energy cost economization. This study aims to design the architecture of a system, particularly on the side of production sources and to propose an optimal sizing method by integrating the optimized management of the operation of sources and loads through the use of Mixed Linear Programming (MLP).

(Foggia, 2009) studied an optimal energy control of residential and tertiary multi-sources systems, in order to reduce energy consumption. He proposed a set of solving methods for each: provisional dispatching (MILP and dynamic programming), load forecasting, anticipative unit commitment, corrective strategies and adaptive strategies.

In 2010, as part of the MeRegioMobil research initiative in Germany, a smart home was designed (MeRegioMobil, 2012). It is a prototype of future home with high-energy efficiency, with the integration of electric vehicles, an energy storage system and low energy consumption equipment into intelligent home management.

Automatic generation of optimization problems for the design and management of electrical networks in intelligent buildings with multi-source and multi-load was proposed by (Warkozek, 2011).

In 2012, with the advent of demand response program (DR) (Chen, 2018; Haider et al., 2016; Hussain et al., 2015; Pipattanasomporn et al., 2012; Vasques et al., 2019), began the trend of advanced technology in HEMS to reduce energy consumption, energy cost and peak demand, for household appliances such as heating, air conditioning, electric vehicles (EV), etc.

The ANR (REACTIVHOME) project (ANR, 2017) dedicated to intelligent control of energy in buildings. The objective is to optimize the production and consumption of energy according to various criteria such as the cost of energy, reduce the negative environmental impact, as well as, minimize the peaks of demand of energy consumption with respect to the user comfort. This optimization could be achieved by controlling household equipment: energy production from local generators (PV, electrical storage, etc.), electrical and thermal loads.

4.3. Home energy management system concept

Definition: *A home energy management system (HEMS) is defined as a technology platform comprised of both hardware and software that allows the user to efficiently monitor and manage the energy production, consumption and energy conservation to automate and/or manually control the use of energy within the home* (Han et al., 2011; Son et al., 2010).

HEMS provides the opportunity for the economic incentives to manage the demand-side resources by shifting their electricity consumption during peak demand periods in response according to the changes in electricity prices in case of dynamic price. These economic incentives include the total cost of electricity bill, improve using of smart and efficient household appliance and home energy saving (Tsui and Chan, 2012).

4.3.1. HEMS architecture

Figure.4.2 shows the overall architecture of a conceived HEMS scheme. The general architecture of HEMS typically consists of six components, which are described below:

Energy management centre: includes a processor used for concentrating, storage, management and treatment data and information, in addition to a centralized intelligent controller system to provide the householder monitors and adjusts power consumption through a monitoring modules and control functionality based on the home communication network (Kuzlu et al., 2012).

Smart meters and sensors: the using of smart meters allow to a real-time electricity consumption data from household appliances, including schedulable and non-schedulable appliances, can also be collected by the main panel of the smart HEMS to achieve optimal demand allocation (Dimeas et al., 2014).

Gateway: the home gateway, like the smart meter, can be used as an interactive communication interface between electric utilities and the smart home. The gateway allows to network between HEMS and the outside world to facilitate remote access via the Internet(Dam et al., 2013).

Smart appliances: a smart appliance system offers the residents an awareness regarding their energy usage, the action of enabling energy-efficient and eco-friendly. They are appliances equipped with intelligence as well as a communication system which facilitates a remote mode of controlling as well as monitoring. For implementation purpose, the appliances can be categorized as:

- Non-schedulable household appliance, e.g., freezer, printing machines, micro ovens, TV, hairdryer.
- Schedulable household appliances that can be set or reset for optimal operation and may be shifted and scheduled and switched on/off during any time, e.g., washing machine, dishwasher, iron, EVs.

Renewable energy resources: renewable energy sources in homes such as solar (electrical and thermal) and wind energy, can be fully integrated into the interactive generation management and control operations of HEMS.

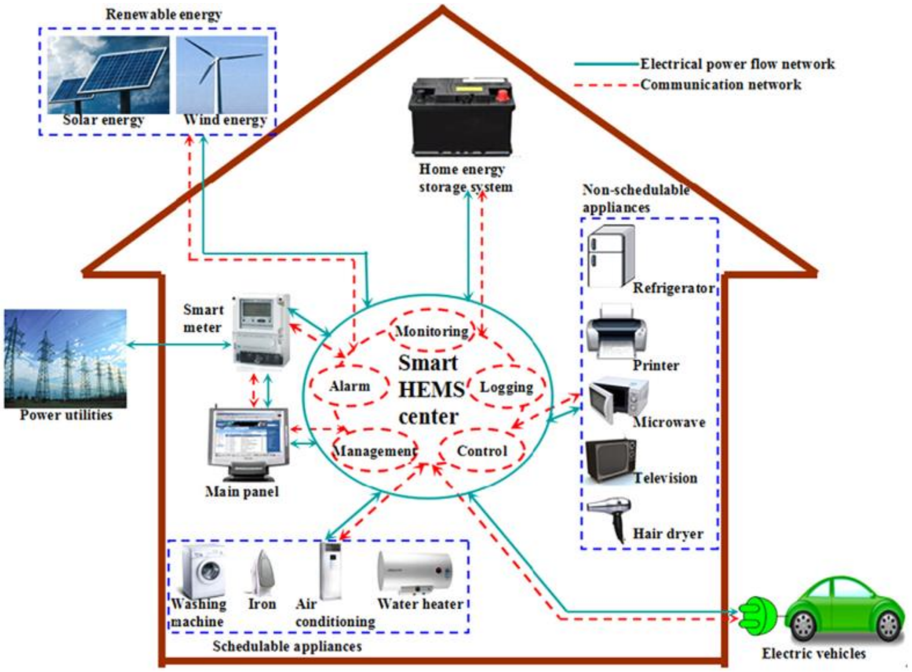


Figure.4. 2. Architectural components of a HEMS (Zhou et al., 2016).

Energy storage system: Due to the intermittency and randomness nature related to renewable energy sources such as solar and wind energy, the energy storage systems have an essential role in power balance and makes the energy system more reliable.

4.3.2. Functionalities of HEMS

In order to make HEMS more flexible in energy-saving and demand response (DR), HEMS should have some functionalities to manage and control renewable energy resources, energy consumption through controlling smart household appliances, and energy storage system (ESS) as shown in Figure.4.3. (Al-Ali et al., 2011). Moreover, the active control services, including real-time data measurements through smart meters on the amount of energy consumption and energy pricing, can be provided to the user based on HEMS. However, the user can choose their preferences via the human-machine interface (HMI) to schedule the time slot of various appliances to enhance the efficiency of energy using (Son et al., 2010). The main functional modules of a smart HEMS centre including monitoring, logging, control, management and alarm are detailed in the description bellow(Dam et al., 2013; Son et al., 2010):

Monitoring: Monitoring provides for users easier access to real-time information about energy production and consumption, and allows users to focus on his objectives for energy saving and cost reduction. As well as, it can provide services for users such as displaying the operation modes and the status of each household appliance.

Logging: Logging is considered as data acquisition system aim to collate and save the data information of in HEMS among them (the energy consumed by household appliance, the generated energy from RESs and the state of energy storage device). This service offers a demand response analysis for real-time prices from grid utility.

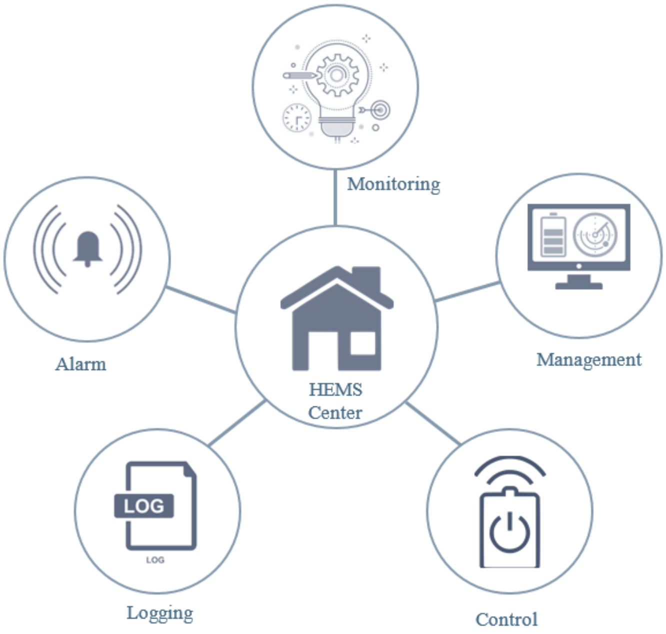


Figure.4. 3. Functionalities of smart HEMS.

Control: The control aims to monitor and manage the energy consumption in the home on real-time according to updated data and constraints (the price of energy, meteorological data). However, there are two kinds of control, which are direct control and remote control. Direct control which is implemented on both the equipment that allows controlling the system automatically; whereas, remote control means which allows the customers for online access to monitor and control the energy consumption patterns of household appliances via personal computer or smartphone from a distance.

Management: Management presents the most important function of the HEMS system to improve energy efficiency and optimization of energy utilization in the home. Also, this function can cover a variety of services including, renewable energy system management, energy storage management, household appliances management, and Plug-in EV management.

Alarm: Alarm aims to inform the users by any fault detected in the system. In case a detected fault or abnormal situation, the Alarm will generate alert and sent it to the smart HEMS centre with all information on the fault location.

4.4. Home energy management strategies

4.4.1. Direct control of loads

The Direct Load Control (DLC), is a control strategy that aims to reduce the peaks of energy consumption by relying on load shedding of several appliances (interruptible). It is considered as a remotely controllable switch that can turn a load or device on or off. Such a strategy could also be used to regulate the amount of power consumption of loads. The operation of direct load controllers can be done by a utility or third-party energy provider to reduce a customer's energy demand at certain times (for example, in peak hours).

This method of energy management has been widely used by power companies for the past 20 years. This strategy of management could not exist only in the distribution network but also at the level of consumers within household appliances. Indeed, this load shedding management program targets, in particular, the residential and tertiary sector, through certain categories of characteristic appliances: water heater, air conditioning, heating (Bargiotas and Birdwell, 1988), temporary loads such as the washing machine. Usually, in the research works, the main objective of DLC is: minimization of the consumption peak over the period; minimizing the energy consumption cost taking into account the comfort of the occupant; minimization of the number of solicited customers for load shedding, make it possible to maintain the power constraint.

The direct control of the loads aims to act on certain targeted loads which are grouped and have the same action (On/Off control), that presents the decision variable of the problem. For example, assuming a control strategy for controlling the groups of air conditioning equipment for 30 min, the variable to be calculated is then the number of air conditioning groups for which the control must be started, at each time step.

The choice of the optimization algorithm is made. The two main possibilities encountered are:

- Linear programming (Kah-Hoe and Sheblé, 1998; Kurucz and Brandt, 1996; Lee and Wilkins, 1983);
- Dynamic programming (Cohen and Wang, 1988; Wen-Chen Chu, Bin-Kwie Chen, 1993).

4.4.2. Demand-Side Management

The Demand-Side Management (DSM) also known demand-side response (DSR) aims to control the energy demand through programming and scheduling of energy demand, which is based on the economic constraint (reducing the consumer electricity bill through minimizing the use of electricity in peak periods). For instance, the example of (Castillo-Cagigal et al., 2011b), the authors have been proposed approach to organize the consumption of tasks (Household appliances) during the day in order to favour the using of the energy source of renewable nature (PV) compared to the energy supplied by the network in a house equipped with a photovoltaic (PV) source and a storage system connected to the network.

This strategy of management is made up of two stages (Mouna Abarkan, 2018):

Distribution: This step for the estimation of energy consumption during the day, it consists in connecting the various electrical equipment according to the daily planning established by the user to control the load and the operating time as well as the requested power.

Centralization: This step contains two basic units:

A prediction unit: this unit consists of receiving the information concerning predictions of the power generation of renewable energy sources, the state of charge of the storage system as well as the state of the electrical network.

A supervision and control unit: this unit aims to manage the tasks according to the predictions and information obtained by the prediction unit.

4.4.2.1. Classification of DSM

The DMS strategy can be classified regarding its optimization methods on three main categories: user interactions, optimization approach and time scale (as presented in Figure.4.4):

User interactions: DSM systems can be designed to optimize either individual users or a cooperative utility community's use of electric resources. In the first case, users are handled to manage his energy consumption separately, whereas in the second case customers are working together to determine their operating plans, and DSM approaches are used to optimize a mutual utility feature.

Optimization approach: The parameters of DSM systems, such as the output power of sources, the energy use preferences of devices and the price of energy for future periods, are estimated by anticipation methods. However, the optimization problem for DSM relies on towing techniques for designing the energy management system; deterministic and stochastic. In deterministic optimization problems, parameters are defined as deterministic data. In contrast, in the stochastic technique, parameters are represented as random variables in order to consider uncertainty in the decision-making process.

Time scale: DSM systems for the optimization problem can be classified according to the timescale used to manage energy consumption in daily-ahead and real-time scale. In the first one, the planning of electric resources of users is defined for the next 24-h time period based on the data forecast (generally, in a day in advance)(Ayón et al., 2017; Lee et al., 2014a; Ma et al., 2018). Therefore, DSM mechanisms require predictions/estimates of some parameters of the system, such as the energy generation of local sources (such as PV and wind energy), electricity prices and appliance usage preferences for the next day. The second one is the real-time scale thus; the users' plan should be rescheduled according to real-time events and updated data forecast (Ahmed et al., 2017; Kang et al., 2014; Khalid et al., 2019). As a consequence, DSM systems behave similarly to demand-response frameworks (dynamic electric price). In general, stochastic techniques are used to design real-time DSM methods to address the issue of unexpected events.

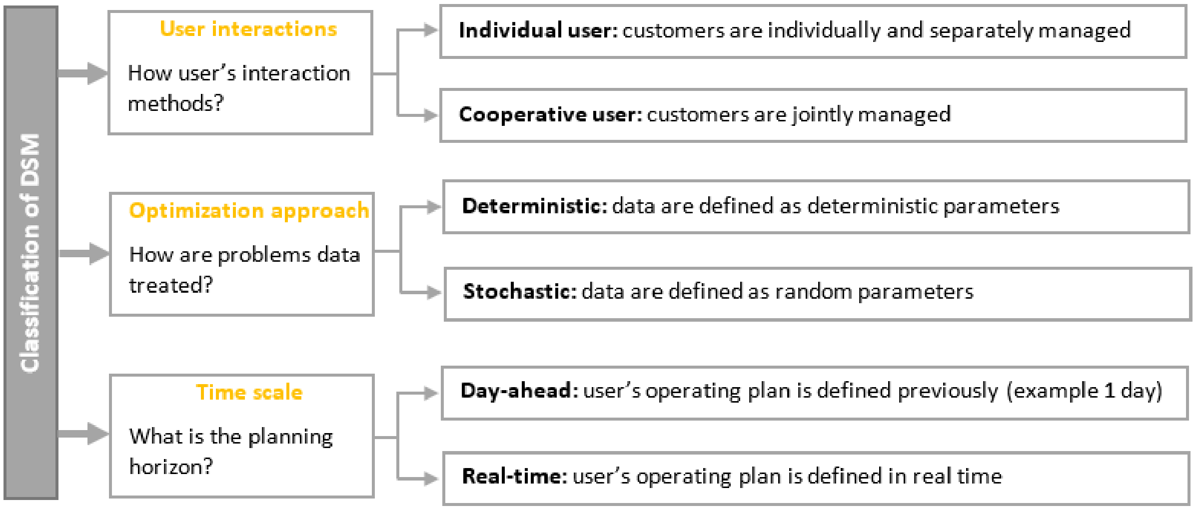


Figure.4. 4. Classification of DSM based on optimization model (Barbato and Capone, 2014).

4.4.3. Active Demand-Side Management (ADSM)

Active demand-side management (ADSM) is an improvement of the DSM strategy by using an automated system for scheduling and control. In most of the literature studies (Amer et al., 2014, 2013; Castillo-Cagigal et al., 2011a, 2011b) have used the ADSM strategy for the management of a multi-source home energy system.

The ADSM strategy allows the consumer to benefit from the advantages of ADSM for the management of energy consumption in complete safety and with the minimum possible comfort. The implementation of ADSM actions can modify the demand profile in order to reduce household electricity bill, reduce losses in the network, to maximize of own consumption in households when renewable energy sources are available, to reduce the grid load at peak demand times, save energy and rational the use of energy (Wang et al., 2013; Zong et al., 2012).

ADSM uses forecasting models based on artificial intelligence techniques (such neural network) to estimate the energy produced from renewable energy sources such as solar and wind energy. (Krömerb, 2015) proposed a heuristic approach to the ADSM strategy for the management of habitat in an isolated site in order to reduce power losses thanks to intelligent scheduling of energy consumption.

4.5. Demand response

Definition: According to the definition of the FERC (Federal Energy Regulatory Commission, 2011), DR is: *Changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized.*

4.5.1. Demand response services

Usually, demand response can provide five categories of services in order to manage energy consumption in the system: (1) peak shaving (peak clipping), (2) load shifting, (3) filling valleys, (4) strategic conservation and (5) strategic of load growth (Gellings, 1985). The first three can be grouped as load management, and the last two categories can be grouped as load shape change.

4.5.1.1. Load Shifting

In some cases, the load demand is higher than the average level over a certain period, especially in Multi-SES with RES (such as solar and wind power) in which the period of power generation often does not coincide with the time of the power demand, or the price of energy is high at a certain period in the case of an electric utility grid which works dynamic pricing. However, several loads must be moved from this period to other periods. Load shifting is mainly based on shiftable devices (e.g., washing machine, dishwasher, water heater, etc.). Load shifting can be achieved daily from the peak period (high energy price) to the off-peak period (low energy price) in order to reduce the electricity bill (Graditi et al., 2015; Lin and Chen, 2016; Setlhaolo et al., 2014; Setlhaolo and Xia, 2014; Zhu et al., 2019) or avoid the energy shortage and saving the energy (saving energy of storage systems) in the case of stand-alone renewable energy sources (Bouakkaz et al., 2019; Dai and Mesbahi, 2013). Figure.4.5, shows a daily load shift in which part of the peak demand is shifted from 18: 00–20: 00 to 2: 00–6: 00. It does not reduce the total consumption but only changes the usage time.

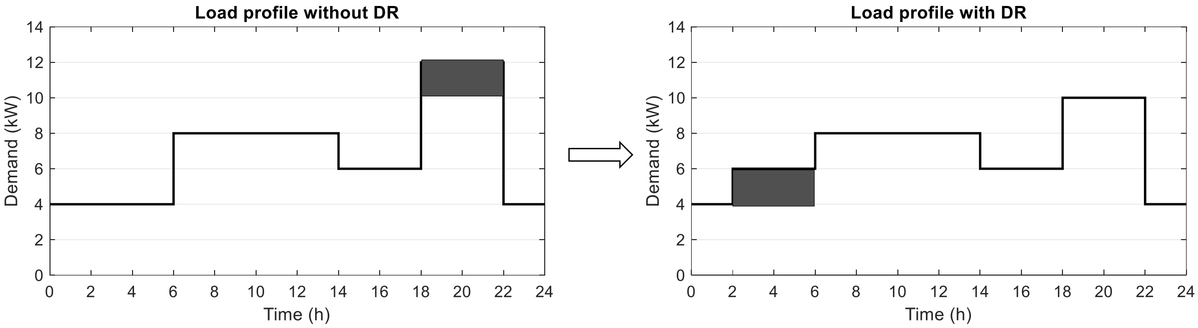


Figure.4. 5. Load shifting.

4.5.1.2. Peak shaving

In some cases, energy demand is approaching the supply capacity threshold, which has a negative impact on the electrical stability of the network. Therefore, some grid operators add an additional cost during these peak demand periods. However, to avoid this additional cost and to reduce the total cost of energy consumption, this peak demand must be reduced. This can be achieved by direct control of the load in the residential sector by applying power curtailment to some electrical appliances (e.g., lowering the thermostat of heaters and increasing the temperature of refrigerators, dimming the light) (Lee et al., 2014b; Paul et al., 2014; Rastegar, 2018). Also, this can be achieved by shifting loads from peak period to the off-peak period. Figure.4.6. shows a peak reduction from 12 KW to 10 KW during the period from 6:00 p.m. to 8:00 p.m. This service can help release stress on the system during the peak period. However, since the curtailment of the consumption of some loads, may cause dissatisfaction of the customer.

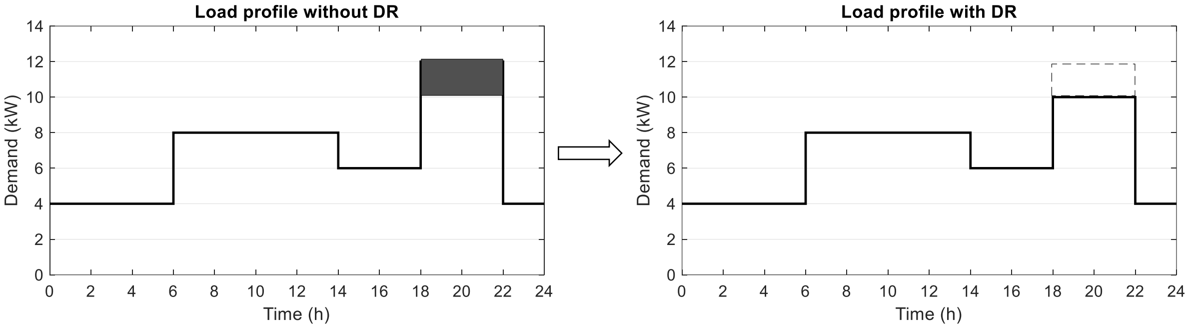


Figure.4. 6. Peak shaving.

4.5.1.3. Valley Filling

In some cases, the energy demand is low at off-peak hours, which is not good for the stability of the system (as in the case of photovoltaic energy). Consequently, the demand should be increased. Therefore, the most common way to save energy is by adding storage devices (for example, thermal storage for heaters and plug-in electric vehicles). Figure.4.7, shows a valley filling from 4 kW to 6 kW during the period from 0:00 to 6:00 a.m. This service will increase the total electricity consumption and contribute to the stability of the network.

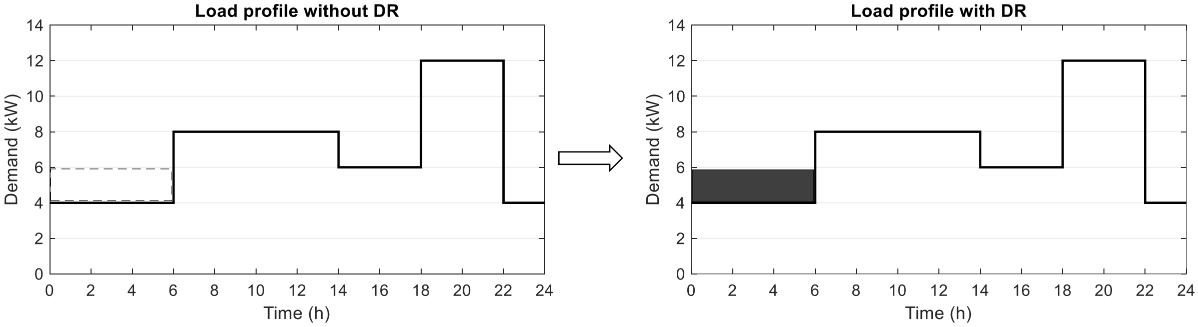


Figure.4. 7. Valley filling.

4.5.1.4. Conservation strategy

The consumer can reduce their energy consumption (i.e. reduce the total cost of energy consumption) by changing their lifestyle for energy consumption. One basic method is to improve energy efficiency. This can be done by replacing the traditional appliances with efficient and smart ones (for example, replacing incandescent lamps with LED lamps). Figure.4.8, shows the strategic conservation from a high power level to a low level.

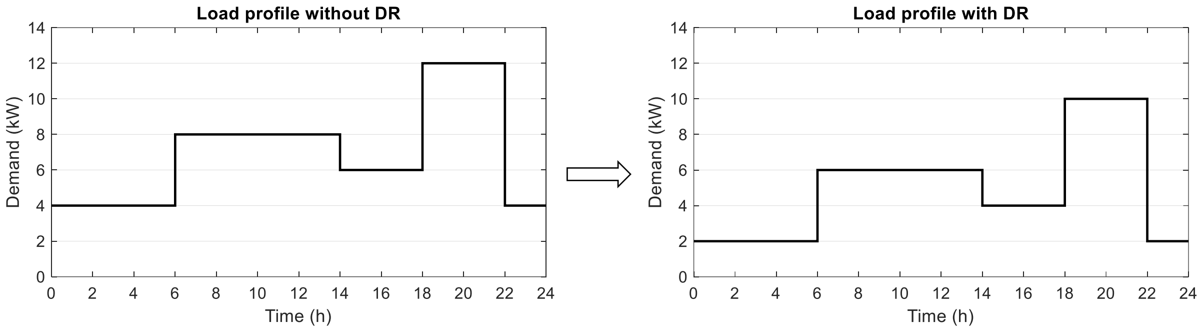


Figure.4. 8. Conservation strategy.

4.5.1.5. Load Growth strategy

In the case demand falls below the normal level of supply, network managers encourage customers to increase their overall consumption in order to maintain energy balance by rescheduling their energy consumption and using electric vehicles.

4.5.2. Scheduling strategy

Recently, various decision support tools have been reported for the demand response program for the implementation and optimization of scheduling strategies of household appliances with electrical energy services for consumers in homes (Energy, 2008; Federal Energy Regulatory Commission, 2011; Muratori et al., 2014; Pedrasa et al., 2010). However, scheduling strategy is based on shifting electrical devices (shiftable appliances) from peak periods to off-peak periods to reduce energy costs as well as reduce the peaks of energy consumption (Merdanoğlu et al., 2020; Rahmani-Andebili, 2017; Yahia and Pradhan, 2020; Yuce et al., 2016; Zhu et al., 2019). In the literature review, there are several studies, and research work has been carried out regarding the scheduling strategies of household appliances in order to manage the energy consumption in buildings. Therefore, (Beaudin and Zareipour, 2015; Zhou et al., 2016) are summarized and analysed the different scheduling strategies proposed. For instance, the authors (Lin and Chen, 2016) proposed optimal scheduling for HEMS based on real-time pricing using Taguchi genetic algorithm (TGA). (Ma et al., 2018) applied Multi-Swarm PSO to program the device under daily prices and PV production. The load consumption planning strategy based on the calculation of optimal static load sizes and photovoltaic energy production using mixed linear programming (MILP) in order to maximize the use of solar energy proposed by (Habib et al., 2017).

4.6. Multi-layer and multi-scale control mechanism

The general architecture of a multi-layer and multi-scale control mechanism was proposed by (Duy-Long HA, 2007). This architecture based on decomposing of complex optimization problem into several optimization levels in order to simplify the solving of the problem. These different optimization levels correspond to hierarchical resolution algorithms according to different time scales. First, the optimization solution is calculated in the highest level, which corresponds to the longest sampling of time (example: one day in advance with one hour order sampling) with taking into account in this level the predictions are relatively imprecise. Then, the obtained solution for the optimizing problem is refined from the level of the control layer to a lower level by updating the calculated solution in the previous level. So on until obtaining a solution that tends towards the real consumption of equipment in the home.

The multi-time scale control mechanism consists of three control layers depending on the optimization horizon and the different sampling periods: an anticipatory layer, a reactive layer and a local layer. The schematic of the architecture for three control layers is presented in Figure.4.9. While the operating role and the explanation of the different layers of this mechanism are detailed in the paragraphs below.

4.6.1. Anticipatory layer

The anticipation layer is the layer of control with the highest level of management in the pilotage mechanism, which is responsible for scheduling and planning the energy consumption and production in advance (generally a day in advance) in a predictive way. The anticipation solutions calculated by this layer are based on weather forecasts (temperature, solar irradiation, wind speed, etc.), scheduling of services by the occupants as well as the forecast of their presence, the electricity market (the price of energy) and the available power (subscription).

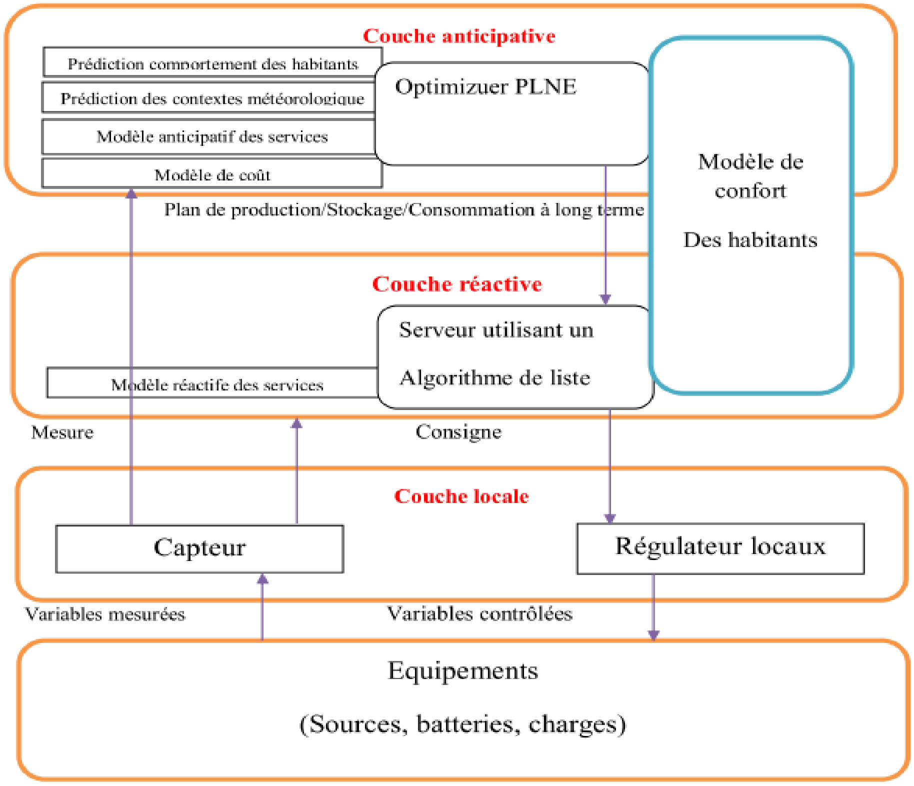


Figure.4. 9. Multi-layer control mechanism architecture for home energy management (Le, 2012).

The calculated solution in this layer is updated when new forecasts are available. (Duy-Long HA, 2007) detail the models used in this management layer and (Le, 2012) proposes to extend these functionalities.

4.6.2. Reactive layer

Since the anticipatory layer works on average values with a long time scale, a closer level to the equipment is necessary to take into account the actual energy consumption values. It is considered as a complement control unit to the anticipatory layer, it sends to the anticipatory layer the instructions calculated through the model in RL and adjusts them to the actual execution conditions. However, the reactive layer works with a short time scale (the order of a minute) to prevent punctual constraints being violated: it helps the anticipatory layer to carry out the energy source allocation plan taking into account energy constraints and user comfort in real-time. If the energy of sources is unavailable or limited, the reactive layer will intervene by deactivating the consumption of several services in order to balance energy between consumption and production. On the other hand, if there is no unexpected event, this layer does not intervene, and in this case, its role is to transmit the instructions to the local layer.

4.6.3. Local control layer

The local control layer is linked to the control/command system of each element of the equipment. Its role is to execute the instructions and the order received from the reactive layer. For example, in thermal environments, this layer works on all or nothing function (on-off control) to maintain the temperature of a thermal environment at values close to the set temperature calculated by the anticipatory layer and then is adjusted by the reactive layer.

4.7. Our proposed pilotage mechanism

The architecture of the control system presented in Figure.4.10 is designed as a multilayer control and supervision system, each layer having a different function and based on a decision with multiple criteria.

The multilayer of control and supervision mechanism is made up of several layers, a control layer which contains two principal control unites, and an anticipative control unit (ACU) and a reactive control unite (RCU). The anticipative control unite aims to control the energy flow in the system by planning and scheduling the consumption and production of energy in advance (one day-ahead), while the reactive control unit aims to control the flow energy in the system in real-time or in a very short sampling period (less than a minute) according to the state of the system.

The information layer contains a data acquisition system (DAS) that collects information from inside and outside the building. A third layer called the operation layer; its role is to execute the orders and the instruction of energy management policies sent by the control layer.

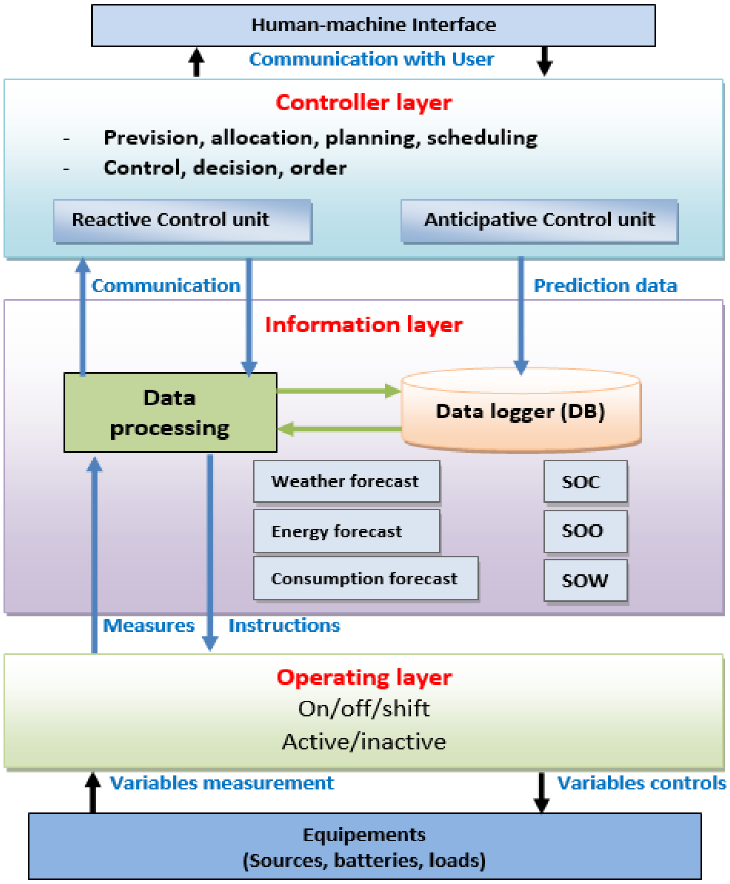


Figure.4. 10. Architecture of a multi-layer control and supervision system.

4.7.1. The control layer

The control layer is considered to be the brain of the energy management system in the building, which is responsible for planning, scheduling and issuing decisions and orders. The solutions to the optimization problems are based on meta-heuristic optimization algorithms. This layer contains two control unites which performed tow functions of control (anticipation and reactive control):

4.7.1.1. Anticipative Control Unit (ACU)

This control unit aims to anticipate the production and the consumption of energy, as well this model is responsible for calculating the optimization solutions and then to propose optimal planning and scheduling of energy consumption for long-term scale (one day or one week in advance), these solutions are based on the data of weather forecast information and user schedules (preferences) sent by the information layer.

The main objective of the anticipative control unit (ACU) is the anticipation of probable scenarios of energy over a long term horizon through:

- Estimate the daily energy demand of the loads based on the time of use;
- Estimate the energy production from renewable sources based on meteorological data (electricity supply from renewable sources is calculated from a time series of hourly values of wind and solar irradiation in the system as well as weather data);
- Determination of the appropriate time to shift household appliances (Scheduling) using meta-heuristics algorithms.

4.7.1.2. Reactive Control Unit (RCU)

The reactive control unit aims to a real-time intervention to manage the unexpected variations that may occur in the system in order to maintain the security of supply at all times. (Balancing electricity flows) by adjusting in real-time the plan developed by the ACU. The RCU based on real data (state of charge of the battery, the presence of the occupant) provided by the information layer according to certain constraints (the energy cost criterion and comfort criterion) and the unexpected variations may occur to ensure the comfort of the occupants.

4.7.2. The information layer

The information layer is the unit responsible for collecting data and information in the entire system, including the current state of all building components (from inside and outside the building), meteorological data, occupant presence (state of occupant: SOO), device status, battery charge status (state of charge: SOC), energy production, energy cost, etc. It allows the interaction between the different layers, a flow of information flows between the control layer and the operation layer and allows communication between the control layer and the information layer, as well as, it contains a memory which makes it possible to save the data and the schedules carried out by the control layer on a database (DB).

4.7.3. The operating layer

The operation layer presents the active part in the control and supervision mechanism in the building. It is responsible for the execution of the orders established by the control layer, it allows the interaction between the different system components (sources, electrical charges, etc.). Its role is to set commend on/off for the devices also is responsible for collecting the measurements from all devices (sources, batteries and appliances) and send it to information layer.

4.7.4. Human-machine interface

Is the part which allows the communication between the energy management system and the user, it allows the occupant to access the different data of the system such as the consumed/produced powers, the states of the services, satisfaction values which calculated by the system, temperatures, energy costs and energy stored in batteries ..., as well as, it gives the user the possibility to adjust and change the plans according to their comfort and preferences.

4.8. A proposed approach for the anticipatory control unit

In this section, we propose our approach for the anticipation control unit which is used to manage and to control the energy consumption through the planning (scheduling) of household appliances during the day, based on a day ahead data forecast (meteorological data, cost of energy...). The scheduling strategy is based on shifting electrical devices (shiftable loads) from the peak periods to off-peak periods in order to reduce the cost of energy, reducing peaks of energy consumption as well as saving the energy.

4.8.1. Energy demand model

Usually, the appliances in homes divide into two groups: fixed appliances which are the appliances that haven't liberty in operation time and thus, could not change their operation time (such as refrigerator, freezer, lamps); the other appliances are the appliances that have more liberty in the operation time, and we could change their operation time (such as washing machine, dishwasher, iron...). We assumed appliances contain a set of fixed appliances $X_i \in \{X_1; X_2; \dots; X_n\}$ and the set of shiftable appliances $Y_i \in \{Y_1; Y_2; \dots; Y_m\}$. So, the energy demand for each time step (t) can calculated by Equation (4.1), while the total energy demand for whole day is given by Equation (4.2).

$$E(t) = \left(\sum_{i=1}^{n} P_{X;i}\,(t) + \sum_{i=1}^{m} P_{Y;i}\,(t)\right) \cdot \Delta T \tag{4.1}$$

$$E_{TOT} = \sum_{t=0}^{T} (E(t)) \tag{4.2}$$

where $P_{X;i}$, $P_{Y;i}$ present respectively the power demand for fixed and shiftable appliances, and $E(t)$ present the energy demanded for each time t. $T$and ΔT, are the time period and time step.

The problem addressed in the anticipatory layer is to find previously the optimal start-up time for the operation of appliances based on forecasting data (meteorological data, electricity price...). This type of device represents an activity that is required at a certain time and which must be performed at a certain time during the day (temporary services such as washing machine, iron, etc.). Depending on these data, the optimization algorithm can find and calculate the optimal start-up time for turn on the service using a meta-heuristic algorithm.

Each service (i) is characterized by the required power during the operation $P(i)$, the operating time $dt(i)$, the time of starting operation $S_t\,(i)$, which is the decision variable associated with the temporary services and the and a time of ending operation $E_t\,(i)$. Each shiftable appliance has a time slot for running $t \in (S_{min};\ S_{max})$.

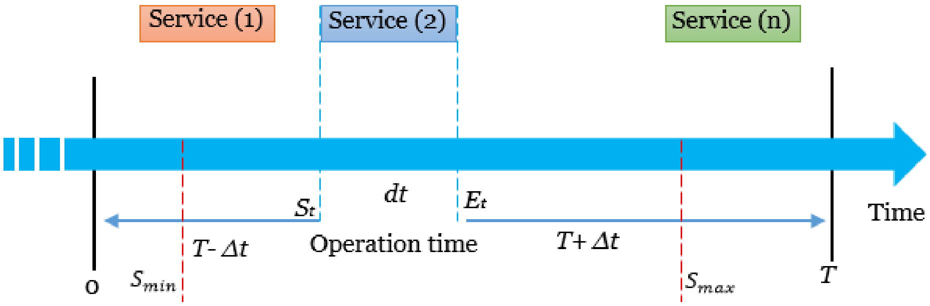


Figure.4. 11. Description of the proposed scheduling strategy.

4.8.2. The objective function

The main objective of the proposed scheduling strategy is to obtain optimum performance in the system by balancing at all times the production and consumption of electrical energy as indicated in Equation (4.3), with minimal energy cost (minimizes energy costs and improves system reliability by reducing the peaks consumption) as presented by Equation (4.4).

$$\sum_{k=1}^{M} Source(P_k(t)) \geq \sum_{i=1}^{N}\left(\sum_{i=1}^{n} P_{X;i}\,(t) + \sum_{i=1}^{m} P_{Y;i}\,(t)\right) \tag{4.3}$$

$$Min(Cost) \sum_{t=0}^{T} \sum_{k=1}^{M} C_k(t) \tag{4.4}$$

The algorithm will look for the optimal start-up time for the operation of services in the period {*0, T*}. In the beginning the algorithm will generate a random solution S1 = t, and considers this solution as the best solution in the current state, then it continues the calculation process *S2 = (T-Δt)* or *S2 = (T + Δt)* according to the convergence of the optimization algorithm depending based on the objective function until the optimal solution is obtained.

4.9. Conclusion

In this chapter, we have described the different energy management mechanisms in homes with multi-source energy. However, a state of the art was presented to focus on the different strategies that exist and to know the problems facing energy management systems in buildings. Also, a review of the most strategies dedicated to homes energy management systems has presented.

After presenting a multi-layer and multi-time scale piloting mechanism, we proposed our control and supervision system for controlling energy in the habitat, this mechanism based on two control mechanisms, a control mechanism anticipatory aims to manage energy consumption in days in advance to minimize peaks in energy consumption thus reducing energy losses, the other mechanism is a reactive control mechanism to control energy in real-time.

Finally, we presented our anticipative control approach, which allows the control of energy by scheduling electrical equipment one day in advance.

The following part of this thesis, we will present an application for the scheduling of household appliances for the validation of the home energy management proposed in this chapter.

CHAPTER 5

Implementation of the proposed control approach for a home with Multi-SES

After having presented in the previous chapter, the pilotage mechanisms of energy, also, the most strategies of energy control and management in homes with a multi-source system. This chapter is dedicated to using the proposed strategy in our energy pilotage approach for managing the energy in homes for both stand-alone and grid-connected hybrid energy system. This strategy is based on the scheduling of energy consumption and energy balance in multi-source (hybrid) energy systems.

The strategy of the scheduling of the energy consumption of a habitat supplied by a multi-source energy system developed within the framework of this work has three main objectives:

- Minimization of demand energy peaks where energy consumption is high;
- Management of the energy of the storage system in order to minimize energy losses and saving energy;
- Reducing the total cost of energy consumption.

5. Implementation of the proposed control approach for a home with Multi-SES

5.1. Optimal Scheduling of Household Appliances in Off-Grid Multi-SES

The control strategy adopted in this work for the anticipatory control unit (ACU) consists in controlling the energy in a stand-alone multi-source system through the scheduling of energy consumption according to the energy availability through an optimization algorithm. The scheduling algorithm is based on climatic data forecasts (wind speed, solar irradiation and ambient temperature) for one day-ahead renewable energies production and the daily energy consumption profile.

5.1.1. The general architecture of the studied system

In this study, the selected system is designed as a stand-alone hybrid energy system that contains two energy sources operate in parallel (wind, PV) with an energy storage system and a diesel group used as a backup energy source. The hybrid energy system is presented in Figure.5.1 which is suggested as a stand-alone multi-source energy system for a local production of renewable energy, associated with an energy storage system (ESS) to store surplus energy and use it in the absence or insufficient energy in order to make the system more reliable. A diesel group is used as an emergency supply system in the event of a load supply deficit.

The PV source ensures energy production during the day as long as there is solar irradiation. The wind turbine (WT) energy source works as a support source besides the PV energy source by the production of energy during the all-day as long as there is enough wind speed in order to make the system more flexible and more reliable.

The batteries aim to store the energy for using it later; it works as a load by charging of the surplus energy when the energy supply more than demand, as well as, the batteries work as an energy source to supply the loads energy demand by discharging the stored energy when the energy supply is less than the demand or when the energy production cannot meet the energy demand. The total capacity of the battery depends on the autonomy time for the energy supply for the home. The diesel generator (DG) works as a back-up energy source in case of an energy shortage.

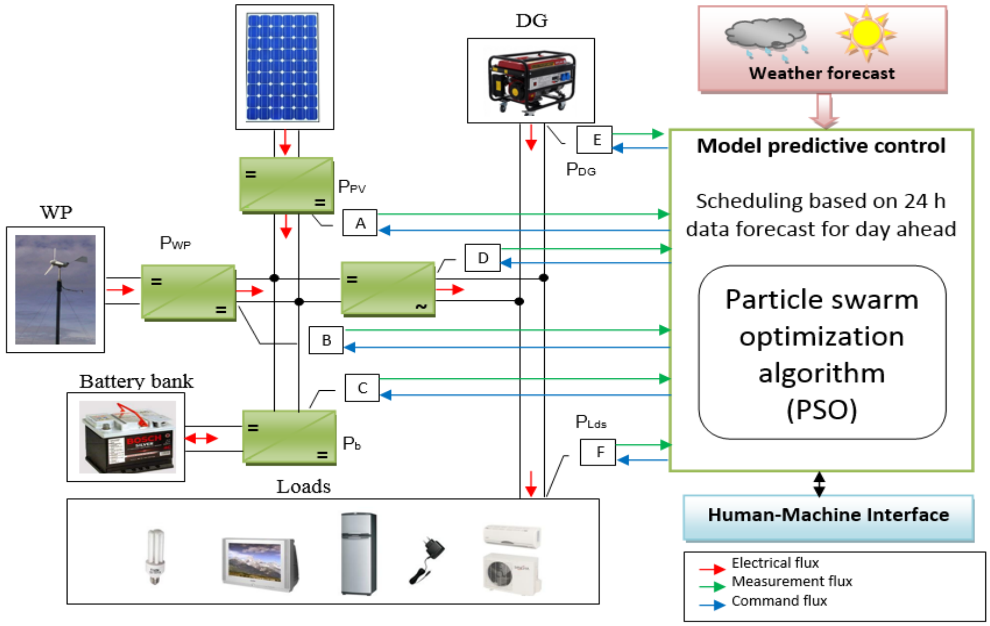


Figure.5. 1. The general architecture of the studied stand-alone M-SES.

5.1.2. Energy management strategy

Generally, in multi-source energy systems, the use of energy produced by renewable energy sources is favoured over conventional sources to supply electrical charges. However, the big challenge in renewable energy systems is to maintain the energy balance between supply and demand. In addition, in stand-alone energy systems with the absence of a permanent energy source makes maintaining the energy balance more complicated compared to the systems connected to the permanent source, this challenge consists in maintaining the equivalence between energy supply and demand at all times and under all constraints.

In the chosen system, the balance of energy between supply and demand as given by Equation (5.1):

$$P_{pv}(t) + P_{wp}(t) + \alpha \cdot P_b(t) + \beta \cdot P_{DG}(t) - P_{lds} - P_{loss} = 0 \tag{5.1}$$

where:

- $P_{pv}(t)$: the output power of the PV generators (W);
- $P_{wp}(t)$: the output power of the wind generator (W);
- $P_b(t)$: the power of the batteries (W);

- $P_{DG}(t)$: the output power of the diesel generator (W);
- $P_{lds}(t)$: the power required by the loads (W);
- $P_{loss}(t)$: power losses in the system (W);
- α: index indicating the state of the battery (1: charging, -1: discharging and 0: disconnecting);
- β: index indicating the state of the diesel generator (1: on, 0: off);
- t: the time step.

Regarding the operation of the PV-wind-Batteries-diesel hybrid system, the power balance in the system is managed according the algorithm presented in Figure.5.2.

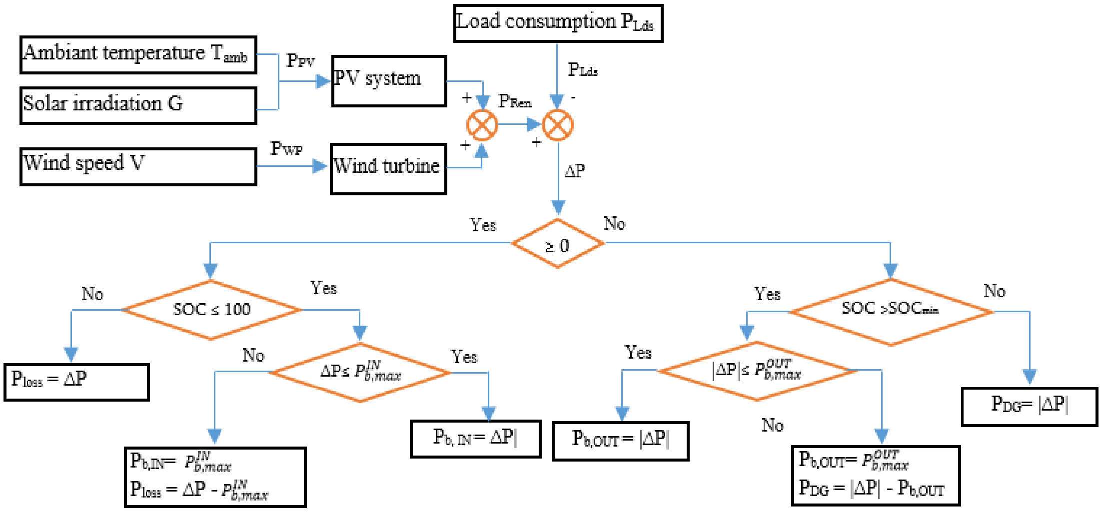


Figure.5. 2. Power balance flowchart of the hybrid energy system.

5.1.3. Optimization problem formulation

The energy management strategy proposed in this study makes it possible to anticipate one day in advance, the appropriate periods for the operation of the household appliances. Therefore the appliances can be shifted based on meteorological data (solar irradiation and wind speed) using a particle swarm optimization algorithm (PSO).

The objective function

The scheduling strategy for household appliances aims to maintain and ensure the energy balance between demand and supply in the system, as presented previously in Equation (5.1). In addition, to minimizing the cost of energy, taking into account the following constraints:

$$SOC_{min} \leq SOC(t) \leq SOC_{max} \quad (5.2)$$

$$P_b(t) \leq P_{disc.max}(t) \quad (5.3)$$

$$P_b(t) \leq P_{ch.max}(t) \quad (5.4)$$

where: SOC_{min} is the minimum state of charge to protect the battery from deep discharge, SOC_{max} is the maximum state of charge to protect the battery from overcharging;

In this study, we assume that the cost of energy produced from renewable sources as free and we considering only the cost of energy produced from both batteries and diesel generator for the calculation of the total cost of energy. However, the objective is to minimize using the energy of both the battery and the diesel generator in particular during peak consumption periods. Also, we maximize the use of energy produced by renewable energy sources. The objective function of the scheduling strategy is expressed by Equation (5.5):

$$Min(Cost) = Min \sum_{t=0}^{288} C_B(t) + C_{DG}(t) \quad (5.5)$$

where C_B, C_{DG} are respectively the cost of the energy delivered by the batteries and the diesel group, which can be calculated as follows:

$$C_B(t) = P_b(t) \cdot \frac{C_b^a}{E_b^n \cdot N_{cycle}} \quad (5.6)$$

$$C_{DG}(t) = CON_{DG}(t) \cdot C_f \cdot \Delta t \quad (5.7)$$

where:
C_f: The price of one litre of fuel,

C_b^a : Battery acquisition costs,

E_b^n : The nominal energy of the battery,

N_{cycle} : The number of battery life cycles.

5.1.4. Application of a case study

To test the efficiency of the proposed scheduling strategy, a case study with real data and real parameters is carried out, where the PSO optimization algorithm and simulations were performed in MATLAB environment. This section is devoted to implementing a case study of our approach for the management and control of habitat with multiple loads and multi-source of energy.

5.1.4.1. Electrical household appliance

For validating the algorithms used for energy management, we chose the case study of usual household appliances in habitat, where we considered eight household appliances. Figure.5.3 shows the daily distribution of household appliances. While the energy consumption and time of use of each electrical appliance are more detailed in Table.5.1.

Table.5. 1. list of electrical charges used in the study.

Appliances	Rated power (kW)	Start (h)	Finish (h)	Time of use (h)	Nature of service
Refrigerator	0.25	[00:00]	[24:00]	24	Non shiftable
Light	0.12	[7:00 & 20:00]	[8:00 & 24:00]	5	Non shiftable
Clothes washing	2.2	[10:00]	[12:00]	2	Shiftable
Iron	2	[20:00]	[20:30]	0.5	Shiftable
TV + DSR	0.08	[08:00 & 19:00]	[10:00 & 22:00]	4	Non shiftable
Desktop	0.13	[19:00]	[22:00]	3	Non shiftable
Hair dryer	2.2	[07:00]	[07:30]	0.5	Shiftable
Electric Stove	1.5	[12:00 & 19:00]	[13:00 & 20:00]	2	Non shiftable

5.1.4.2. Meteorological data

Regarding the meteorological data (wind speed, solar radiation and ambient temperature) used for the simulation in this study, 24 hours data with time steps of five minutes from a southern region in Spain. Figure.5.4 shows the estimation of the power output profiles of solar and wind energy systems.

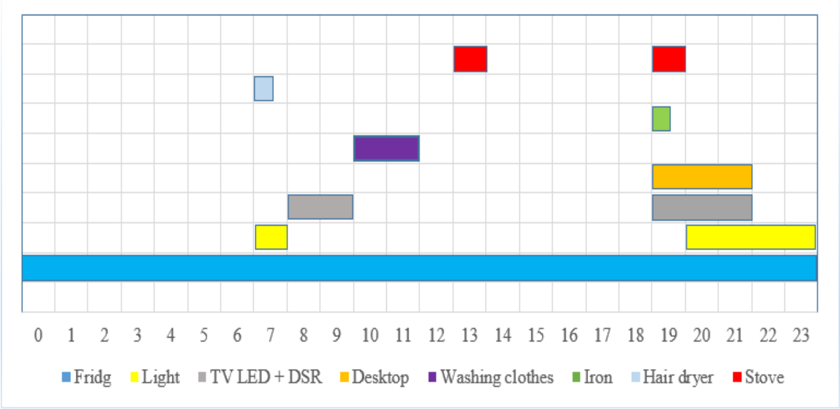


Figure.5. 3. Daily distribution of household appliances.

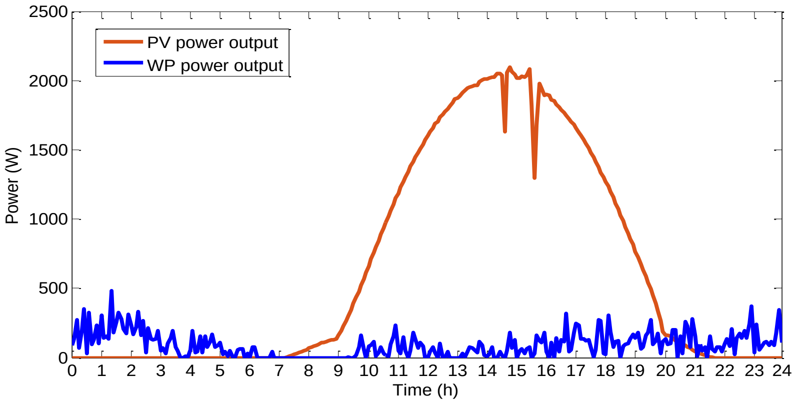


Figure.5. 4. The power output profiles of the PV and WT used for the study.

5.1.4.3. PSO algorithm structure

As the problem dealt with the optimization problem, we used the PSO algorithm for solving the optimization problem.

The PSO algorithm is a metaheuristic optimization algorithm inspired from the social behaviour of birds and fish, which introduced by Kennedy and Eberhart (Kennedy and Eberhart, 1995). The algorithm is based on the movement of particles swarm in a multidimensional search space, each particle position $X_i(k)$ and speed $V_i(k)$. The algorithm begins with a random initial position for all particles. At each iteration, the position and the speed of each particle of the swarm are updated according to the best current position, according to the following equations:

$$V_i(k+1) = w \cdot V_i(k) + C_1 \cdot r_1\big(X_{i,best}(k) - X_i(k)\big) + C_2 \cdot r_2\big(X_{g,best}(k) - X_i(k)\big) \quad (5.8)$$

$$X_i(k+1) = X_i(k) + V_i(k+1) \quad (5.9)$$

Where, $X_{i,best}$ is the best personal position in the current iteration and $X_{g,best}$ is the best global position which represents the optimal adaptation solution in the current iteration, C_1, C_2 are the coefficients of personal and social acceleration for particles. The parameters r_1 and r_2 are random numbers between [0; 1], w represents the weight coefficient of inertia for particles which is calculated as follows:

$$w(k) = w_{max} - \frac{(w_{max} - w_{min})}{N_{iter}} \quad (5.10)$$

Where w_{max} and w_{min} represent the maximum and minimum inertia of the weight, N_{iter} is the number of iterations. The parameters of the algorithm used here are mentioned in Table.5.2.

Table.5. 2. The input parameters of the PSO algorithm.

Parameter	**Scheduling with user preference**	**Optimal scheduling**
w_{min}	0.4	0.4
w_{max}	0.9	0.9
$C1$	1.2	1.2
$C2$	1.2	1.2
Lower bound	[120,216,192]	[0,0,0]
Upper bound	[144,264,226]	[288,288,288]
Population	10	10
Max iteration	500	500

The structure of the PSO algorithm adopted in the scheduling strategy is given below:

```
Step 1: Initialization
        Load meteorological data;
        Load system component parameters;
        Load list of appliances;
        Set the initial PSO parameters;
        Set the initial velocity;
Step 2: Set random initial solution
```

```
        For each particle i of the population {
        Set the initial random particles, $X_{i\,gbest}$;
        Call cost function;
        $X_{i.best} = X_i$ ;
        $P_{i.best} = fitness(X(i))$;
        If ($P_{i.best} < gbest$)
        $gbest = P_{i.best}$ ;          }
Step 3: Update initial solution
        For each iteration k {
        Update inertia weights;
        Update velocity ($V_i$);
        Update position ($P_i$);
        For each particle i of the population {
        Call cost function;
        $X_{i.best} = Xi$ ;
        $P_{i.best} = fitness(X(i))$;
        If ($P_{i.best} < gbest$)
        $gbest = P_{i.best}$}          }
Step 4: Set final solution
        gbest is the solution
```

5.1.5. Energy management scenarios and results

In this study, we consider three different scenarios, the first one is a scenario without scheduling, and the second scenario is the scheduling of household appliances taking in the account the user preferences, while the third scenario is optimal scheduling which doesn't take the user preferences (in this case the algorithm has more liberty to schedule the appliances). To validate the efficiency of the proposed energy management system, we have carried out two different optimization scenarios: an optimization scenario take in to account the user interval time preferences for working the appliance, and the other scenario gives the algorithm the option to select the time to shift the appliances with more liberty. The comparison of these two scenarios with the base scenario without optimization will be assessed in relation to the totality of the energy consumed and the cost of this energy. For all scenario, we have kept on the same parameters, measurements and the same equipment.

5.1.5.1. Scenario 1: without scheduling

In this scenario, no scheduling of household appliances will be executed. Only the information available to the user is the forecast of energy production at the source as well as the behaviour of the energy storage system which based on daily energy consumption for the next day. Figure.5.5 presents the management of the forecast energy for the next day without scheduling, while Figure.5.6 presents the behaviour of the battery during the day.

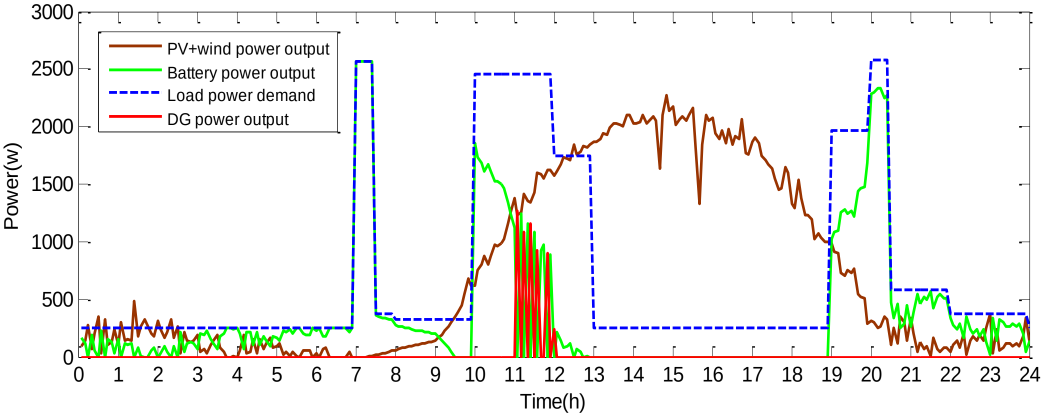


Figure.5. 5. The energy balance of the system in a single day (scenario 1).

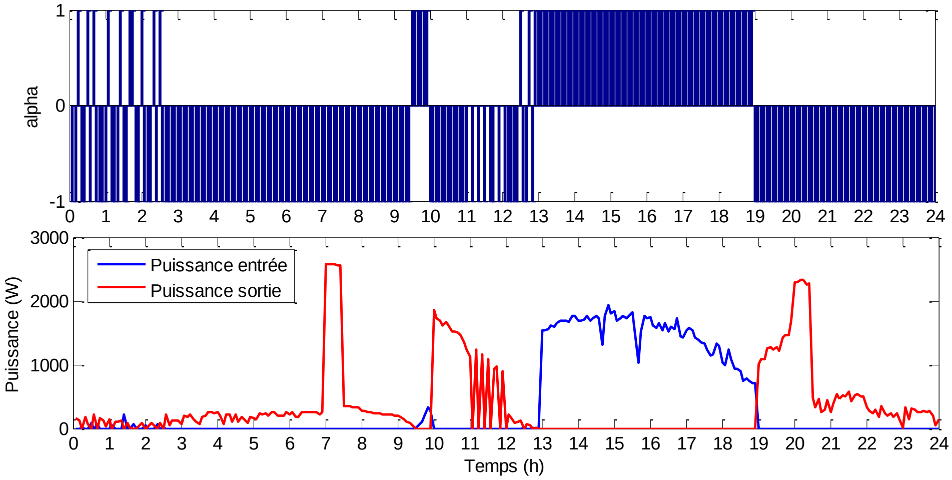


Figure.5. 6. Battery charging and discharging process for scenario 1.

5.1.5.2. Scenario 2: scheduling with user preferences

For the second scenario, we kept the same parameters used in the first scenario. The solution is based on the choice of the user according to their preferences, in this case, the user allows to specify the period for the operation of household appliances, and for example, we assumed the user prefers to start the operating of the electrical appliance as follows:

Table.5. 3. Time of use of the shiftable loads for scenario 2.

Equipment	**The time slot of the user preference(h)**	
Washing machine	10:00	12:00
Iron	18:00	22:00
Hair dryer	16:00	18:00

Figure.5.7 presents the management of the energy anticipation for the next day with the scheduling of operating time of the devices according to user preferences, while Figure.5.8 shows the behaviour of the battery during the day for this scenario.

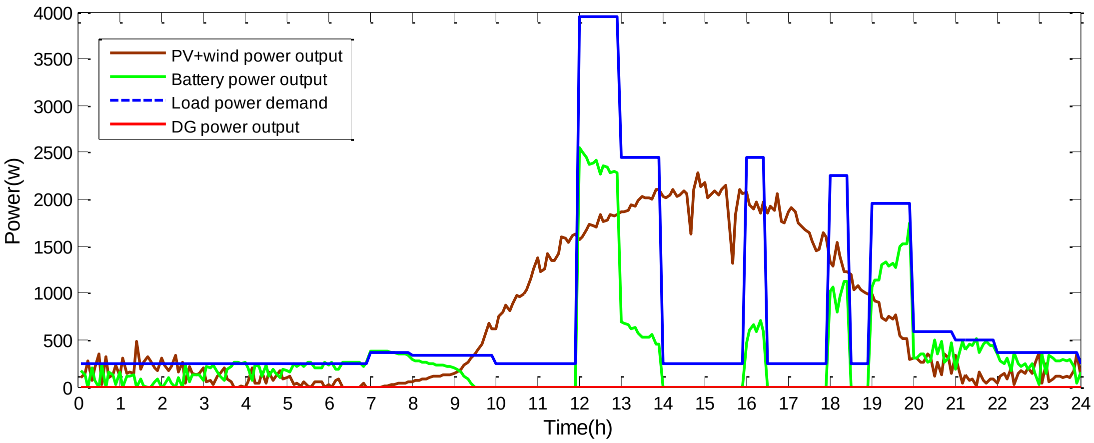


Figure.5. 7. The energy balance of the system in a single day for scenario 2.

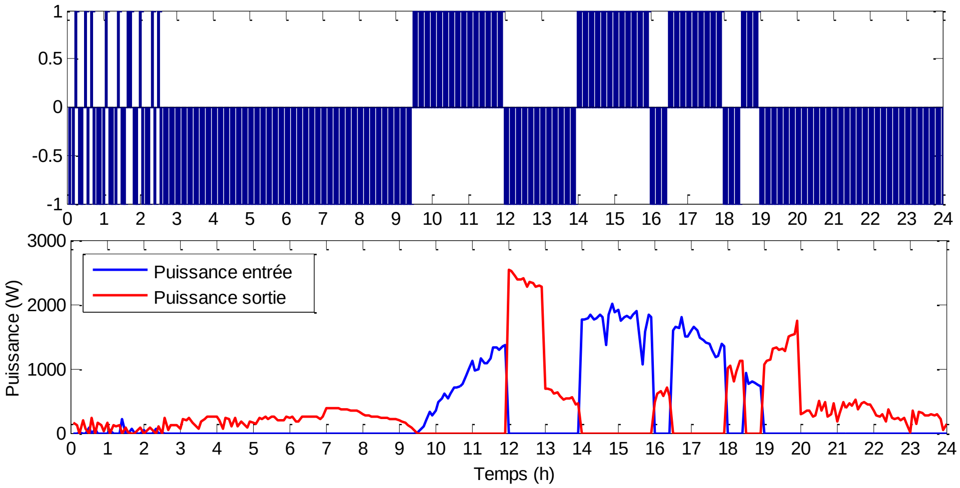


Figure.5. 8. Battery charge and discharge for scenario 2.

5.1.5.3. Scenario 3: Optimal scheduling

In this scheduling scenario, the PSO algorithm has no time restrictions on the part of the user. However, the algorithm will choose the optimal possible solution and give the appropriate time to run the household appliances with the minimum possible cost and with the minimum peaks of consumption.

Figure.5.9 shows the management of the forecast energy for the next day with optimal time scheduling for the operation of the devices, while Figure.5.10 presents the behaviour of the battery during the day for this scenario.

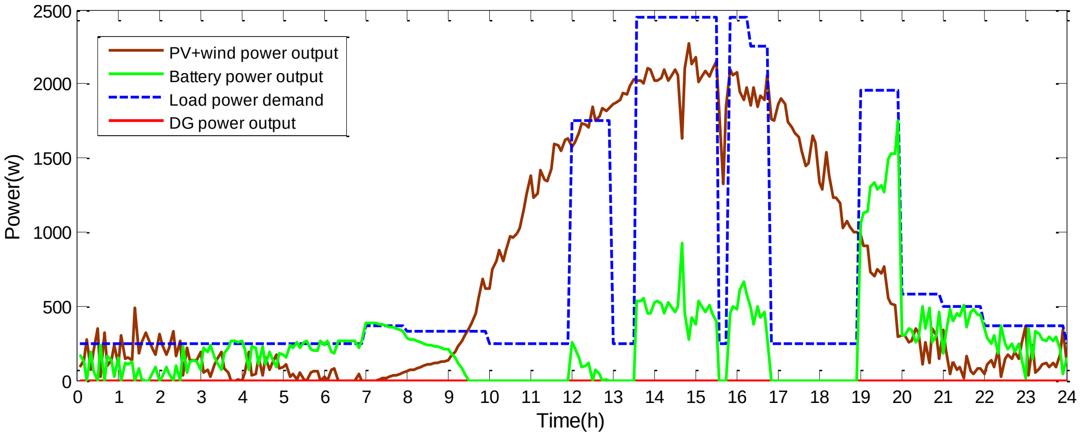


Figure.5. 9. The energy balance of the system in a single day for scenario 3.

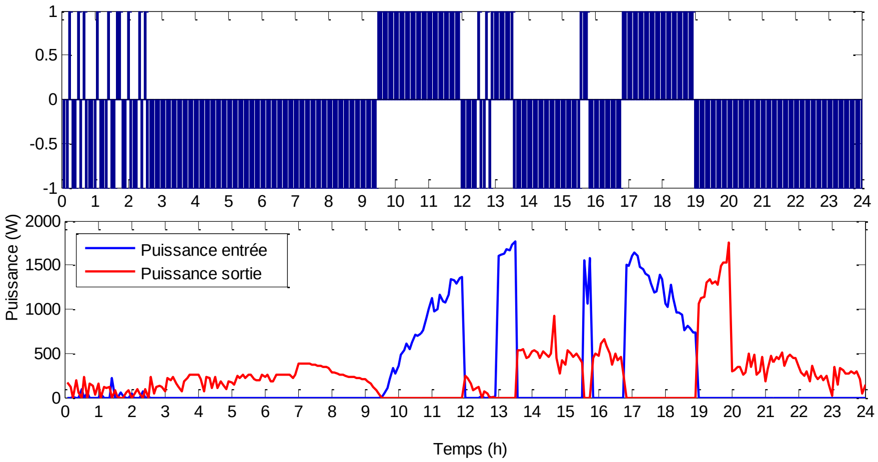


Figure.5. 10. Charging and discharging the battery for scenario 3.

5.1.6. Comparison and discussion of the obtained results

The comparison of the three scenarios shows that the PSO algorithm can provide an optimal solution in minimization of the energy cost and saving energy. The results obtained by the PSO for the scheduling strategy are summarized in the table.5.4, the first and second columns present the reduced energy cost which is present by the objective function, the energy of the diesel generator produced is displayed in the third column, column 4 indicates the energy stored in the batteries at the end of the day, while column 5 shows the energy saved value before and after the scheduling of household appliances.

Table.5. 4. The results obtained by the PSO for the scheduling strategy.

Scenario	**Cost ($)**	**Reduced cost (%)**	**Diesel power (kWh)**	**Energy saved on battery (kWh)**	**Energy saved (kWh)**
Without scheduling	0.636	-	0.464	1.233	-
Scheduling with user preferences	0.307	52	0	1.241	0.472
Optimal scheduling	0.227	64	0	1.580	0.811

The results show that the reduced cost of scheduling with user preferences can reach 52% and save 0.472 kWh of energy, while the reduced cost of optimal scheduling can reach 64% and save 0.811 kWh of energy. The time of use for the appliances in the three scenarios is presented in table.5.5. Figure.5.11 shows the load profile for the three scenarios. Figure.5.12 shows the state of charge (SOC) and the battery power output for the three scenarios. It noted that in the optimal scheduling scenario for household appliances, the state of charge of batteries (SOC) ratios is converged at all times, which means less use of the battery, followed by scheduling with user preferences compared to the scenario without scheduling household appliances.

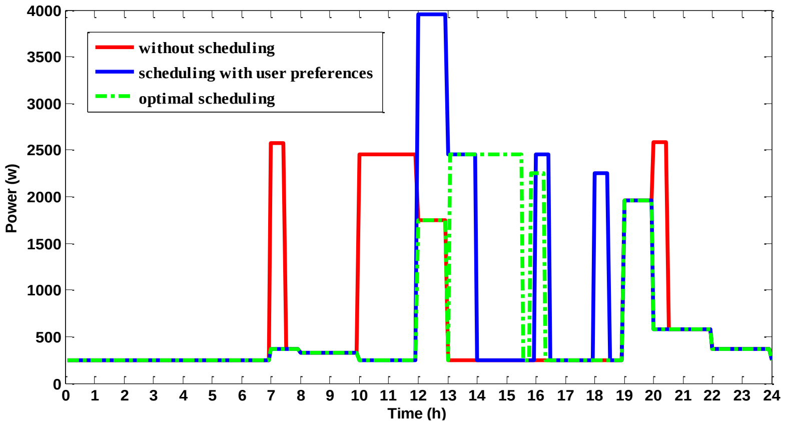


Figure.5. 11. Load profile for the three scenarios.

Table.5. 5. Time of use of the shiftable loads for the three scenarios.

Scenario	Without scheduling		Scheduling with user preferences		Optimal scheduling	
Appliance	Start	finish	start	finish	start	finish
Clothes washing	[10:00]	[12:00]	[12:00]	[14:00]	[13:35]	[15:35]
Iron	[20:00]	[20:30]	[18:00]	[18:30]	[15:50]	[16:20]
Hair dryer	[07:00]	[07:30]	[16:00]	[16:30]	[13:05]	[13:35]

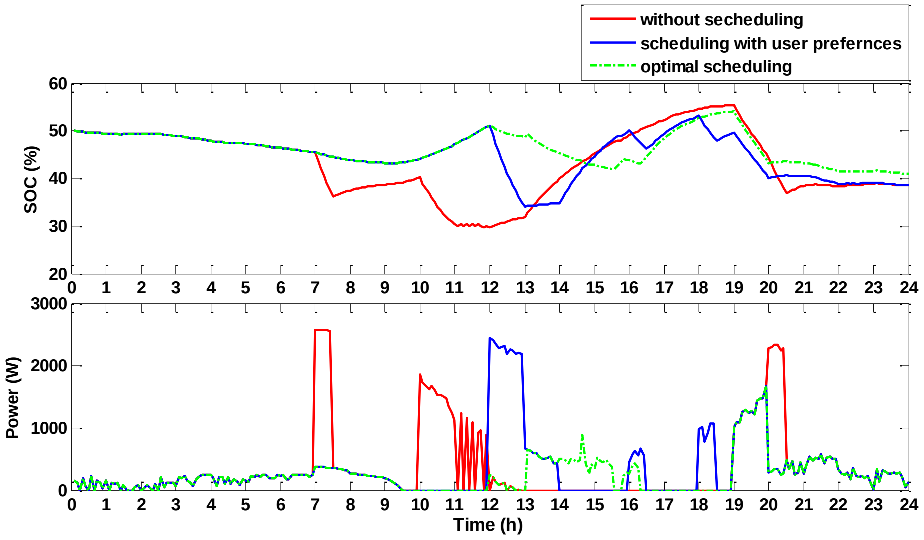


Figure.5. 12. SOC and battery power for the three scenarios.

5.2. Scheduling of energy consumption in grid connected hybrid energy system with energy storage

In this study, we propose a strategy to help householders to reduce the total cost of energy consumption, also, for saving the energy through reducing energy losses in a grid-connected home with multi-source of energy (Power grid system, PV, and battery storage system). The scheduling algorithm is based on day-ahead data forecasts (wind speed, solar irradiation and ambient temperature), the electricity price forecast for one day in advance and the daily energy consumption profile, while the optimization problem is solved using a particle swarm optimization algorithm (PSO) using Matlab. Also, in order to prove the efficiency and performance of the proposed optimization model, we consider two optimization scenarios of optimization, and we compare the results with the base model.

5.2.1. The general architecture of the studied system

The general architecture of the studied system is presented in Figure.5.13 which contains two subsystems: the first presents the unit of power system which includes a PV generation unit, an energy storage system (ESS) and the grid utility, while the second subsystem presents the energy control unit which contains the forecast data (price, weather data and load profile).

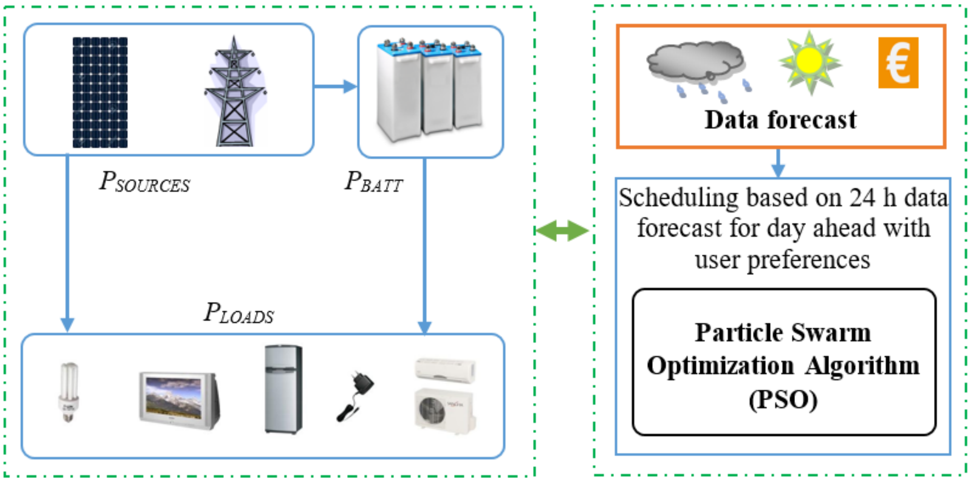


Figure.5. 13. System architecture with optimization.

The system configuration is shown in Figure.5.14, the system contains two buses DC and AC bus. In the DC bus, a PV and a battery are connected to the DC / DC converter for MPP PV power. From the DC / DC converter, the power bus is divided into two components, the DC input power to the DC/AC converter and the charging power to the battery. On the other hand, in the AC bus, the converted DC power from PV and battery is connected to AC bus plus grid power and load power demand through DC/AC converter.

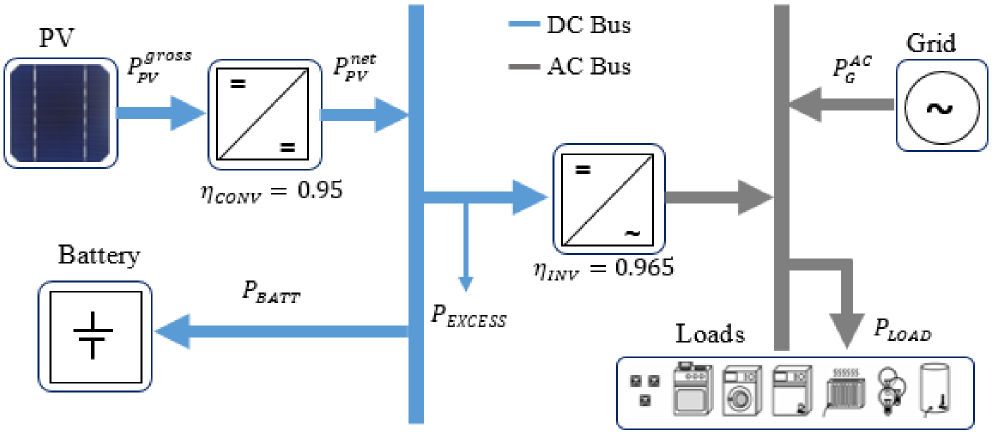


Figure.5. 14. Micro-grid hybrid energy system configuration.

5.2.2. Energy management strategy

In the studied system, it is necessary to maintain the power balance between supply and demand, thus the electricity demand must be satisfied each moment (t) such is presented in the Equation (5.11). Therefore, the use of the energy produced by the PV generators is favoured to supply the loads demand and, when the demand is satisfied, the excess of energy will be stored in the batteries. Otherwise, the shortage of energy will be completed by the energy of the batteries or the energy of the grid.

$$P_{PV}^{net}(t) - P_{BATT}(t) - \frac{\left(P_{LOAD}(t) - P_G^{AC}(t)\right)}{\eta_{INV}} = 0 \qquad (5.11)$$

where:

- $P_{PV}^{net}(t)$: the net power output of the PV generators (W);
- $P_{BATT}(t)$: the power of the batteries (W);

- $P_{LOAD}(t)$: the power required by the loads (W);
- $P_G^{AC}(t)$: the power of grid (W);
- η_{INV}: The DC/AC converter efficiency.

For the power balance model the following constraints should be met.

$$P_{PATT}\ (t) < P_{PATT,MAX} \tag{5.12}$$

$$SOC_{MIN} \leq SOC\ (t) \leq SOC_{MAX} \tag{5.13}$$

$$P_G^{AC}(t) < P_{G,MAX} \tag{5.14}$$

where $P_{PATT,MAX}$ is the maximum charging and discharging power of the battery, SOC , SOC_{MIN} and SOC_{MAX} are the state of charge at t , the minimum and maximum state of charge respectively. Concerning the constraint (5.14), it corresponds to a power grid limit. If the grid power is greater than the limit, an extra charge will be added to the cost of energy.

5.2.3. Problem formulation

The main objective of this work is to reduce electricity consumption costs and save energy. For reach this objective, we proposed an efficient energy consumption strategy based on a model of energy cost that considers the cost of both the energy used from the grid and the battery for the optimal energy use.

For grid electricity price, a day ahead electricity price is considered which is assumed variable and it depends on the period of energy consumption, so the price is high in the peak period when the electricity demand is high, and the price is low in the off-peak hour.

The cost of energy consumed from the grid is given by the equation (5.15):

$$C_g(t) = (P_g^{AC}(t)G_{price}(t)) \tag{5.15}$$

Regarding the price of the battery, a model of the price per kWh of energy stored in the batteries is considered. Also, the battery price is assumed variable and depends on the state of charge (SOC), (i.e., the price increases when the SOC is decreased). The price of battery energy given by Equation (5.16) is calculated using the number of battery life cycles provided by the battery manufacturer, the nominal battery energy and the costs of the battery (including investment, operation and maintenance costs).

$$B_{price}(t) = \frac{C_{BATT}^{Acq}}{E_{BATT}^{NOM}\, N_{cycle}\; SOC(t)} \tag{5.16}$$

The cost of energy consumed from battery each time slot *t* equals to:

$$C_{BATT}(t) = (P_{BATT}(t) B_{price}(t)) \tag{5.16}$$

The total cost of energy consumed every time slot *t* is given by the Equation (5.18):

$$COST(t) = C_g^{AC}(t) + C_{BATT}(t) \tag{5.18}$$

Objective function

The objective function is the minimization of the total daily energy cost, through the optimal using of energy of PV, batteries and grid. On the other hand, the energy of PV is considered free in order to maximize the power produced by PV. The objective function of the scheduling strategy is expressed by Equation (5.19).

$$Minimize(Cost) = Min \sum_{k=0}^{288} COST(t) \tag{5.19}$$

Subject to:

$$\begin{cases} (5.11); (5.12); (5.13); (5.14) \\ S_{min} \leq Y_i(S_t, E_t) \leq S_{max} \end{cases} \tag{5.20}$$

where the Equations 5.8, 5.9, 5.10 and 5.11 are respectively constraints of power balance, the maximum battery charge and discharge power, the minimum and maximum SOC limitation of the battery to protect the battery (from over charge and deep discharge), and the power grid limitation. The other constraint is the earliest starting time S_{min}, and the latest starting time S_{max} for the appliance $Y_i(S_t, E_t)$.

5.2.4. Application of a case study

The selected loads for the simulation consist of 12 household appliances, among them, six appliances considered as shiftable loads, in addition to the power consumption of appliances in standby mode. Table.5.6 shows the selected appliances with their power ratings, daily start and end time operation, and the time windows for shiftable appliances which depend on users' preferences.

Table.5. 6. Electric appliances used in simulations.

Appliance	**Rated power (kW)**	**Shiftable**	**Start time (S_t)**	**End time (E_t)**	**$S_{MIN}(t)$**	**$S_{MAX}(t)$**
Washing machine	2.200	1	{8.00}	{10.00}	{7.00}	{12.00}
Dish washer	1.800	1	{16.00}	{18.00}	{13.00}	{18.00}
Cloth Dryer	3.000	1	{18.00}	{19.00}	{14.00}	{20.00}
Vacuum cleaner	1.200	1	{9.00}	{9.50}	{8.00}	{16.00}
Iron	2.000	1	{20.00}	{20.30}	{08.00}	{20.00}
Water Heating	3.000	1	{7.00,17.00}	{7.50; 17.50}	{4.00; 12.00}	{7.00; 17.00}
Refrigerator	0.300	0	{0.00}	{24.00}		
Desktop	0.190	0	{21.00}	{23.00}		
Electric oven	2.500	0	{11.00; 19.00}	{11.50; 19.50}		
Microwave	1.000	0	{7.00; 13.00; 19.00}	{7.25; 13.25; 19.25}		
TV+DSR	0.070	0	{10.00; 12.50; 15.00}	{11.00; 13.50; 20.00}		
Light	0.120	0	{6.00; 19.00}	{08.00; 23.00}		
Standby	0.020	0	{0.00}	{24.00}		

For this study, a 1.5 kWp of PV power production (six panels of 250 W) is used. The data of irradiation and temperature have been obtained from the south of Spain (Cadiz). For the energy storage, a 7.56 kWh battery capacity of storage is used and an initial state of charge of 50% is assumed. The parameters used for the simulation are summarized in Table.5.7.

Table.5. 7.Parameters used in validation of simulation.

Parameter	**Value**
Total power rate of PV	1.5 kWp
Battery capacity	630 Ah
Battery voltage	12 V
Battery initial state of charge *SOCint*	50%
Battery efficiency	0.90
Inverter efficiency	0.965

5.2.5. Energy management scenarios

In this study, we are considered three scenarios; the first scenario is a base scenario without optimization, the second scenario regards the application of the optimization algorithm to schedule the energy consumption through shifting appliances from the peak hour period to off-hour period. In contrast, the third scenario regards the reducing of the total cost of energy consumption by scheduling both of shiftable appliances and the energy of the battery.

In the first and second scenarios, the criterion of using the energy of the battery depends on the power (the power of PV cannot meet the power demand. In contrast, in the third scenario, the criterion for using battery energy scheduling depends on the price of the energy that the algorithm looks when the cost of the energy of the grid is low. In this case, the algorithm makes a priority for using the energy of the grid and vice versa. Also, the results of the second and the third scenarios will be compared with the results of the first scenario to show the efficient and the optimal scenario.

5.2.5.1. Scenario 1: Base model (without scheduling)

In this scenario (base model), the simulation results are presented to show the difference before and after the scheduling. Figure.5.15 shows the daily distribution of the household appliances. The power balance (PV, battery charging and discharging power, power from the grid and the power demand) is presented in Figure.5.16-a, while Figure.5.16-b presents the histogram of energy values in the system for 24 hours. The total energy demand during the day is 14.95 kWh, the net energy of PV is 8.95 kWh, and the battery charged and discharged energy is 5.75 kWh and 6.33 kWh respectively. The total energy demanded from grid equals to 5.75 kWh. The energy losses are 2.11 kWh. These losses come from energy storage and power conversion.

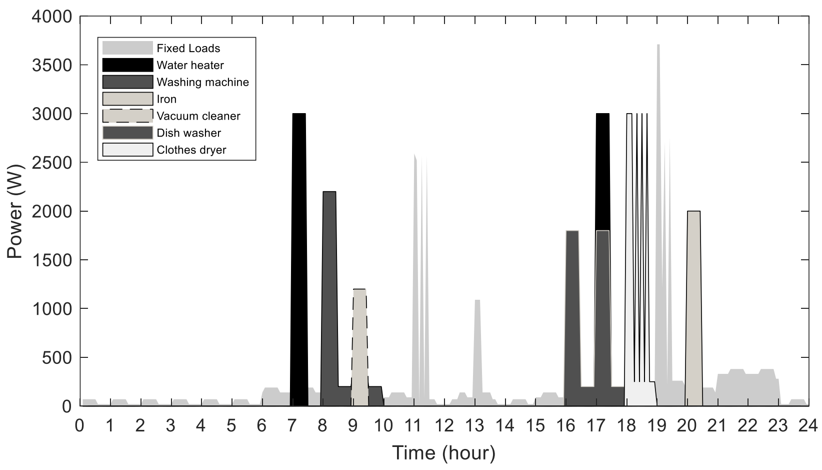
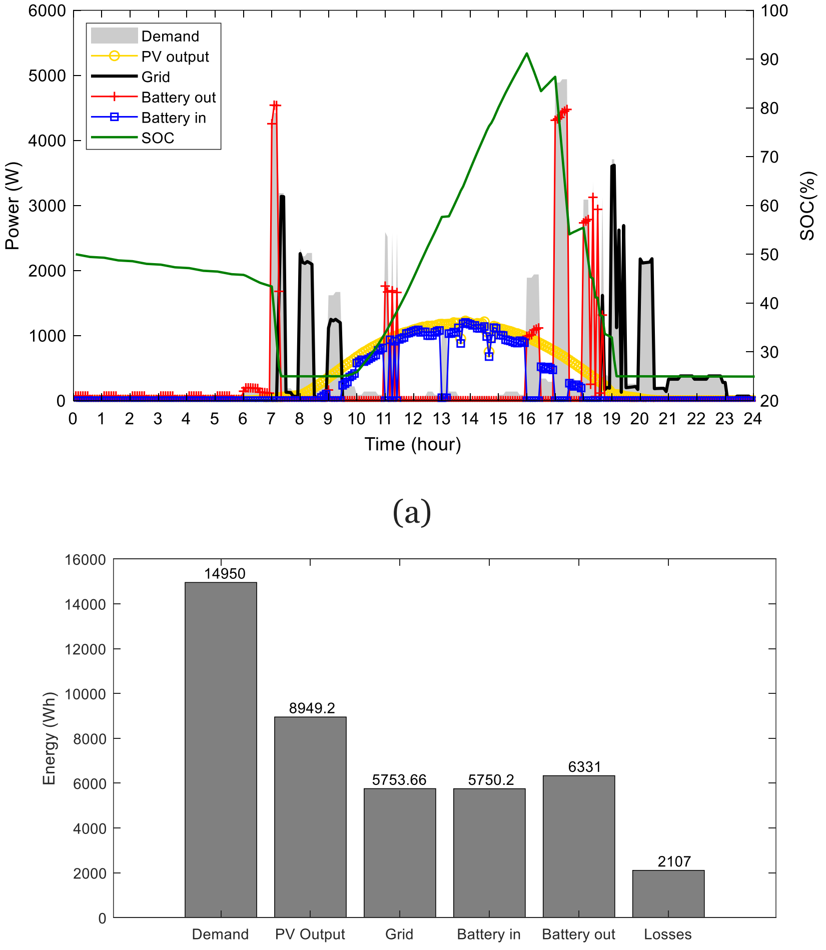


Figure.5. 15. Daily distribution of appliance for base scenario.



(a)

(b)

Figure.5. 16. The energy balance (PV, Batteries, Grid, loads and losses);

5.2.5.2. Scenario 2: Optimization by scheduling appliances (OSA)

In this scenario, cost minimization is based on the scheduling of the time of use of appliances, by shifting them from the periods of high electricity price to periods of low price. Figure.5.17 shows the convergence of the PSO algorithm. Figure.5.18 presents the distribution of the appliances which indicates that most of the shiftable appliances are shifted to the period between 11:00 a.m. - 5:00 p.m. that presents the highest PV energy production period and also coincides when the price of electricity from the grid is lower. Figure.5.19-a shows the most representative powers of the power balance of the system. From Figure.5.19-b, it is observed that the energy supplied by the grid is slightly reduced from 5.75 kWh to 5.51 kWh. While the charged energy is reduced from 5.75 kWh to 4.46 kWh, the same thing with the discharged energy which reduced from 6.33 kWh to 5.29 kWh which means the battery is less used and the loads are supplied using the energy of PV. Also, a remarkable reduction for energy losses from 2.11 kWh to 1.86 kWh (12% energy losses reduced) is achieved.

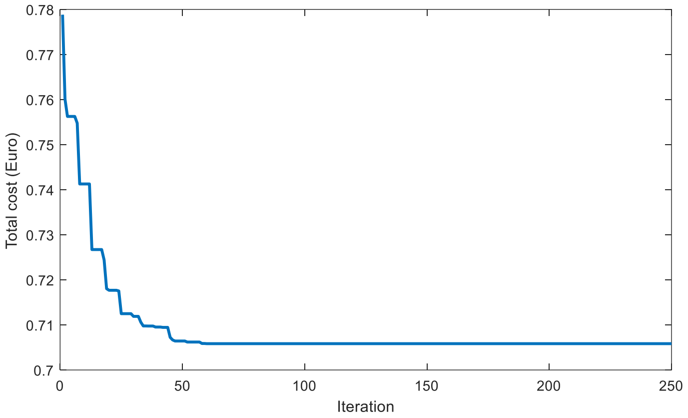


Figure.5. 17. The convergence of the PSO algorithm of OSA.

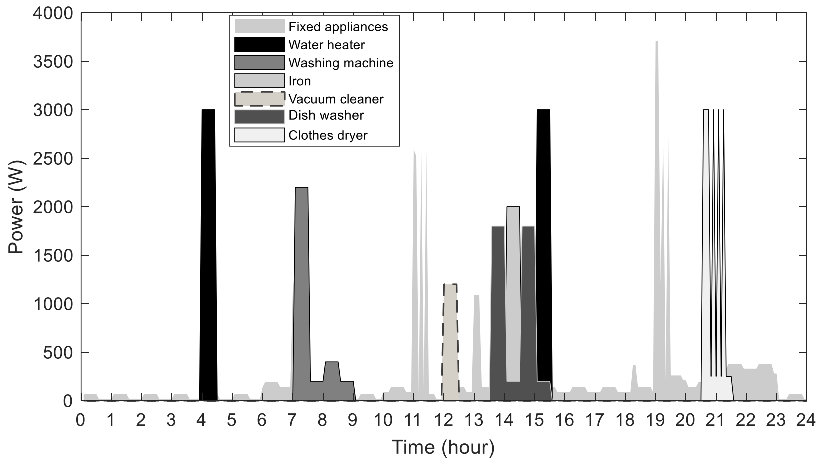
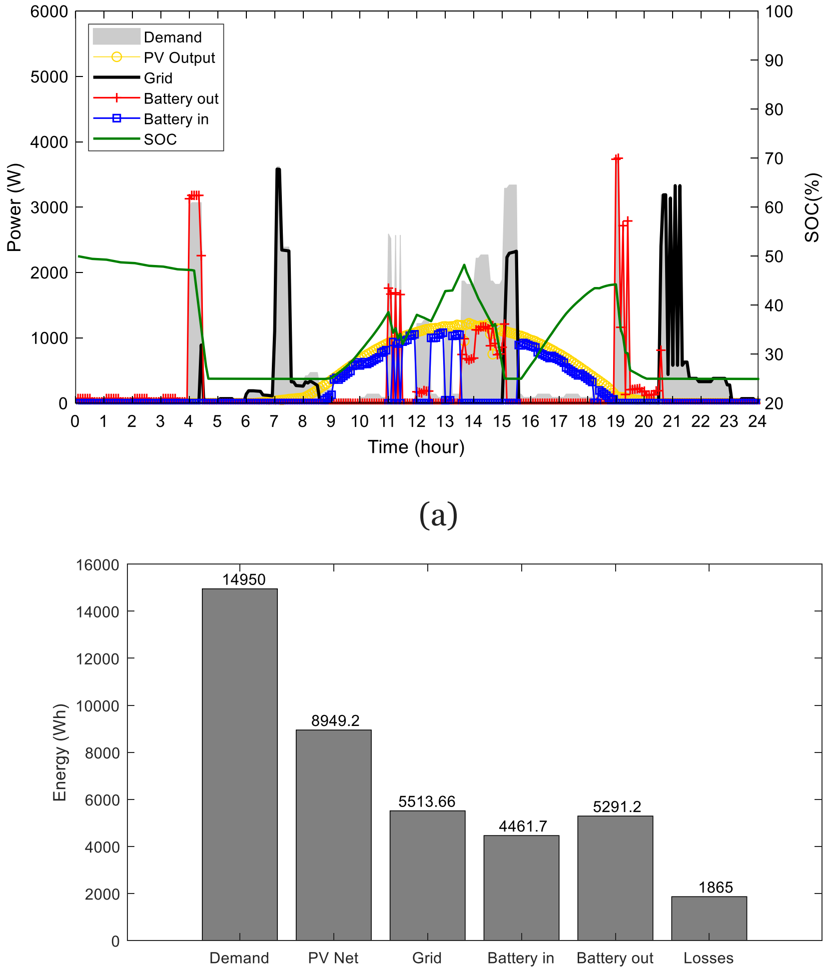


Figure.5. 18. The distribution of loads for OSA.



(a)

(b)

Figure.5. 19. The energy balance for the OSA.

5.2.5.3. Scenario 3: Optimization by scheduling appliances and batteries (OSAB)

In this scenario, we consider the scheduling of energy of the battery in addition to the scheduling of appliances, to minimize the total cost of electricity consumption. However, the optimal use of energy of batteries contributes to reducing the total cost of electricity by using their energy in the periods when the price of electricity from the grid is high. Figure.5.20 shows the convergence of the PSO algorithm for this scenario. The distribution of the appliances is presented in Figure.5.21, which also indicates that the appliances are shifted to the period (11:00-17:00). Figure.5.22-a shows the power balance in the system, and from Figure.5.22-b, it is observed that the energy of the grid increases from 5.75 kWh to 6.31 kWh. Also, a significant reduction in energy of charged and discharged energy from 5.75 kWh to 3.90 kWh with a reduction almost 32.2% of charged energy and from 6.33 kWh to 3.91 kWh with reduction almost 38.3% of discharged energy respectively. This reduction in energy means that the battery is used much less. Also, we achieved a remarkable reduction in energy losses from 2.11 kWh to 1.64 kWh (22% energy losses reduced).

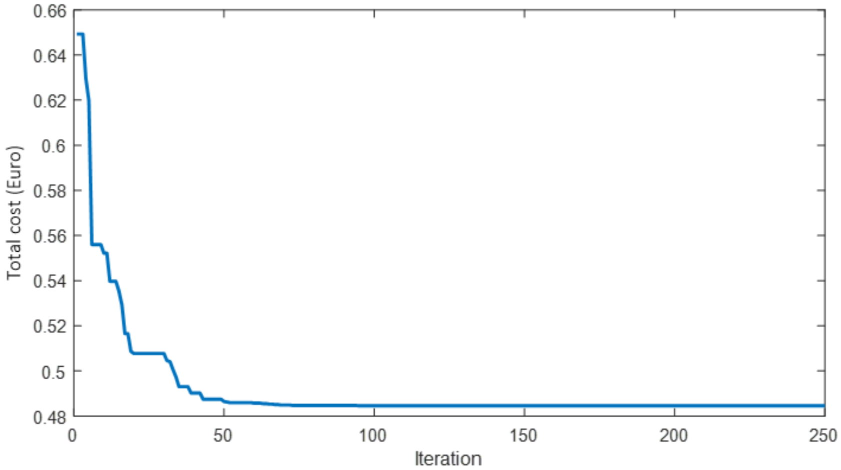


Figure.5. 20. The convergence of the PSO algorithm of OSAB.

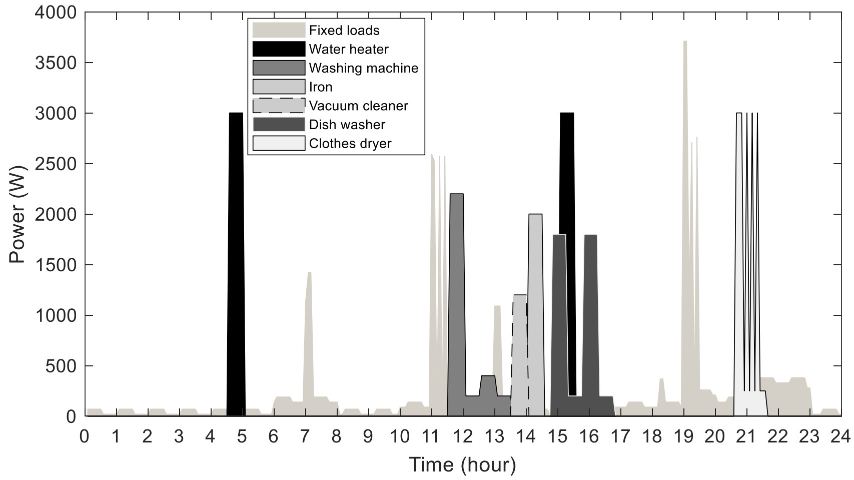
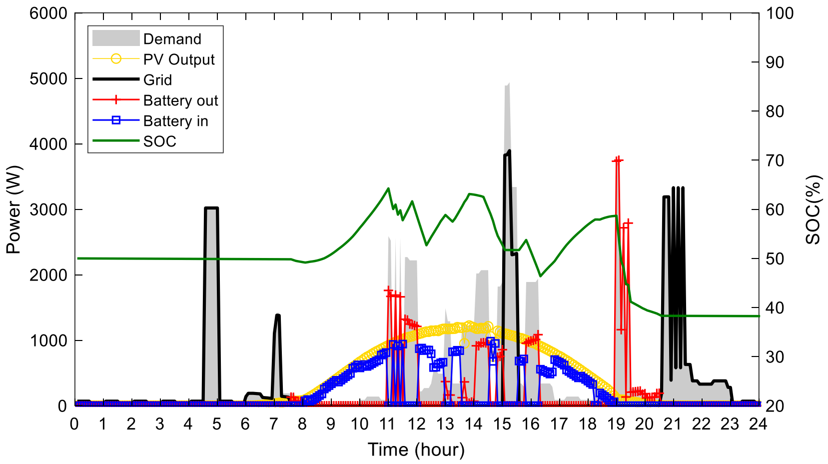
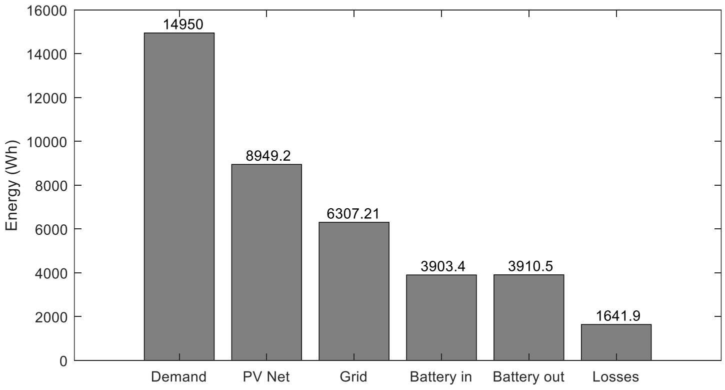


Figure.5. 21. The distribution of loads for OSAB.



(a)



(b)

Figure.5. 22. The energy balance for OSAB.

5.2.6. Comparison and discussion of the obtained results

In order to examine the efficiency of the proposed scheduling strategy in reducing the cost and saving energy, a comparison of results is proposed. The results of the simulation for the three scenarios are presented in Table.5.8 for energy (demanded energy, energy from the grid, energy of the battery at the end and the energy losses) and in Table.5.9 for the cost of energy consumption (cost of energy from the grid, cost of energy used from the battery and the total cost). Figure.5.23 shows the energy costs used from both the grid and the energy.

Table.5. 8. Comparison of energy results for three scenarios.

SCENARIOS	LOAD DEMAND (Wh)	GRID (Wh)	BATTERY (Wh)	LOSSES (Wh)	REDUCED LOSSES (%)
Base scenario	14950	5753.60	1885.09	2107.01	-
Optimization by scheduling appliance OSA	14950	5513.66	1886.82	1865.00	11.50
Optimization by scheduling appliance and battery OSAB	14950	6307.21	2904.55	1641.90	22.07

Table.5. 9. Comparison of costs results for three scenarios

SCENARIOS	GRID (€)	BATTERY (€)	TOTAL COST (€)	REDUCED COST (%)
Base scenario	0.566	0.428	0.994	-
Optimization by scheduling appliance OSA	0.270	0.435	0.705	29%
Optimization by scheduling appliance and battery OSAB	0.264	0.220	0.484	45%

From the results shown in tables (5.8) and (5.9), the energy used from the grid in the base scenario is 5.75 kWh, with a cost of 0.566 € while, in the OSA scenario the energy from the grid is slightly reduced to 5.51 kWh with a reduction about 53% in the cost of energy which is 0.270 €, that is due to the shifting of appliances from high-cost energy periods to low cost. In addition, we obtained a reduction in energy losses. For the OSAB scenario, it is observed an increase of energy from the grid from 5.75 kWh to 6.31 kWh with a reduction of about 53% of the cost of energy which is 0.264 €, this interpreted by the optimal use of energy for both the grid and the battery since the algorithm prioritizes to use the energy from the grid when the price is low rather than using the battery energy that was saved to use when the price energy of the grid is high. Moreover, the energy stored in the battery at the end is 2.90 kWh (SOC = 39%) while in base and OSA scenarios the battery is discharged to SOCmin (SOC = 25%), which means saving more than 14% of energy.

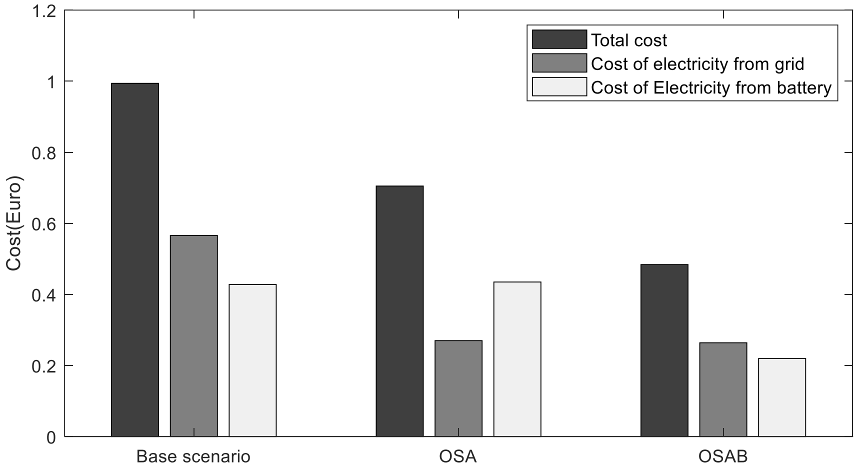


Figure.5. 23. Results of the cost of energy consumption.

5.3. Conclusion

In this chapter, we implemented the anticipative control approach of the energy management system proposed in chapter 4. We focused on a daily management strategy which was based on meteorological data of one day ahead. This strategy is based on the optimal scheduling of household appliances in both stand-alone and grid-connected home with multi-source of energy; however, the optimizations problem was solved using the PSO optimization algorithm.

For the stand-alone system, we carried out two scheduling strategy scenarios, and we compared the result to the scenario without scheduling of household appliances. The obtained results of the simulation showed that the optimal scheduling of household appliances could save energy, reduce peak consumption, also, reduce the energy cost of the system (avoid running the diesel generator) through the efficient use of the battery energy and maximizing the use of renewable energy.

For grid-connected home, two scenarios of scheduling strategy were considered; the first one was scheduling based on shifting the household appliances from high price periods to low price periods. In the second scenario, a managing approach for the energy of the battery was applied besides the scheduling of appliances. The results of the two scenarios were compared with the base scenario without scheduling. The simulation results showed that the proposed scheduling based on the scheduling of household appliances and the energy of batteries (OSAB) was more effective in reducing the energy cost (45% of the total cost was reduced) and the best for energy-saving (22% of energy was saved) compared to OSA and base scenario.

Conclusions and perspectives

The presented work in this thesis is a set up an energy management strategy for controlling the energy in a home equipped with a multi-source system energy production based on alternative and renewable energy sources.

The objective was to find a control/command solution for the home energy system composed of domestic equipment and multiple energy sources, either connected (via the national electricity network) or local production sources (stand-alone). This solution makes it possible to find a dynamic policy for managing the energy supply and demand, taking into account the different constraints such as; cost, user comfort, the state of equipment and weather conditions.

To this end, we proposed a control and supervision mechanism for energy management in a home. This mechanism contains two control mechanisms, a mechanism called "anticipative control" allows energy consumption to be managed in advance (usually a day advance), based on weather forecasts, energy demand profile and the cost of energy. This control mechanism aims to minimise peaks in energy consumption, reduce the cost of energy consumption as well as reduce energy losses associated with energy storage systems. The other mechanism is called "reactive control" is considered a corrective system that allows controlling the energy flow in real-time.

Finally, we presented in the last chapter implementation of our control approach, which, based on the scheduling of electrical appliances for a day-ahead to manage the energy consumption for a home with multi-sources of energy. Therefore, we applied the strategy of scheduling for both houses connected to the stand-alone system and home connected to the grid.

For the first case, the strategy of scheduling aims to control the energy in a home connected to a stand-alone system (solar energy source, wind source, diesel generator and ESS), in order to save energy and reduce the energy cost (avoiding the running of the diesel generator) by optimizing using the energy of batteries and maximizing using of renewable energy sources. Whereas, the second application concerning the scheduling of energy in a home connected to a hybrid energy system (utility grid, PV, and battery storage system). The scheduling strategy aims to reduce the cost of energy consumption, saving energy and avoiding the peak of power demand through optimal scheduling of both batteries and electric appliances.

The work carried out in this thesis is a continuation of the previous research works carried out on energy management in buildings. Indeed, it is necessary to continue the work on energy management systems in buildings (the one considered as an extensive and complex research axis) by the integration of other new methods of optimization and development. 'Another more effective strategy to improve the quality of life of occupants with minimum cost and while respecting our environment. Also, the author encourages for further investigation in future works on the long term optimization as well as, the use of stochastic models and the extension to a set of houses grouped community.

Bibliography

Ahmed, M.S., Mohamed, A., Khatib, T., Shareef, H., Homod, R.Z., Ali, J.A., 2017. Real time optimal schedule controller for home energy management system using new binary backtracking search algorithm. Energy Build. 138, 215–227. https://doi.org/10.1016/j.enbuild.2016.12.052

Akinyele, D.O., Rayudu, R.K., 2014. Review of energy storage technologies for sustainable power networks. Sustain. Energy Technol. Assessments 8, 74–91. https://doi.org/10.1016/j.seta.2014.07.004

Al-Ali, A.R., El-Hag, A., Bahadiri, M., Harbaji, M., Ali El Haj, Y., 2011. Smart home renewable energy management system. Energy Procedia 12, 120–126. https://doi.org/10.1016/j.egypro.2011.10.017

Al-hadhrami, L.M., Alam, M., 2015. Pumped hydro energy storage system : A technological review 44, 586–598. https://doi.org/10.1016/j.rser.2014.12.040

Algeria, M. of energy and mining of, 2011. Le Programme des Energies Renouvelables et de l'Efficacité Énergétique. Algeria. http://www.mem-algeria.org/francais/index.php?page=le-programme-des-energies-renouvelables-et-de-l-efficacite-energetique. [Consulted on : 5/2020]

Ali, W., Farooq, H., Rehman, A.U., Awais, Q., Jamil, M., Noman, A., 2019. Design considerations of stand-alone solar photovoltaic systems. 2018 Int. Conf. Comput. Electron. Electr. Eng. ICE Cube 2018 1–6. https://doi.org/10.1109/ICECUBE.2018.8610970

Amasyali, K., El-gohary, N., 2016. Building lighting energy consumption prediction for supporting energy data analytics. Procedia Eng. 145, 511–517. https://doi.org/10.1016/j.proeng.2016.04.036

Amer, M., Naaman, A., M'Sirdi, N.K., El-Zonkoly, A.M., 2014. Smart home energy management systems survey. 2014 Int. Conf. Renew. Energies Dev. Countries, REDEC 2014 167–173. https://doi.org/10.1109/REDEC.2014.7038551

Amer, M., Namaane, A., M'Sirdi, N.K., 2013. Optimization of hybrid renewable energy systems (HRES) using PSO for cost reduction. Energy Procedia 42, 318–327. https://doi.org/10.1016/j.egypro.2013.11.032

Amirat, M., 2005. Economies d ’ Energie dans le Secteur de l ’ Habitat Consommation Electrique des Ménages. Renew. Energy 8, 27–37.

ANR, 2017. Multicom - Equipe du LIG : Laboratoire d’Informatique de Grenoble.

APRUE, 2020. Agence Nationale pour la Promotion et la Rationalisation de l’Utilisation de l’Energie (APRUE).http://www.aprue.org.dz/prg-eco-bat.html.

APRUE, 2016. Agence Nationale pour la Promotion et la Rationalisation de l’Utilisation de l’Energie -APRUE-.

Aslam Bhutta, M.M., Hayat, N., Farooq, A.U., Ali, Z., Jamil, S.R., Hussain, Z., 2012. Vertical axis wind turbine - A review of various configurations and design techniques. Renew. Sustain. Energy Rev. 16, 1926–1939. https://doi.org/10.1016/j.rser.2011.12.004

Ayón, X., Gruber, J.K., Hayes, B.P., Usaola, J., Prodanović, M., 2017. An optimal day-ahead load scheduling approach based on the flexibility of aggregate demands. Appl. Energy 198, 1–11. https://doi.org/10.1016/j.apenergy.2017.04.038

Baadsgaard, M., Nygaard Nielsen, J., Spliid, H., Madsen, H., Preisel, M., 1997. Estimation in Stochastic Differential Equations with a State Dependent Diffusion Term. IFAC Proc. Vol. 30, 1369–1374. https://doi.org/10.1016/s1474-6670(17)43033-3

Bacher, P., Bacher, P., 2010. Models for Energy Performance Analysis Financed by The Danish Electricity Saving Trust DK-2800 Kongens Lyngby.

Barbato, A., Capone, A., 2014. Optimization models and methods for demand-side management of residential users: A survey. Energies 7, 5787–5824. https://doi.org/10.3390/en7095787

Bargiotas, D., Birdwell, J.D., 1988. RESIDENTIAL AIR CONDITIlONER DYNAMIC MODEL 3, 2119–2126.

Baring-Gould, E.I., Corbus, D., 2006. Modeling Results of Wind / Diesel Retrofit Options for Santa Cruz , Galapagos.

Barote, L., Weissbach, R., Teodorescu, R., Marinescu, C., Cirstea, M., 2008. Stand-alone wind system with Vanadium Redox Battery energy storage, in: 2008 11th International Conference on Optimization of Electrical and Electronic Equipment. pp. 407–412. https://doi.org/10.1109/OPTIM.2008.4602441

Beaudin, M., Zareipour, H., 2015. Home energy management systems: A review of modelling and complexity. Renew. Sustain. Energy Rev. 45, 318–335. https://doi.org/10.1016/j.rser.2015.01.046

Beltran, H., Barahona, J., Vidal, R., Alfonso, J.C., Ariño, C., Pérez, E., 2016. Ageing of different types of batteries when enabling a PV power plant to enter electricity markets. IECON Proc. (Industrial Electron. Conf. 1986–1991. https://doi.org/10.1109/IECON.2016.7794082

Bernal-Agustín, J.L., Dufo-López, R., 2009. Simulation and optimization of stand-alone hybrid renewable energy systems. Renew. Sustain. Energy Rev. 13, 2111–2118. https://doi.org/https://doi.org/10.1016/j.rser.2009.01.010

Bert, D.F, E. a., 2012. Balancing Renewable Electricity. Energy Storage, Demand Side Management and Network Extension from an Interdisciplinary Perspective.

Bilodeau, A., Agbossou, K., 2006. Control analysis of renewable energy system with hydrogen storage for residential applications. J. Power Sources 162, 757–764. https://doi.org/https://doi.org/10.1016/j.jpowsour.2005.04.038

Blazquez, F., Veganzones, C., Martinez, S., 2005. Large scale integration of wind energy into power systems. Electr. Power Qual. Util. Mag. 1, 15–22.

Bouakkaz, A., Haddad, S., Martín-García, J.A., Gil-Mena, A.J., Jiménez-Castañeda, R., 2019. Optimal scheduling of household appliances in off-grid hybrid energy system using PSO algorithm for energy saving. Int. J. Renew. Energy Res.

C, J.S. V, Raghunath, M., Nair, M.G., n.d. Optimal Scheduling And Energy Management of A Residential Hybrid Microgrid 1–6.

Capehart, B.L., Muth, E.J., Stop, M.O., 1982. MINIMIZING RESIDENTIAL ELECTRICAL ENERGY COSTS USING MICROCOMPUTER ENERGY MANAGEMENT SYSTEMSt 6, 261–269.

Castillo-Cagigal, M., Caamaño-Martín, E., Matallanas, E., Masa-Bote, D., Gutiérrez, A., Monasterio-Huelin, F., Jiménez-Leube, J., 2011a. PV self-consumption optimization with storage and Active DSM for the residential sector. Sol. Energy 85, 2338–2348. https://doi.org/10.1016/j.solener.2011.06.028

Castillo-Cagigal, M., Gutiérrez, A., Monasterio-Huelin, F., Caamaño-Martín, E., Masa, D., Jimenéz-Leube, J., 2011b. A semi-distributed electric demand-side management system with PV generation for self-consumption enhancement. Energy Convers. Manag. 52, 2659–2666. https://doi.org/10.1016/j.enconman.2011.01.017

CDER, 2018. Revue des Energies Renouvelables - Centre de Développement des Energies Renouve?ab?es.

CHALAL, L., 2013. UNIVERSITÉ DES SCIENCES ET TECHNOLOGIES Coordination de systèmes multisources pour favoriser la production d ' énergie électrique renouvelable. UNIVERSITÉ DES SCIENCES ET TECHNOLOGIES DE LILLE.

Chen, C., 2018. Demand response: An enabling technology to achieve energy efficiency in a smart grid, Application of Smart Grid Technologies: Case Studies in Saving Electricity in Different Parts of the World. Elsevier Inc. https://doi.org/10.1016/B978-0-12-803128-5.00004-0

Chen, H., Cong, T.N., Yang, W., Tan, C., Li, Y., Ding, Y., 2009. Progress in electrical energy storage system: A critical review. Prog. Nat. Sci. 19, 291–312. https://doi.org/10.1016/j.pnsc.2008.07.014

Cho, Y., Shim, J.W., Kim, S.J., Min, S.W., Hur, K., 2013. Enhanced frequency regulation service using Hybrid Energy Storage System against increasing power-load variability. IEEE Power Energy Soc. Gen. Meet. https://doi.org/10.1109/PESMG.2013.6672784

Chowdhury, M.M., Haque, M.E., Aktarujjaman, M., Negnevitsky, M., Gargoom, A., 2011. Grid integration impacts and energy storage systems for wind energy applications — A review, in: 2011 IEEE Power and Energy Society General Meeting. pp. 1–8. https://doi.org/10.1109/PES.2011.6039798

Cohen, A.I., Wang, C.C., 1988. 612 IEEE Transactions on Power Systems, Vol. 3, No. 2, May 1988. Power 3, 612–618.

Com, A., 2020. ICONIC LAND: THE SAHARA DESERT OF ALGERIA.

Costanzo, G.T., 2013. Simulation models for household consumption 32.

Costanzo, G.T., Sossan, F., Marinelli, M., Bacher, P., Madsen, H., 2013. Grey-box modeling for system identification of household refrigerators: A step toward smart appliances. IYCE 2013 - 4th Int. Youth Conf. Energy. https://doi.org/10.1109/IYCE.2013.6604197

Dai, R., Mesbahi, M., 2013. Optimal power generation and load management for off-grid hybrid power systems with renewable sources via mixed-integer programming. Energy Convers. Manag. 73, 234–244. https://doi.org/10.1016/j.enconman.2013.04.039

Dam, S.S. Van, Bakker, C.A., Buiter, J.C., 2013. Do home energy management systems make sense ? Assessing their overall lifecycle impact. Energy Policy 63, 398–407.

https://doi.org/10.1016/j.enpol.2013.09.041

Darcovich, K., Gupta, N., Davidson, I.J., Caroni, T., 2010. Residential electrical power storage scenario simulations with a large-scale lithium ion battery. J. Appl. Electrochem. 40, 749–755. https://doi.org/10.1007/s10800-009-0053-6

Delarue, E., Morris, J., 2015. Renewables Intermittency: Operational Limits and Implications for Long-Term Energy System Models.

Dimeas, B.A., Drenkard, S., Hatziargyriou, N., Karnouskos, S., Kok, K., Ringelstein, J., 2014. Smart Houses in the Smart Grid. IEEE, Electrif. Mag. 2, 81–93. https://doi.org/10.1109/MELE.2013.2297032

Dotton, J.A., 2020. R-Value | EGEE 102: Energy Conservation and Environmental Protection.

Dougal, R.A., Liu, S., White, R.E., 2002. Power and life extension of battery-ultracapacitor hybrids. IEEE Trans. Components Packag. Technol. 25, 120–131. https://doi.org/10.1109/6144.991184

Duy-Long HA, 2007. Un système avancé de gestion d’énergie dans le bâtiment pour coordonner production et consommation. Hal.Inria.Fr. Institut Polytechnique de Grenoble.

Energy, U.D. of, 2008. Combined antithrombotic therapy [5], Cmaj. https://doi.org/10.1503/cmaj.1070122

Era, 2015. Programme National des Energies Nouvelles et Renouvelables.

Fardadi, M., Ghafari, A.S., Hannani, S.K., 2005. PID Neural Network control of SUT building energy management system. IEEE/ASME Int. Conf. Adv. Intell. Mechatronics, AIM 1, 682–686. https://doi.org/10.1109/aim.2005.1511061

Farhadi, M., Mohammed, O., 2015. Energy storage systems for high power applications. IEEE Ind. Appl. Soc. - 51st Annu. Meet. IAS 2015, Conf. Rec. 89. https://doi.org/10.1109/IAS.2015.7356787

Federal Energy Regulatory Commission, 2011. Assessment of Demand Response and Advanced Metering Staff Report Federal Energy Regulatory Commission, Energy.

Foggia, G., 2009. Pilotage optimal de systèmes multi-sources pour le bâtiment.

Galasiu, A.D., Veitch, J.A., 2006. Occupant preferences and satisfaction with the luminous environment and control systems in daylit offices: a literature review. Energy Build. 38, 728–742.

https://doi.org/10.1016/j.enbuild.2006.03.001

Gao, D.W., 2015. Applications of ESS in Renewable Energy Microgrids, Energy Storage for Sustainable Microgrid. https://doi.org/10.1016/b978-0-12-803374-6.00002-0

Garvey, S.D., Pimm, A., 2016. Compressed Air Energy Storage, Storing Energy. Elsevier Inc. https://doi.org/10.1016/B978-0-12-803440-8/00005-1

Gellings, C.W., 1985. The Concept of Demand-Side Management for Electric Utilities. Proc. IEEE 73, 1468–1470. https://doi.org/10.1109/PROC.1985.13318

Gergaud, O., 2002. Modélisation énergétique et optimisation économique d ' un système de production éolien et photovoltaïque couplé au réseau et associé à un accumulateur To cite this version : HAL Id : tel-00439079 de l ' ÉCOLE NORMALE SUPÉRIEURE de CACHAN Spécialité : Éle.

Gersema, G., Wozabal, D., 2018. Risk-optimized pooling of intermittent renewable energy sources. J. Bank. Financ. 95, 217–230. https://doi.org/10.1016/j.jbankfin.2017.03.016

Gonçalves, F., Mesquita, G., 2010. Design Optimization of Stand-Alone Hybrid Energy Systems. UNIVERSIDADE DO PORTO.

Graditi, G., Di Silvestre, M.L., Gallea, R., Sanseverino, E.R., 2015. Heuristic-based shiftable loads optimal management in smart micro-grids. IEEE Trans. Ind. Informatics 11, 271–280. https://doi.org/10.1109/TII.2014.2331000

Gupta, J.K., Ram Gopal, M., Chakraborty, S., 2007. Modeling of a domestic frost-free refrigerator. Int. J. Refrig. 30, 311–322. https://doi.org/https://doi.org/10.1016/j.ijrefrig.2006.06.006

Habib, A.H., Disfani, V.R., Kleissl, J., Callafon, R.A. De, 2017. Optimal switchable load sizing and scheduling for standalone renewable energy systems. Sol. Energy 144, 707–720. https://doi.org/10.1016/j.solener.2017.01.065

Haider, H.T., See, O.H., Elmenreich, W., 2016. A review of residential demand response of smart grid. Renew. Sustain. Energy Rev. 59, 166–178. https://doi.org/10.1016/j.rser.2016.01.016

Han, J., Choi, C.S., Park, W.K., Lee, I., 2011. Green Home Energy Management System through comparison of energy usage between the same kinds of home appliances. Proc. Int. Symp. Consum. Electron. ISCE 1–4. https://doi.org/10.1109/ISCE.2011.5973168

Harris, D.J., 2012. A GUIDE TO ENERGY MANAGEMENT IN BUILDINGS. Spon Press, USA; Canada.

Haupt, S.E., 2014. Weather matters for energy. Choice Rev. Online 52, 52-0863-52–0863. https://doi.org/10.5860/choice.52-0863

Hemmati, R., Saboori, H., 2017. Stochastic optimal battery storage sizing and scheduling in home energy management systems equipped with solar photovoltaic panels. Energy Build. 152, 290–300. https://doi.org/10.1016/j.enbuild.2017.07.043

Hermes, C.J.L., Melo, C., 2009. Assessment of the energy performance of household refrigerators via dynamic simulation. Appl. Therm. Eng. 29, 1153–1165. https://doi.org/10.1016/j.applthermaleng.2008.06.007

Hermes, C.J.L., Melo, C., Knabben, F.T., Gonçalves, J.M., 2009. Prediction of the energy consumption of household refrigerators and freezers via steady-state simulation. Appl. Energy 86, 1311–1319. https://doi.org/https://doi.org/10.1016/j.apenergy.2008.10.008

Hossain, E., Perez, R., Bayindir, R., 2017. Implementation of hybrid energy storage systems to compensate microgrid instability in the presence of constant power loads, in: 2016 IEEE International Conference on Renewable Energy Research and Applications, ICRERA 2016. https://doi.org/10.1109/ICRERA.2016.7884498

Hussain, I., Mohsin, S., Basit, A., Khan, Z.A., Qasim, U., Javaid, N., 2015. A review on demand response: Pricing, optimization, and appliance scheduling. Procedia Comput. Sci. 52, 843–850. https://doi.org/10.1016/j.procs.2015.05.141

IEA, I.E.A., 2018. Key world energy statistics.

Irena, 2020. Wind Energy. Am. Soc. Mech. Eng. Sol. Energy Div. SED.

Irena, 2015. Battery Storage for Renewables : Market Status and Technology Outlook. Irena.

ISO, 1994. ISO 7730:1984 Moderate thermal environments — Determination of the PMV and PPD indices and specification of the conditions for thermal comfort. Iso.

Kah-Hoe, N., Sheblé, G.B., 1998. Direct load control - a profit-based load management using linear programming. IEEE Trans. Power Syst. 13, 688–695. https://doi.org/10.1109/59.667401

Kaldellis, J.K., 2010. Stand-alone and hybrid wind energy systems, Stand-alone and hybrid wind energy systems. https://doi.org/10.1533/9781845699628

Kang, S.J., Park, J., Oh, K.Y., Noh, J.G., Park, H., 2014. Scheduling-based real time energy flow control strategy for building energy management system. Energy Build. 75, 239–248.

https://doi.org/10.1016/j.enbuild.2014.02.008

Kennedy, J., Eberhart, R., 1995. Particle Swarm Optimization 1942–1948.

Khalid, A., Javaid, N., Mateen, A., Ilahi, M., Saba, T., Rehman, A., 2019. Enhanced time-of-use electricity price rate using game theory. Electron. 8. https://doi.org/10.3390/electronics8010048

Kim, Y., Chang, N., 2014. Design and Management of Energy-Efficient Hybrid Electrical Energy Storage Systems. Springer, Switzerland. https://doi.org/DOI 10.1007/978-3-319-07281-4

Krömerb, S.M.J.S.J.P., 2015. A heuristic approach to Active Demand Side Management in Off-Grid systems operated in a Smart-Grid environment. Energy Build. j 96, 272–284.

Kumar, N., Member, S., 2015. Superconducting Magnetic Energy Storage (SMES) System.

Kunz, H., Hagens, N.J., Balogh, S.B., 2014. The influence of output variability from renewable electricity generation on net energy calculations. Energies 7, 150–172. https://doi.org/10.3390/en7010150

Kurucz, C.N., Brandt, D., 1996. A linear programming model for reducing system peak through customer load control programs. IEEE Trans. Power Syst. 11, 1817–1824. https://doi.org/10.1109/59.544648

Kuzlu, M., Pipattanasomporn, M., Rahman, S., 2012. Hardware demonstration of a home energy management system for demand response applications. IEEE Trans. Smart Grid 3, 1704–1711. https://doi.org/10.1109/TSG.2012.2216295

Le, M.H., 2012. Prise en compte des incertitudes de prédiction dans la gestion des flux d ’ énergie dans l ’ habitat To cite this version : HAL Id : tel-00747459 Prise en compte des incertitudes de prédiction dans la gestion des flux d ’ énergie dans l ’ habitat. UNIVERSITÉ DE GRENOBLE.

Leary, J., While, A., Howell, R., 2012. Locally manufactured wind power technology for sustainable rural electrification. Energy Policy 43, 173–183. https://doi.org/10.1016/j.enpol.2011.12.053

Lee, S.H., Wilkins, C.L., 1983. A Practical Approach to Appliance Load Control Analysis: A Water Heater Case Study. IEEE Power Eng. Rev. PER-3, 64. https://doi.org/10.1109/MPER.1983.5519192

Lee, Sungjin, Kwon, B., Lee, Sanghoon, 2014a. Joint energy management system of electric supply and demand in houses and buildings. IEEE Trans. Power Syst. 29, 2804–2812. https://doi.org/10.1109/TPWRS.2014.2311827

Lee, Sungjin, Kwon, B., Lee, Sanghoon, 2014b. Joint energy management system of electric supply and demand in houses and buildings. IEEE Trans. Power Syst. 29, 2804–2812. https://doi.org/10.1109/TPWRS.2014.2311827

Lin, S., Chen, C., 2016. OPTIMAL ENERGY CONSUMPTION SCHEDULING IN HOME ENERGY MANAGEMENT SYSTEM 10–13.

Lund, H., Salgi, G., 2009. The role of compressed air energy storage (CAES) in future sustainable energy systems. Energy Convers. Manag. 50, 1172–1179. https://doi.org/https://doi.org/10.1016/j.enconman.2009.01.032

Ma, K., Hu, S., Yang, J., Xu, X., Guan, X., 2018. Appliances scheduling via cooperative multi-swarm PSO under day-ahead prices and photovoltaic generation. Appl. Soft Comput. J. 62, 504–513. https://doi.org/10.1016/j.asoc.2017.09.021

Manwell, J.F., Jon, G., 1993. Lead acid battery storage model for hybrid energy systems 50, 399–405.

May, G.J., Davidson, A., Monahov, B., 2018. Lead batteries for utility energy storage: A review. J. Energy Storage 15, 145–157. https://doi.org/10.1016/j.est.2017.11.008

Mazidi, P., Baltas, G.N., Eliassi, M., Rodriguez, P., 2018. A Model for Flexibility Analysis of RESS with Electric Energy Storage and Reserve, in: 7th International IEEE Conference on Renewable Energy Research and Applications, ICRERA 2018. https://doi.org/10.1109/ICRERA.2018.8566992

ME, 2020. Ministère de l'Énergie _ Algérie.

MEM, 2017. Bilan Energétique National, https://www.energy.gov.dz/Media/galerie/benational_2016_edition_2017_5dac4b0c5762d.pdf.

Men, R.L., 1979. SOLAR ENERGY MAGDENT SYSTEM. PhD Propos. 1. https://doi.org/10.1017/CBO9781107415324.004

Menanteau, P., 2007. Amélioration des performances énergétiques des équipements de froid domestique : étiquettes , normes de performances et accords volontaires. Grenoble CEDEX 9.

Ménézo, C., 2007. Energy, domotics, materials: welcome to the home of the future. CNRS Int. Mag. 5, 18_27.

Merdanoğlu, H., Yakıcı, E., Doğan, O.T., Duran, S., Karatas, M., 2020. Finding optimal schedules in a home energy management system. Electr. Power Syst. Res. 182, 106229. https://doi.org/10.1016/j.epsr.2020.106229

MeRegioMobil, 2012. KIT-Research Project MeRegioMobil - Electric Mobility in the Future Energy SystemThe Smart Home.

Mora, R., Bean, R., 2018. Thermal comfort: Designing for people. ASHRAE J. 60, 40–46.

Mouna Abarkan, M.N.K., 2018. Modélisation et Analyse du comportement d’un Batiment équipé d’un Système Multi Sources d’énergie. Aix Marseille Université et l’Université Sidi Mohamed Ben Abdellah.

Mounted, P., Vehicle, E., 2010. 1 Descriptions of Function. Group 1–15.

Moura, S.J., Fathy, H.K., Callaway, D.S., Stein, J.L., 2011. A Stochastic Optimal Control Approach for Power Management in Plug-In Hybrid Electric Vehicles. IEEE Trans. Control Syst. Technol. 19, 545–555. https://doi.org/10.1109/TCST.2010.2043736

Müller, H., Rudolf, A., Aumayr, G., 2001. Studies of distributed energy supply systems using an innovative energy management system. IEEE Power Ind. Comput. Appl. Conf. 87–90. https://doi.org/10.1109/pica.2001.932324

Muratori, M., Schuelke-Leech, B.A., Rizzoni, G., 2014. Role of residential demand response in modern electricity markets. Renew. Sustain. Energy Rev. 33, 546–553. https://doi.org/10.1016/j.rser.2014.02.027

Obayashi, F., Tokunaga, Y., 2003. A study of building energy management system based of multi agents. SICE 2003 Annu. Conf. (IEEE Cat. No.03TH8734) 2, 1526–1530.

Pallabazzer, R., 1995. Evaluation of wind-generator potentiality. Sol. Energy 55, 49–59. https://doi.org/https://doi.org/10.1016/0038-092X(95)00040-X

Patent, U.S., 2000. HORIZONTALAXIS WIND TURBINE.

Paul, A.K., Hossen, R., Sarker, B., 2014. An Approach to Demand Side Load Curtailment for the Future Intelligent and Smart Power Grid of Bangladesh.

Paul Breeze, 2018. Hydrogen Energy Storage, Power Syst. ed. Elsevier Ltd. https://doi.org/10.1016/B978-0-12-812902-9.00008-0

Pedrasa, M.A.A., Spooner, T.D., MacGill, I.F., 2010. Coordinated scheduling of residential distributed energy resources to optimize smart home energy services. IEEE Trans. Smart Grid 1, 134–143. https://doi.org/10.1109/TSG.2010.2053053

Pérez-Lombard, L., Ortiz, J., Pout, C., 2008. A review on buildings energy consumption information. Energy Build. 40, 394–398. https://doi.org/10.1016/j.enbuild.2007.03.007

Pham, T.T.H., Clastres, C., Wurtz, F., Bacha, S., Ploix, S., 2008. Mise en œuvre de l ' optimisation pour le dimensionnement et les études de faisabilité de systèmes multi-sources électriques dans le bâtiment 2008, 1–12.

Pipattanasomporn, M., Member, S., Kuzlu, M., Rahman, S., 2012. An Algorithm for Intelligent Home Energy Management and Demand Response Analysis. IEEE Trans. Smart Grid 1–8.

Pothitou, M., Hanna, R.F., Chalvatzis, K.J., 2017. ICT entertainment appliances ' impact on domestic electricity consumption. Renew. Sustain. Energy Rev. 69, 843–853. https://doi.org/10.1016/j.rser.2016.11.100

Rahman, S., Bhatnagar, R., 1986. Computerized energy management systems-why and how. J. Microcomput. Appl. 9, 261–270. https://doi.org/10.1016/0745-7138(86)90022-9

Rahmani-Andebili, M., 2017. Scheduling deferrable appliances and energy resources of a smart home applying multi-time scale stochastic model predictive control. Sustain. Cities Soc. 32, 338–347. https://doi.org/10.1016/j.scs.2017.04.006

Rastegar, M., 2018. Impacts of Residential Energy Management on Reliability of Distribution Systems Considering Customer Satisfaction Model 8950, 1–11. https://doi.org/10.1109/TPWRS.2018.2825356

René B. J. Kemna, 1999. Development of the E- Polis instrument to evaluate the country specificity: the case of wet appliances, Energy Efficiency in Household Appliances. Springer, Berlin. https://doi.org/https://doi.org/10.1007/978-3-642-60020-3_31

Riffonneau, Y., Barruel, F., Bacha, S., 2008. Problématique du stockage associé aux systèmes photovoltaïques connectés au réseau 11, 407–422.

Rim MISSAOUI, B., 2012. Gestion Énergétique optimisée pour un bâtiment intelligent validations Résumé. Université de Grenoble.

Robert A., H.D., 2004. Environnement et construction.

Romijn, R., Özkan, L., Weiland, S., Ludlage, J., Marquardt, W., 2008. A grey-box modeling approach for the reduction of nonlinear systems. J. Process Control 18, 906–914. https://doi.org/https://doi.org/10.1016/j.jprocont.2008.06.007

Ruetschi, P., 2004. Aging mechanisms and service life of lead–acid batteries. J. Power Sources 127, 33–44. https://doi.org/https://doi.org/10.1016/j.jpowsour.2003.09.052

Saint-Gobain, 2020. Visual comfort in buildings - Lighting solutions | Multi Comfort - Saint-Gobain.

Savard, G.T.C.; G.Z.; M.F.A.; G., 2012. A System Architecture for Autonomous Demand Side Load Management in Smart Buildings. IEEE Trans. Smart Grid 3, 2157–2165. https://doi.org/10.1109/TSG.2012.2217358

Setlhaolo, D., Xia, X., 2014. Optimal scheduling of household appliances incorporating appliance coordination. Energy Procedia 61, 198–202. https://doi.org/10.1016/j.egypro.2014.11.1062

Setlhaolo, D., Xia, X., Zhang, J., 2014. Optimal scheduling of household appliances for demand response. Electr. Power Syst. Res. 116, 24–28. https://doi.org/10.1016/j.epsr.2014.04.012

Shin, D., Kim, Y., Seo, J., Chang, N., Wang, Y., Pedram, M., 2011. Battery-supercapacitor hybrid system for high-rate pulsed load applications. Proc. -Design, Autom. Test Eur. DATE 875–878. https://doi.org/10.1109/date.2011.5763295

Shin, D., Kim, Y., Wang, Y., Chang, N., Pedram, M., 2012. Constant-current regulator-based battery-supercapacitor hybrid architecture for high-rate pulsed load applications. J. Power Sources 205, 516–524. https://doi.org/10.1016/j.jpowsour.2011.12.043

Shivam, K., Tzou, J.-C., Wu, S.-C., 2020. Multi-Objective Sizing Optimization of a Grid-Connected Solar–Wind Hybrid System Using Climate Classification: A Case Study of Four Locations in Southern Taiwan. Energies 13. https://doi.org/10.3390/en13102505

SIDLER, O., 1999. Maîtrise de la demande d ’ Electricité Etude expérimentale des appareils de cuisson , de froid ménager et de séchage dans 100 logements.

Son, Y.S., Pulkkinen, T., Moon, K.D., Kim, C., 2010. Home energy management system based on power line communication. IEEE Trans. Consum. Electron. 56, 1380–1386. https://doi.org/10.1109/TCE.2010.5606273

Sonelgaz, 2012. Sonalgaz press [WWW Document].

Šonský, J., Tesař, V., 2019. Design of a stabilised flywheel unit for efficient energy storage. J. Energy Storage 24, 100765. https://doi.org/10.1016/j.est.2019.100765

Steilen, M., Jo, L., 2015. Hydrogen Conversion into Electricity and Thermal Energy by Fuel Cells : Use of H 2 -Systems and Batteries 143–158. https://doi.org/10.1016/B978-0-444-62616-5.00010-3

Stum. K, Mosier. R, E.H.T., 1997. Energy management systems.

Taylor, J.A., Mathieu, J.L., Callaway, D.S., Poolla, K., 2017. Price and capacity competition in balancing markets with energy storage. Energy Syst. 8, 169–197. https://doi.org/10.1007/s12667-016-0193-9

Thavlov, A., 2008. Dynamic Optimization of Power Consumption. Technical University of Denmark.

Thounthong, P., Chunkag, V., Sethakul, P., Sikkabut, S., Pierfederici, S., Davat, B., 2011. Energy management of fuel cell/solar cell/supercapacitor hybrid power source. J. Power Sources 196, 313–324. https://doi.org/10.1016/j.jpowsour.2010.01.051

Thounthong, P., Raël, S., Davat, B., 2009. Energy management of fuel cell/battery/supercapacitor hybrid power source for vehicle applications. J. Power Sources 193, 376–385. https://doi.org/10.1016/j.jpowsour.2008.12.120

Tian, Y., Zhao, C.Y., 2013. A review of solar collectors and thermal energy storage in solar thermal applications. Appl. Energy 104, 538–553. https://doi.org/10.1016/j.apenergy.2012.11.051

Tsui, K.M., Chan, S.C., 2012. Demand response optimization for smart home scheduling under real-time pricing. IEEE Trans. Smart Grid 3, 1812–1821. https://doi.org/10.1109/TSG.2012.2218835

Vasques, T.L., Moura, P., de Almeida, A., 2019. A review on energy efficiency and demand response with focus on small and medium data centers. Energy Effic. 12, 1399–1428. https://doi.org/10.1007/s12053-018-9753-2

Vinci, S., Nigerian Electricity Regulation Commission, Ministry of Energy, Boampong, R., Phillips, M.A., Cader, C., Blechinger, P., Bertheau, P., Raisch, V., Moner-Girona, M., Ghanadan, R., Solano-Peralta, M., Kougias, I., Bódis, K., Huld, T., Szabó, S., Bhattacharyya, S.C., Palit, D., IEA, 2017. Energy Access Outlook 2017: From poverty to prosperity. Energy Procedia 94, 144. https://doi.org/10.1787/9789264285569-en

Virgone, J., Fabrizio, E., Raffenel, Y., Blanco, E., 2006. Ommande des systèmes multi - énergies pour les bâtiments à haute performance énergétique. Journée thématique SFT-IBPSA mars 2006.

Wacks, K.P., 1991. Utility Load Management Using Home Automation. IEEE Trans. Consum. Electron. 37, 168–174. https://doi.org/10.1109/30.79325

Wang, S., 2007. SUPERCAPACITOR ENERGY STORAGE TECHNOLOGY AND ITS APPLICATION IN RENEWABLE ENERGY POWER GENERATION SYSTEM, in: Proceedings of ISES Solar World Congress 2007: Solar Energy and Human Settlement.

Wang, Z., Gu, C., Li, F., Bale, P., 2013. Storage for Household Energy Management. IEEE Trans. Smart Grid 4, 1888–1897.

Warkozek, G., 2011. Génération automatique de pro blèmes d' optimisations pour la conception et la gestion des réseaux électriques des bâtiments intelligents multi-sources multi-load. Université de Grenoble.

Wayne C. Turner, W.H., 2004. ENERGY MANAGEMENT HANDBOOK, FIFTH EDIT. ed. Fairmont Press, Inc, OKLAHOMA STATE UNIVERSITY.

Wen-Chen Chu, Bin-Kwie Chen, C.-K.F., 1993. Tatung Institute of Technology Taipei, Taiwan 1525. IEEE Trans. power Syst. 8, 0–5.

Wright, A.K., Wood, D.H., 2004. The starting and low wind speed behaviour of a small horizontal axis wind turbine. J. Wind Eng. Ind. Aerodyn. 92, 1265–1279. https://doi.org/10.1016/j.jweia.2004.08.003

Yahia, Z., Pradhan, A., 2020. Multi-objective optimization of household appliance scheduling problem considering consumer preference and peak load reduction. Sustain. Cities Soc. 55, 102058. https://doi.org/10.1016/j.scs.2020.102058

Yuce, B., Rezgui, Y., Mourshed, M., 2016. ANN-GA smart appliance scheduling for optimised energy management in the domestic sector. Energy Build. 111, 311–325. https://doi.org/10.1016/j.enbuild.2015.11.017

Zhou, B., Li, W., Chan, K.W., Cao, Y., Kuang, Y., Liu, X., Wang, X., 2016. Smart home energy management systems: Concept, configurations, and scheduling strategies. Renew. Sustain. Energy Rev. 61, 30–40. https://doi.org/10.1016/j.rser.2016.03.047

Zhu, J., Lin, Y., Lei, W., Liu, Y., Tao, M., 2019. Optimal household appliances scheduling of multiple smart homes using an improved cooperative algorithm. Energy 171, 944–955. https://doi.org/10.1016/j.energy.2019.01.025

Zissis, G., 2016. Energy Consumption and Environmental and Economic Impact of Lighting : The Current Situation. Handb. Adv. Light. Technol. 1–13. https://doi.org/10.1007/978-3-319-00295-8

Zong, Y., Mihet-Popa, L., Kullmann, D., Thavlov, A., Gehrke, O., Bindner, H.W., 2012. Model predictive controller for active demand side management with PV self-consumption in an intelligent building. IEEE PES Innov. Smart Grid Technol. Conf. Eur. 1–8. https://doi.org/10.1109/ISGTEurope.2012.6465618