People's Democratic Republic of Algeria
Ministry of Higher Education and Scientific Research

National Polytechnic School
Department of Electronic
Laboratory of Communication Devices
and Photovoltaic Conversion

PhD Thesis in Electronic

Presented by:

Ismail LAIB

Entitled:

Contribution to the study on the integration of photovoltaic solar energy on the energy balance of high energy quality housing in Algeria

Members of jury:

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Supervisor:	HAMIDAT Abderrahmane	Researches Director, CDER
Co-Supervisor:	HADDADI Mourad	Professor, ENP
Examiners:	LARBES Cherif	Professor, ENP
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République Algérienne Démocratique et Populaire
Ministère de l'Enseignement Supérieur et de la Recherche Scientifique

Ecole Nationale Polytechnique
Département d'Electronique
Laboratoire des Dispositifs de Communication
et de Conversion Photovoltaïque

Thèse de Doctorat En Electronique

Option : **Electricité Solaire**

Présentée par :

LAIB Ismail

Intitulée

Contribution à l'étude de l'apport énergétique de l'intégration du solaire photovoltaïque sur le bilan énergétique de l'habitat à haute qualité énergétique en Algérie

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ENP 2018

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Acknowledgements

I would like to express my sincere appreciation to my thesis supervisor, Director of Research Abderrahmane HAMIDAT, CDER - Algiers, for guidance, motivations, patience, ideas, valuable suggestions, comments, advice, constructive criticisms and encouragement throughout the work. And also, I would like to thank Professor Mourad HADDADI, for their immense support and guidance throughout this project.

I also thank Professor AIT CHEIKH Mohamed Salah, ENP-Algiers, for accepting the chair of the jury. I sincerely thank Professor LARBES Cherif, ENP-Algiers, Professor GUESSOUM Abderrezzak, University of Blida 1 and Director of Research HADJ ARAB Amar, CDER- Algiers, for agreeing to examine this work.

I thank the "*Centre de Développement des Energies Renouvelables (CDER)*" for giving me the opportunity to contribute to a research project on the integration of photovoltaic energy into the residential building pilot of Souidania and to use the results data in my thesis and in my international publications. The project was jointly funded by the CDER and the "*Agence Thématique de Recherche en Sciences et Technologie (ATRST)*".

I am grateful to Professor Abdul Ghani Olabi for his times and support, experiences, and work we shared. at the University West of Scotland (UWS), we have passed good moments. Special thanks to Mr. Fawad Nisar Khatib and Ahmed Al Makkyy for their support.

Not forget to thank Mr. Karim Kaced for his persistent contribution and criticism towards the entire investigation. The effort other postgraduate colleagues Moussaab Bounabi and Zine Elabadine Dahmane towards the project cannot be downplayed. Thanks to my all friends at the research office for the great times and any one helped me out with the laboratory work and always sustained me big thanks.

Finally, I thank my dear parents without them I could never get there, and my wife and all my family and all my friends for their support and encouragement.

ملخص:

يعتبر معدل استهلاك المبنى للطاقة الكهربائية مرتفعا للغاية, حسبما يوضح توزيع إستهلاك الطاقة حسب القطاع. حيث يتراوح المعدل على المستوى العالمي بين 30٪ و 40٪ من اجمالي إستهلاك الطاقة. بالنسبة للجزائر ووفقا لوزارة الطاقة, يقدر هذا المعدل ب 42 ٪. تهدف الرسالة الحالية الى دمج الطاقة الشمسية الكهروضوئية في التوازن الطاقوي لسكن عالي الجودة في الجزائر. من ناحية أخرى، فإن استخدام الطاقة الشمسية يقلل من استهلاك الطاقة ويقلل من غازات الاحتباس الحراري. الهدف من هذه الرسالة هو دراسة أداء النظام الكهروضوئي المتصل بالشبكة وتوازن الطاقة في المبنى السكني. لتحقيق هذا الهد ف تم تنفيذ نموذج في Matlab-Simulink لدراسة و تحسين حجم النظام الكهروضوئي المتصلة بالشبكة مع استراتجية إدارة الطاقة للأداء العالية. وذلك وفقا للضروف الجوية السائدة, وقوة الذروة لمولد الكهرباء PV, ووجود أو غياب شبكة الكهرباء. يتم تطبيق دراسة الحالة في المنطقة الشمالية من الجزائر. يزود النظام الكهروضوئي المنزل بالكهرباء خلال الأيام المشمسة، وخلال الليل أو في الأيام الغائمة، يتم تشغيل المنزل بواسطة الشبكة. يعتمد حساب أداء الطاقة على نهج التحسين والترشيد وتوفير الطاقة. هذا يأخذ في الاعتبار معلومات عن الطاقة من المنازل السكنية والبيانات الحقيقية وظروف الأرصاد الجوية. تظهر النتائج بوضوح أن استخدام الطاقة الموفرة للطاقة والنظام الكهروضوئي المتصل بالشبكة يسمح بتوازن كهربائي سنوي إيجابي للمنزل السكني المدروس. حيث أنتج نظام PV 67.6 ٪ من إجمالي الطاقة المستخدمة في المنزل. وبالتالي يتم شراء 33.4 ٪ من الشبكة فقط. لوحظ أيضا انه يوجد توازن إيجابي في الطاقة قدره 2 كيلوواط في الساعة. من أهم الميزات التي تقدمها هذه المساهمة العلمية تكوين نظام بدون تخزين كهروكيميائية, خفض التكلفة وزيادة موثوقية النظام الكهروضوئي المتصل بشبكة الكهرباء.

الكلمات المفتاحية: الكهروضوئية؛ الكهروضوئية المتصلة بالشبكة؛ أداء الطاقة؛ توازن الطاقة؛ السكن البيو مناخي؛ تحميل ملف؛

Résumé :

La répartition de la consommation d'énergie par secteur montre que le taux de consommation du bâtiment est très élevé. A l'échelle mondiale, le taux varie entre 30 et 40%. En Algérie et selon le bilan énergétique publié par le ministère de l'Energie, le secteur résidentiel des ménages représente environ 42% de la consommation totale d'énergie. La présente thèse vise à la contribution de l'apport énergétique de l'intégration du solaire photovoltaïque sur le bilan énergétique de l'habitat à haute qualité énergétique en Algérie. D'un autre côté, l'utilisation l'énergie solaire dans la réduction de la consommation globale d'énergie et la réduction des gaz à effet de serre. L'objectif principal de cette thèse est d'étudier les performances du système photovoltaïque connecté au réseau et de dresser le bilan énergétique dans le bâtiment résidentiel. Pour atteindre cet objectif, nous avons élaboré un modèle optimisé du dimensionnement des systèmes photovoltaïques connecté au réseau avec une stratégie de gestion de la charge énergétique destinés à des maisons à haute performance énergétique dans les zones suburbaines. Ce modèle a été implémenté dans Matlab-Simulink. La méthodologie adoptée est basée sur les profils de consommation réels, les conditions météorologiques réelles, la puissance de pointe du générateur photovoltaïque, la présence et l'absence du réseau électrique. Une étude de cas est appliquée dans la région nord de l'Algérie. Le système photovoltaïque alimente la maison en électricité pendant les journées ensoleillées et pendant la nuit ou les jours nuageux, la maison est alimentée par un réseau électrique. Le calcul de la performance énergétique est basé sur l'optimisation, la rationalisation et l'économie d'énergie. Ceci prend en compte les profils énergétiques des résidences, les données réelles et les conditions météorologiques. Les résultats montrent clairement que l'utilisation d'une économie d'énergie et d'un système photovoltaïque raccordé au réseau permet un bilan électrique annuel positif. En effet, le système PV a généré 67,6% de l'énergie totale utilisée dans la maison. Seulement, 33,4% d'énergies ont été achetées sur le réseau. Un bilan énergétique positif de 2 kWh / jour a été observé. Notre contribution offre un triple avantage : un système sans stockage électrochimique, un coût réduit et une fiabilité accrue du système PV connecté au réseau électrique.

Mots Clé : Photovoltaïque; Connecté au réseau; Performance énergétique ; Bilan énergétique; Logement bioclimatique; profile de charge ;

Abstract :

The distribution of energy consumption by sector shows that the consumption rate of the building is very high. On a worldwide scale, the rate varies between 30 and 40%. In Algeria and according to the energy balance published by the Ministry of Energy, the residential household sector represents of about 42% of the total energy consumption. The present thesis aims at the Contribution to the study on the integration of photovoltaic solar energy on the energy balance of high energy quality housing in Algeria. In other hand, using solar energy in reducing overall energy consumption and reducing greenhouse gases. The main objective of this thesis is to study the performance of the grid-connected photovoltaic system and the energy balance in the residential building. To achieve this goal, a model to optimize the sizing of photovoltaic systems connected to the grid with the strategy of management of the energy load for houses with high energy performance in suburban areas. The recommended model has been implemented in Matlab-Simulink, the methodology adopted is based on actual consumption profiles, actual weather conditions, the peak power of the PV generator, the presence and absence of the power grid. A case study is applied in the northern region of Algeria. The photovoltaic system supplies the house with electricity during the sunny days, and during the night or the cloudy-days, the house is powered by grid. The calculation of energy performance is based on the optimization, rationalization and saving energy approach. This takes into account the energy profiles of residential homes, real data and meteorological conditions. The results show clearly that the use of saving energy and grid-connected photovoltaic system allows a positive annual electricity balance of the studied residential house. The PV system generated 67.6% of the overall energy used in the house. Only, 33.4% are purchased from the grid. An energy positive balance of 2 kWh/day is observed. Our contribution offers a triple advantage, system without electrochemical storage and reduced cost, increased reliability of the PV system connected to the electricity grid.

Keywords: Photovoltaic; Grid-connected; Energy performance; Energy balance; Bioclimatic housing; load profile

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Acronyms

HEP	High Energy Performance	
HEQH	High Energy Quality housing	
RH	Reference House	
EEMs	Energy Efficiency Measures	
PV	Photovoltaic	
CSP	Concentrated solar power	
GHG	Greenhouse Gas	
SEGS	solar energy generating systems	
GCPVS	Grid-Connected Photovoltaic System	
APRUE	Agence de la Promotion et de la Rationalisation de l’Utilisation de l’Energie	
AC	Alternative Current	
DC	Direct Current	
MED-ENEC	energy efficiency in the construction sector of the Mediterranean	
MEM	Ministère de l’Energie et des Mines	
Toe	Tonne of oil equivalent	
IEA	International Energy Agency	
FF	Fossil Fuels	
RES	Renewable energy system	
MPPT	Maximum Power Point Tracking	
MLI	Multilevel Inverter	
3L-VSI	Three-Level Voltage Source Inverter	
Solar radiation		
β	Angle of inclination of the PV generator	(°)
θs	Solar incidence angle	(°)
θz	Zenith angle	(°)
G (β)	Global radiation on tilted surface	(kJ/hr.m^2)
B (β)	Direct radiation on tilted surface	(kJ/hr.m^2)
D (β)	Diffuse radiation on tilted surface	(kJ/hr.m^2)
R (β)	Reflected radiation on tilted surface	(kJ/hr.m^2)
Photovoltaic system		
Iph	Photo-current (current source)	[A]
Rs	Resistance series of the module	[Ω]
Rsh	Shunt resistance of the module	[Ω]
Rc	load resistor	[Ω]
Ish	Shunt current	[A]
Iph, ref	Short-circuit current in reference conditions	[A]
G	Solar irradiance	[W / m^2]
Gref	Solar irradiance under reference conditions	[W / m^2]
$\mu_{I,\ sc}$	Temperature coefficient of the short-circuit current	[A / ° K]

T	Operating temperature of the cell	[° K]
Tref	Operating temperature in reference conditions	[° K]
Isat	Saturation current of the diode	[A]
Vth	Thermal residual voltage	[V]
n	number of Ideal diode factor of the solar cell	
Isat, ref	Diode current in reverse under reference conditions	[A]
Eg	Semiconductor gap energy band	[V]
P_{ac}	ac-power output from inverter based on input power and voltage	(W)
P_{dc}	dc-power input to inverter, typically assumed to be equal to the PV array maximum power	(W)
V_{d}	dc-voltage input, typically assumed to be equal to the PV array maximum power voltage	(V)
P_{aco}	maximum ac-power "rating" for inverter at reference or nominal operating condition, assumed to be an upper limit value	(W)
P_{dco}	dc-power level at which the ac-power rating is achieved at the reference operating condition	(W)
V_{dco}	dc-voltage level at which the ac-power rating is achieved at the reference operating condition	(V)
P_{so}	dc-power required to start the inversion process, or self-consumption by inverter, strongly influences inverter efficiency at low power levels	(W)
P_{nt}	ac-power consumed by inverter at night (night tare) to maintain circuitry required to sense PV array voltage	(W)
Co	parameter defining the curvature (parabolic) of the relationship between ac-power and dc-power at the reference operating condition, default value of zero gives a linear relationship	(1/W)
C1	empirical coefficient allowing Pdco to vary linearly with dc-voltage input, default value is zero	(1/V)
C2	empirical coefficient allowing Pso to vary linearly with dc-voltage input, default value is zero	(1/V)
C3	empirical coefficient allowing Co to vary linearly with dc-voltage input, default value is zero	(1/V)
P_{PV}	Power produced by the PV system	kW
$P_{Grid\_purchese}$	Power purchased from the utility grid	kW
P_{Grid_sale}	Power injected into the electricity grid	kW
P_{load}	Power consumption by the home	kW

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General Introduction

General Introduction

Energy is indispensable for the wellbeing and for the improvement of the living conditions of the human being. Health, education, food and transportation are closely linked to the availability of energy and mainly, electrical energy [1, 2].

Today, solar energy and in particular photovoltaic systems are currently experiencing strong global growth (+ 16.9% of the photovoltaic power installed in the world in 2015 compared to 2014) and are expected to represent a share of the future energy mix in the space of a few decades, various approaches exist to analyse installed solar PV world capacity [3] and share of grid-connected PV system [4]. Fig. 1 shows the evolution of photovoltaic power installed at the global level expresses a strong growth of the market since the beginning of the decade.

Currently, there are several configurations of Photovoltaic systems in use, grid-connected PV systems (On-grid) and stand-alone Photovoltaic systems (Off-grid) [5, 6].

The installation capacity for off-grid cannot be compared to the grid-connected, as the rapid development of grid-connected PV eliminates the off-grid [7-9]. The share of the photovoltaic configuration in the world, 2010-2015, is given in following illustrations. In Fig. 2 is shown the share of grid-connected and off-grid. The share of off-grid and centralized/decentralized grid-connected PV is shown in Fig. 3.

The resolutions of the Conferences of the Parties (COP) have allowed many countries to consider solar energy as a key element of their future energy mix and sustainable development agenda. It is therefore often subsidized by the State, thus constituting a cost-effective alternative to the use of fossil fuels.

The use of mixed energy represents one of the solutions for sustainable energy that must be developed to increase the electrical production of renewable energies [10]. For example, solar energy is very abundant since the irradiation that the sun sends to earth represents more than 10,000 times the current world primary energy consumption [11, 12]**.**

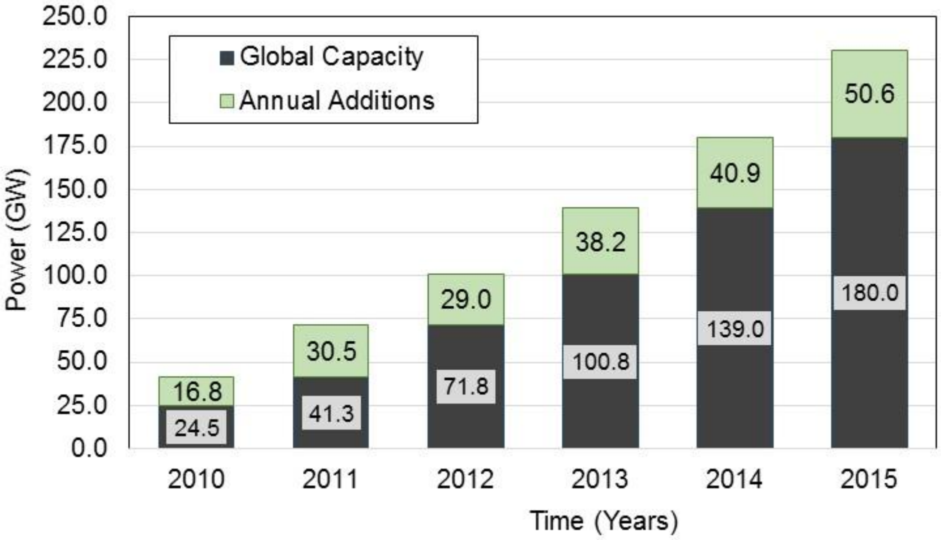


Fig.1 Solar PV global Capacity and Annual Additions, 2010-2015

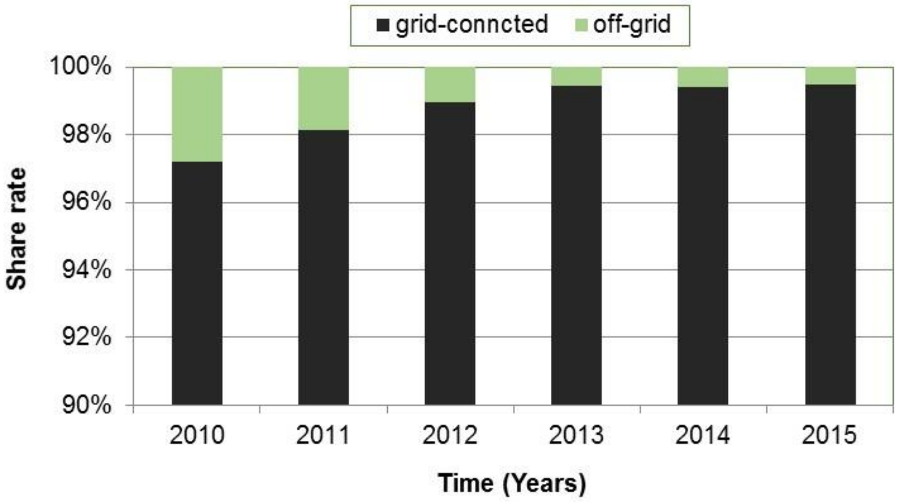


Fig.2 Share of grid-connected and off-grid in the world, 2010-2015

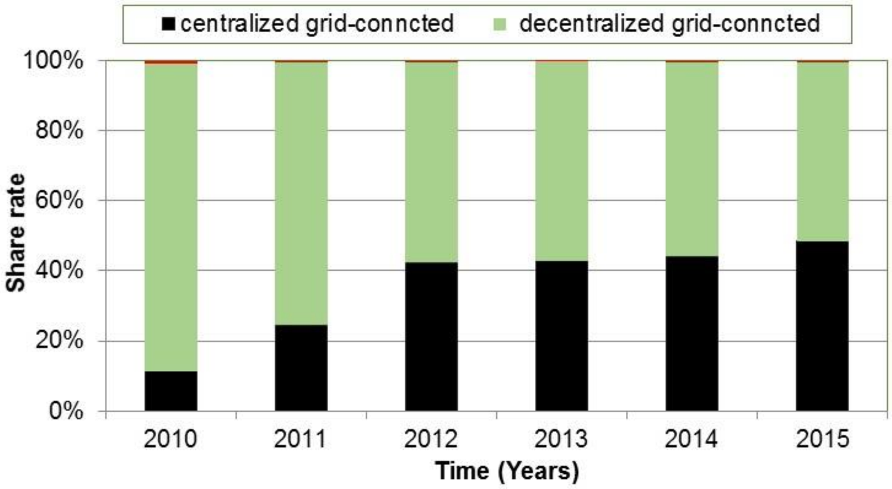


Fig.3 Share of centralized and decentralized grid-connected PV in the world, 2010-2015

The integration of photovoltaic system into the building can enable self-production of electricity. At the same time, the system can help the electricity-grid by injecting the extra photovoltaic electricity produced, especially during hot and sunny periods. Because, during these periods the electrical demand is the highest, due to the use of air conditioning [13, 14]. This will also help in reducing the climate and environmental impacts. However, for the feasibility of a PV system, there should be enough solar energy throughout the year. Algeria is one of many countries that have a high solar energy resource [15, 16]**.**

The techniques developed up till now, depending on the place of use and the power requirements; offer the possibility of combining several energies production systems [17]. The idea of embedded generation has the advantage of not only supplying electricity from renewable energy and the grid, but exporting the generated energy to the grid [18]. For example, the photovoltaic (PV) system can be used for a local grid in an urban environment to supply housing, and in the event of surplus energy, the excess energy can be injected into the grid.

In Algeria, the energy consumption in building sector is one of the consuming energy sectors. So, it is responsible of 42% of the final energy consumption, with 35% in the residential building and 6% in the tertiary building [19]. The rate of energy consumption in the building sector is growing rapidly for several reasons: (a) low cost of conventional energy (government-subsidized energy), (b) substantial increase of population and housing stock, (c) increase number of electrical equipment in each house, (d) use of non-economic electrical equipment such as incandescent lamps and very cheap air conditioners, (e) absence of awareness and lack of culture on the energy saving [20-23]**.**

Thesis Motivation

The main motivations for this thesis are summarized as follows:

- The National Renewable Energy Development Program, adopted in 2011, was revised in 2015 with the aim of achieving, by 2030, a production of 22,000 MW dedicated to local consumption alone, of which more than 4,000 KW will be realized, now until 2020. This program plans to implement a wide range of technological sectors, including the photovoltaic sector and the wind power sector.
- Large national housing projects are interested in high-performance housing. This construction project involves 600 high-quality housing which was launched in 11

states in the country. This project will reduce household energy consumption by almost 40%.

- Several advantages in applying grid-connected PV systems on residential buildings were found, some of these are the operational hours of office building coincide with the peak power production time of PV systems, and they do not require additional land use, since the building surface is used to accommodate PV modules on the roof. Also, the educational benefits that comes with owning buildings with PV system raises the awareness of habitats about RE and energy efficiency issues, where the presented study would be useful and applicable for planning rooftop grid-connected PV installations in any other geographical location in Algeria.

Objectives of the thesis

The main objective of this study is to determine the energy performance of the use of photovoltaic energy in residential housing. A case study was conducted using a grid-connected photovoltaic system installed in a bioclimatic housing in a suburban environment. The main objectives of the presented thesis are list as follows:

- Study the optimization of electrical energy consumption in a home and an approach to studying the performance energy was conducted in this thesis with a evaluate the contribution of solar photovoltaic energy in the energy balance of the habitat.
- Experimental study was conducted on a bioclimatic house located in Algiers in order to study the contribution of the PV system connected to the grid in the improvement of the indoor comfort of the bioclimatic house. Also, validation of the main components of the grid-connected PV system model.
- An approach for the optimum design of rooftop grid-connected PV system is presented based on optimal configuration of PV modules and inverters according to not only MPP voltage range but also maximum DC input current of the inverter, for each configuration using MATLAB computer program.
- The dynamic behavior of a MATLAB/Simulink model for a grid-connected PV system has been studied under different irradiance conditions.

Thesis contributions

In this thesis, we have interested in the calculation of energy performance, which is based on the optimization, rationalization and saving energy approach. This method takes into account the energy profiles of residential homes, real data, and meteorological conditions. The main contributions of this thesis can be listed as follows:

- Grid-connected photovoltaic system integrated into a residential house is studied under Mediterranean climate conditions.
- The calculation of energy performance is based on optimized energy consumption profiles and real meteorological data.
- Annual simulations analysis shows high system performance and the optimized PV system generates a positive balance of energy.
- Proposals for future works are summarized. In the Grid Connected PV system, there is a great need of designing the control system that could control the designed inverter power for the smart grid. The control would ensure the integrating the inverter with other renewable energy sources available.

Methodology and thesis structure

To achieve the above objectives, the present thesis is organized in five chapters, two appendices in addition to a list of references. The chapters are summarized as follows:

Chapter One:

The main aim of this chapter is to present the energy situation and achievements state of photovoltaic systems in Algeria. First, the primary energy situation then the electric energy situation in the word and in Algeria. Secondly discusses renewable energies availability and potential in Algeria especially solar energy resource. Finally, Legal aspects and National Program for renewable energy and energy efficiency. afterward, state Photovoltaic systems installed in Algeria.

Chapter Two:

Presents the High-Quality Energy Housing, and analyzes Algerian context in terms of HQE housing. Then, this chapter sets out some basics of integrating solar energy in the residential sector. We focus on the architectural design of the house for the energy requirements reduction and the application of active solar systems for energy supply, ends with a presentation of the only HQE housing in Algeria of Souidania.

Chapter Three:

First of this chapter is to start by the literature review of the research efforts in the areas of the classification of grid-connected PV systems, power quality improvement of grid-connected PV systems, and application in the residential building. Secondly, this chapter presents a Grid-Connected Photovoltaic chain are demonstrated and the development of rooftop PV technologies are discussed. Then, an overview of PV systems is presented. Finally, the international Codes and Standards for Grid-Connected PV system are introduced.

Chapter Four:

This chapter is concerned of Methodology and Modelling of Rooftop Grid-Connected PV system. Firstly, the system structure and the modeling techniques of each part of the grid-connected PV system have been discussed, mathematical description of the different components. Then, a grid-connected PV system was modelled in order to meet electrical energy loads of the house. Finally, Modelling of the inverter.

Chapter Five:

This chapter presents a description of the residential house study with a detailed model of first-phase rooftop grid-connected PV system is investigated. Secondly, presents a simulation study in steady-state conditions for the grid-connected PV system proposed. MATLAB/Simulink model for the grid-connected PV system proposed. Lastly, results and discussion grid-connected PV system proposed. Finally, a general conclusion and suggestions for future works are provided.

Chapter 1

Energy situation

Chapter 1:

Energy situation

1.1 INTRODUCTION

The building sector, which ranks first in terms of electricity consumption for fossil fuels, is a key sector because it allows for an influence on demand, also a diagnosis of the current state of this sector shows that the importation of urban and architectural models not adapted to the Algerian climate and the intense use of mechanical means of thermal regulation led to an abuse in energy consumption. Additionally, encouraged by the subsidy policy of electricity and gas implemented in Algeria since 1962, the national energy needs reached 55.9 Million tons oil equivalent (MTOE) in 2015, representing an increase of 7.8% as compared to 2013 [3]. Statistics expect energy consumption to increase at about annual growth are of about 3.5% [24]. However, the economy of Algeria heavily depends on hydrocarbons export (oil and natural gas) and the current fall in oil prices caused an economic crisis, which prompted the government to review its energy policy.

Present reserves of oil and natural gas can only cover consumption at this rate for the next 50 years in the case of oil, and for the next 70 years in the case of natural gas. Therefore, one of the fundamental priorities for a country such as Algeria is to use several renewable energies (RE) sources and environmentally friendly energy conversion technologies [25]. Algeria is endowed with large reserves of energy sources, mainly hydrocarbons and a considerable potential for the utilisation of RE sources especially with respect to solar energy. Algeria has the potential to be one of the major contributors in solar energy and become a role model to other countries in the world. RE are now one of the major elements of Algeria's energy policy and in view of boosting the national effort in terms of RE beyond 2011, Algeria has developed a national programme for the period 2011–2030 to promote concrete actions in the fields of energy efficiency and RE in line with the approach adopted by the government.

The main aim of this chapter is to presents an analysis of world and Algeria’s energy contexts, and renewable energies availability and potential in Algeria and their applications of research work done in these theses. First, the chapter discusses the energy situation in Algeria and discusses renewable energies availability and potential in Algeria regarding their

Renewable Energy Sources, especially solar energy resource. Secondly, Renewable energies program and applications in Algeria are demonstrated and developments discussed. Then, a state photovoltaic system installed in Algeria are presented. Finally, the research motivation, objectives, and theses outlines are introduced.

1.2 FOSSIL ENERGIES

1.2.1 Primary energy

Algeria’s primary energy sources include oil, natural gas, electric power, with the remainder either being oil or hydroelectric, this latter constitute a very small proportion in the balance of energy; because of the lack of availability of watersheds necessary to generate electricity. Oil and natural gas are the major source of primary energy in Algeria with about 99.8 % in 2016 according to national office statistics, its economy is heavily relying on the hydrocarbons Sector.

A) Oil: According to British petroleum data, Algeria had 0.7% of the total of the oil proved reserves the end of 2016, that place the country in the largest fourth position in Africa, and the tenth position in OPEC countries. where the extraction was hold onshore, since there had been limited offshore exploration. The government recently approved amendments of Algeria's hydrocarbon law that included fiscal incentives for foreign companies to invest in untapped exploration areas, in particularly the offshore, and in areas believed to contain unconventional resources [26]. Oil consumption has been increasing rapidly as the economy and population grow (about 7% per year). Fossil fuel consumption subsidies are most prevalent in Algeria around 50.7% [27]. Energy price subsidies causes an inefficiency, distortions in the market and the result is an over-consumption of energy, that discourages investment in renewable energy which encourages widely smuggling. In addition, a substantial amount of petroleum products is also smuggled to neighbor-countries, because they are much cheaper. the consumption trend is expected to continue in an unsustainable manner.

B) Natural Gas: There is an impressive amount of reserves of natural gas in Algeria. The known reserves are about 2.4% of the world’s total proven reserves. Therefore, Algeria has a huge potential for gas industry development and could be a major natural gas exporter as well. The average of gross annual production has been around 9,8% since the nationalization.

The Production has steadily declined since 2005 as the countries large and mature fields have been depleted. There is a host of new projects planned to come on line, but they have repeatedly been delayed, where some of them depend on the construction of new infrastructure [27]. The expansion of the distribution system of natural gas and the networks of transportation, under the programs of public distribution, is one of the major policies for sustainable development in the country. The pipeline distribution system for domestic and industrial uses has been extended to 1476 localities against 13 in 1962 [28]. In 2015, the natural gas counts 62.4% of Algeria’s total energy consumption and the government plans to replace the consumption of oil products by natural gas in household and industrial sectors in the coming years.

1.2.1.1 Production and consumption of Oil and Natural gas

According to the latest edition of the "Statistical Review of World Energy" on the production and consumption of oil and gas, published by the British group British Petroleum [29], Algeria ranks third in oil consuming countries in Africa. Advanced by Egypt and South Africa, Algeria consumed, on average in 2016, no less than 412,000 barrels / day [30]. Algeria produces nearly 11.5 million tons (Mton) of fuel per year, while the volume of consumption has reached 15 Mton, the difference of about 3.5 Mton being imported with an invoice exceeding 1 billion USD a year.

At the data British group British Petroleum in 2016 [29], we are illustrated the evaluation oil and natural gas production/consumption in Algeria, as shown in (Figure 1.1) and (Figure 1.2) Algeria is the leading natural gas producer at 82.2 Million tons oil equivalent (MTOE) and among the top three oil producers at 68.5 MTOE. Besides, it is the second-largest natural gas supplier to Europe. However, natural gas and oil production have gradually declined in recent years after 2005. As well, Algerian data on natural gas consumption are updated every year, with an average of 1.90 Mton/day from December 1965 to 2016, with 52 observations. Consumption of natural gas was estimated at 35 MTOE in December 2016, an increase compared to the previous five years of 20 MTOE in December 2010.

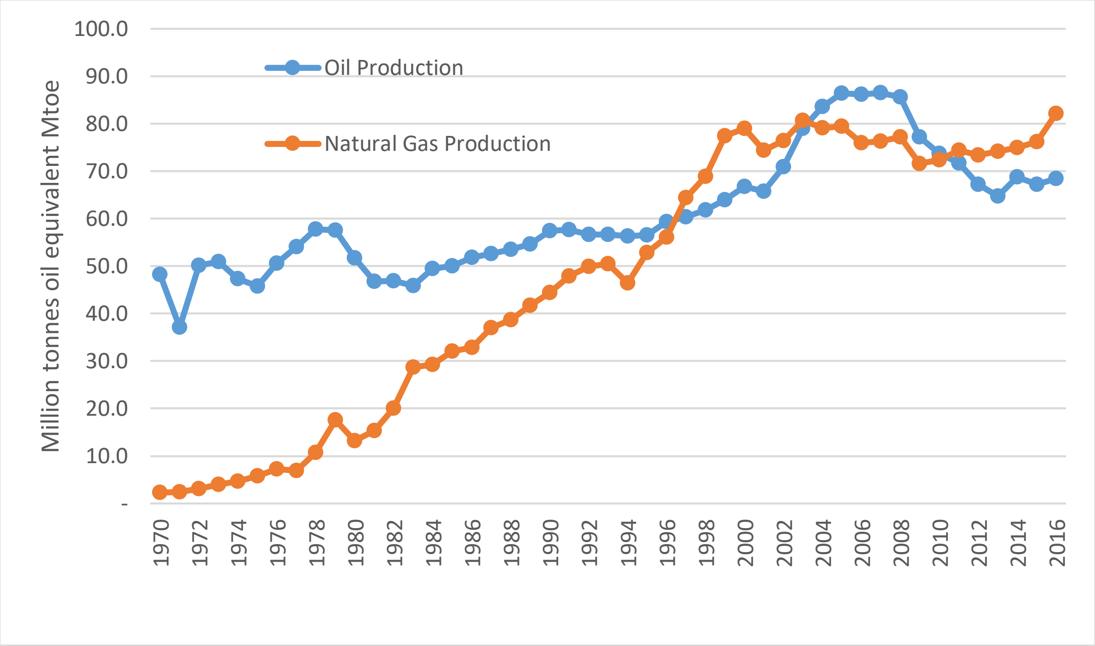


Fig. 1.1 Oil and natural gas production in Algeria

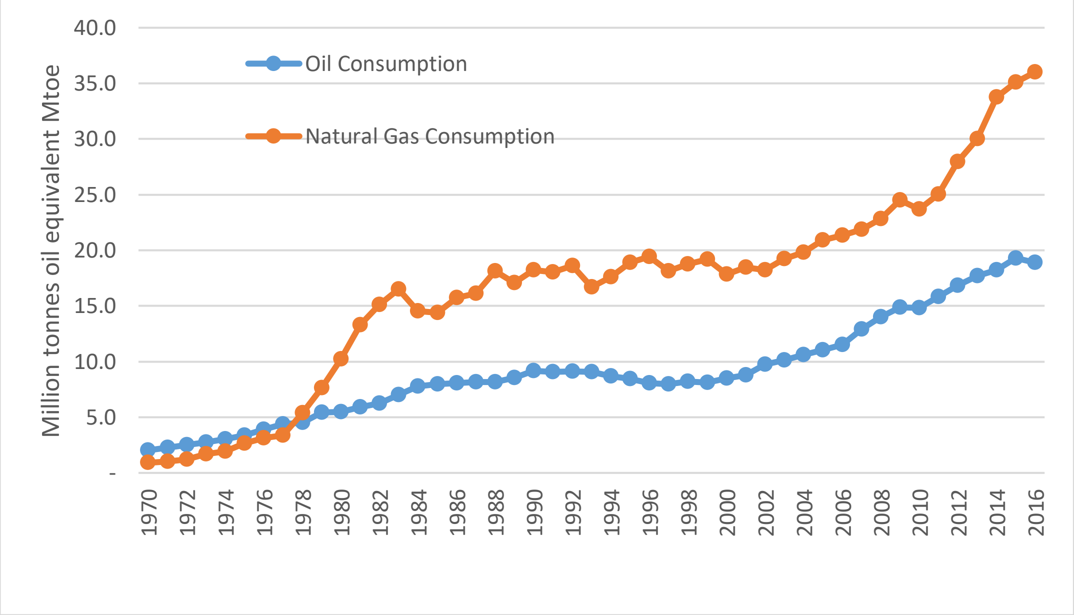


Fig. 1.2 Oil and natural gas consumption in Algeria

1.2.1.2 Evolution of demand

Energy plays a vital role in the economic and social development and in improving the quality of life. Much of the world's energy, however, is produced and consumed in a way that would not be viable in the long term if the technology did not evolve and the total quantities had to rise considerably.

In recent years, a great deal of research has been carried out with the objective of managing and controlling energy demand in all fields. To better understand the need for energy management, this study recalls Algerian energy context with particular attention to electrical energy. Algeria's total final consumption has steadily been increasing in recent years, with a significant rise between 2005 and 2016. Fig.1.3 shows the evolution of energy Production and domestic consumption of hydrocarbons in Algeria [29].

The evolution of energy consumption by category of sources. Like the national production, the petroleum products are the major source of energy in Algeria, followed by electricity and natural gas. According to MEM statistics for energy balance for 2016 [28], the total final energy use accounts for 55 MTOE. Oil and gas remain the main energy consumed by final consumers in Algeria. Conversely, renewable energies represent barely 0.1% of final consumption in Algeria. However, this figure is underestimated because of the lack of general awareness about renewable energies (see Table.1.1). Indeed, there is a figure of renewable energy consumption "officially" represents only a small part of the total energy consumption. Given the current distribution of energy consumption by sector of activity, 44% of Algeria's energy consumption is for the building sector. This is all the more worrying in view of the growth in the number of housing stock that is increasing year by year. According to the latest statistics, the latter has increased by more than two million dwellings during the last decade (see Table 1.2). The social progress and the increase in the quality of life of the Algerians were accompanied by an increase in the demands on the level of thermal comfort inside the houses [19]. Algeria has important potential from the point of view of proven natural gas and oil reserves, 12.2 thousand million barrels of oil and 4.5 trillion cubic meters of natural gas at the end of 2015. An analysis of Algeria's energy balance shows that the country's energy exports of petroleum and natural gas fell from 140 MTOE in 2010 to 150 MTOE in 2016. This downward trend is related to a drop in Production, but mainly to the increase in national consumption, which rose from 38.9 MTOE in 2010 to 54.6 MTOE in 2016 Figure 1.3 [29].

In this year, Algeria produced approximately 68.5 MTOE crude oil, of and 82.2 MTOE of natural gas. Algeria is one of the leading producers and exporter of oil and natural gas in the world. It is the fourth largest oil crude producer in Africa, and the sixth largest natural gas producer in the world [31]. Fig.1.3 shows the evolution of primary and derived energy production between 2005 and 2016 in Algeria.

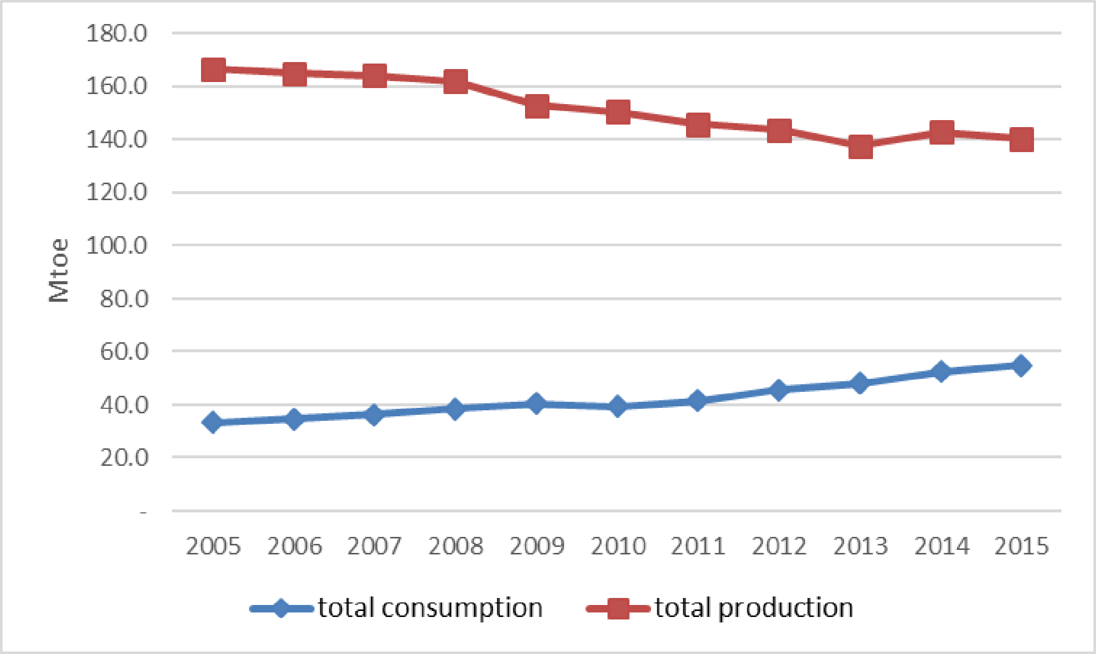


Fig.1.3 Production and domestic consumption of hydrocarbons in Algeria

Table 1.1

Algeria's energy consumption by source in 2015

Energy by source	Energy consumption (MTOE)		
	2005	2010	2015
Oil	11.034	14.835	19.302
Natural Gas	20.904	23.683	35.118
Coal	0.594	0.310	0.179
Nuclear	0.000	0.000	0.000
Hydroelectricity	0.126	0.039	0.033
Renewables	0.000	0.002	0.018
total consumption	32.6583	38.8688	54.6495

Table 1.2

Evolution of the Algerian housing stock

Year	1999	2008	2013	2015
Number of housings	5855584	6686124	7755584	8852378

1.2.2 Electric energy

Electricity plays a vital role in the economic and social development and in improving the quality of life. Much of the world's electricity, however, is produced and consumed in a way that would not be viable in the long term if the technology did not evolve and the total quantities had to rise considerably.

In recent years, a great deal of research has been carried out with the objective of managing and controlling electricity demand in all fields. To better understand the need for energy management, this study recalls the global and Algerian energy context with particular attention to electrical energy.

1.2.2.1 Electricity demand and supply in the world

Today electricity is used to generate any kind of artificial lighting, to heat and cool buildings, to run our information communication technology, to propel trains and buses, to supply factory machinery with reliable and inexpensive energy, to create entirely new industries, and to perform a variety of other useful achievements that make our life cleaner, easier, more secure and enjoyable. In the future, electricity is also expected to power millions of personal vehicles. There are indeed good reasons to believe that we are going towards an electricity-based economy.

Electricity, however, is not a primary form of energy. Currently, fossil fuels cover more than 80% of the energy used by mankind and most of the electricity is produced starting from this primary energy as show in Figure 1.4 [29]. Harnessing coal, oil and gas, the energy resources contained in the storage of our spaceship Earth, have been very convenient, but now we know that this entails severe consequences. As well, electricity represents about 40% of the primary energy consumption and less than 20% of the final energy demand from Figure 1.5 [29]. Electricity production was rising steadily at an average rate of 3% per year from 2000 to 2015, but only by 1.3% in 2008 and decreased in 2009 due to the economic crisis.

According to the estimation done by the International Energy Agency (IEA) [32], a 53% increase in global electricity consumption is foreseen by 2030, energy security is becoming a serious issue as fossil fuels are non-RE and will deplete eventually in near future. In addition, the world's oil resources will peak within a few decades to come (80 years at the most). The share of global electricity consumption in 2015 Fossil Fuels (FF) dominate with nuclear and hydro making up most of the rest. In 2015 FF had 86% share the same as in 2010.

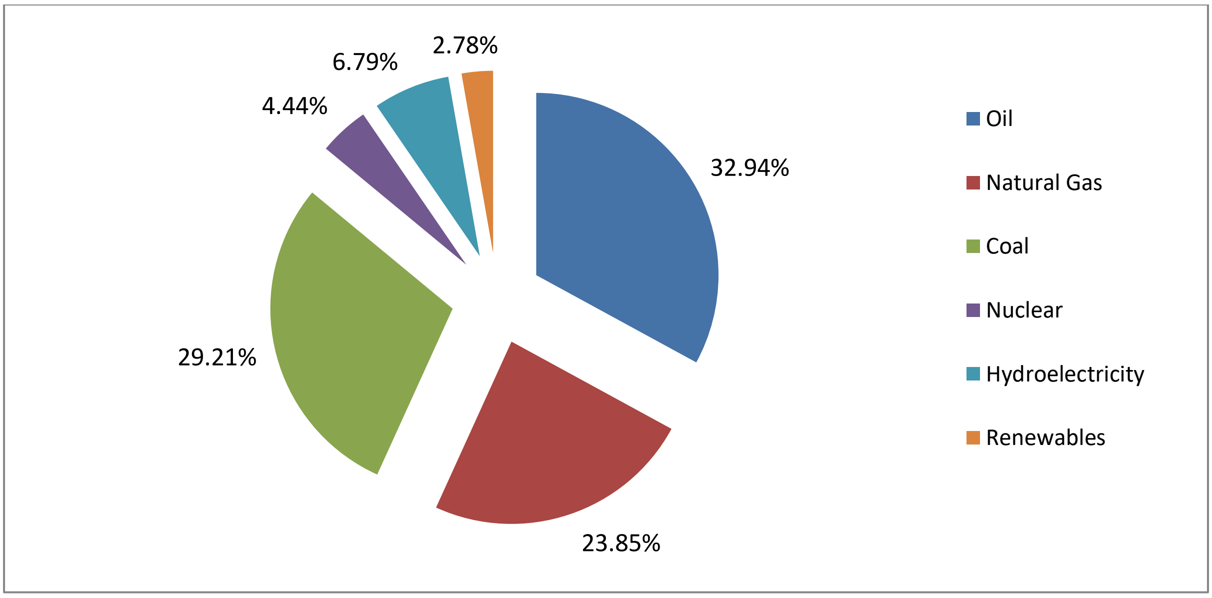


Figure 1.4 World total electricity generation by source in 2015

Electricity can be generated by using a variety of primary energy sources and technologies and more than 60% of the production is obtained by burning fossil fuels (Fig. 1.4). The amount of electricity generated and the per capita consumption of the top ten energy consuming countries are collected in Table 1.3 [33].

Table 1.3: Population, primary energy and electricity consumption, and CO2 emissions from the top 10 world energy consumers. In 2010

		Primary energy	Electric energy consumption	CO2 emission
Country	Populationa	Total (MTOE)	Total (TWh)	Total (MT)
U.S.	309 045 000	2 286	3 906	5 425
China	1 330 415 000	2 432	3 017	7 711
Russia	148 357 000	691	858	1 572
India	1 172 707 000	524	601	1 602
Japan	126 810 000	501	964	1 098
Canada	33 760 000	317	549	541
Germany	81 651 000	320	544	766
France	64 768 000	252	461	397
S Korea	48 636 000	255	402	528
Brazil	201 029 000	254	420	420
Ethiopia	88 013 000	2.8	3.4	6.9
World	6 850 685 000	12 002	17 445	30 398.4

The demand for electricity fluctuates widely from summer to winter, from working day to holiday, and throughout the day from hour to hour and even minute to minute (see figure1.5). The seasonal fluctuations differ from country to country. In Northern Europe, the peak demand is in winter for lighting and heating. In warmer regions, e.g. Southern Europe and Southern US, the peak demand is in summer for air conditioning. The fluctuating demand represents a big problem for power utilities because the grid cannot store electricity. Usually, this problem is solved by using different types of generators, considering the cost as well as other parameters.

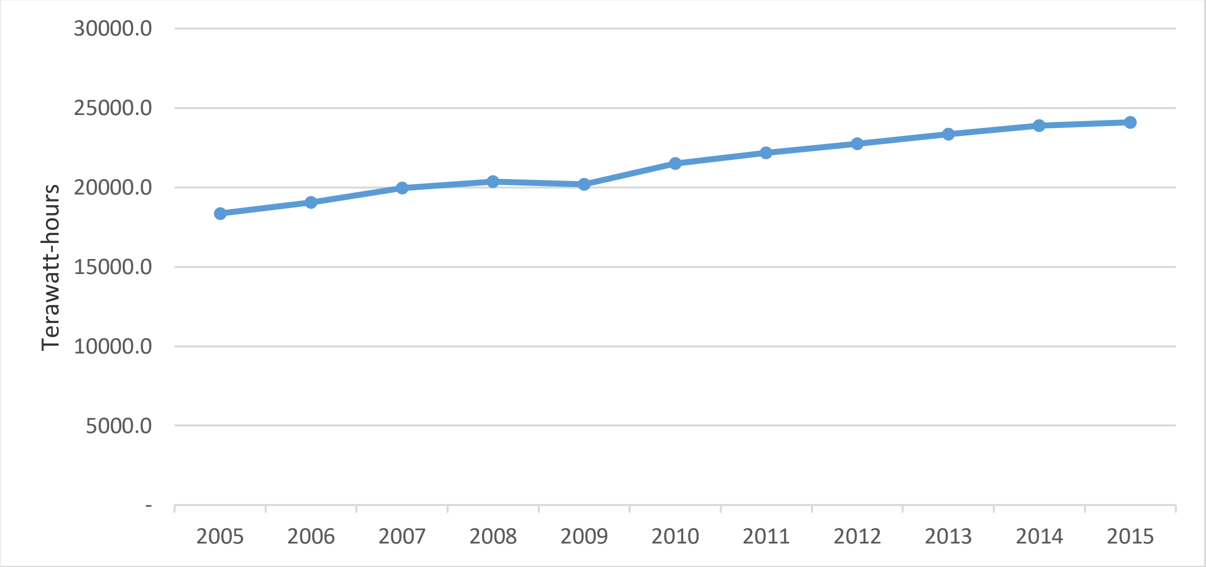


Figure 1.5 World total net electricity generation

The global contribution from buildings towards energy consumption, both residential and commercial, has steadily increased reaching figures between 20% and 40% in developed countries, and has exceeded the other major sectors: industrial and transportation. Growth in population, increasing demand for building services and comfort levels, together with the rise in time spent inside buildings, assure the upward trend in energy demand will continue in the future [34].

The distribution of final consumption between different sectors is presented in Figure 1.6 [29]. Between 2012 and 2014, the total final consumption more increasing. Energy consumption by the different sectors of the economy has not changed dramatically. In 2014, the industry remained the most consumer sector, followed by the transport sector (28%). On the other hand, the share of the residential sector represents a large part of the energy consumption at 23%, showing a steady progression over several years.

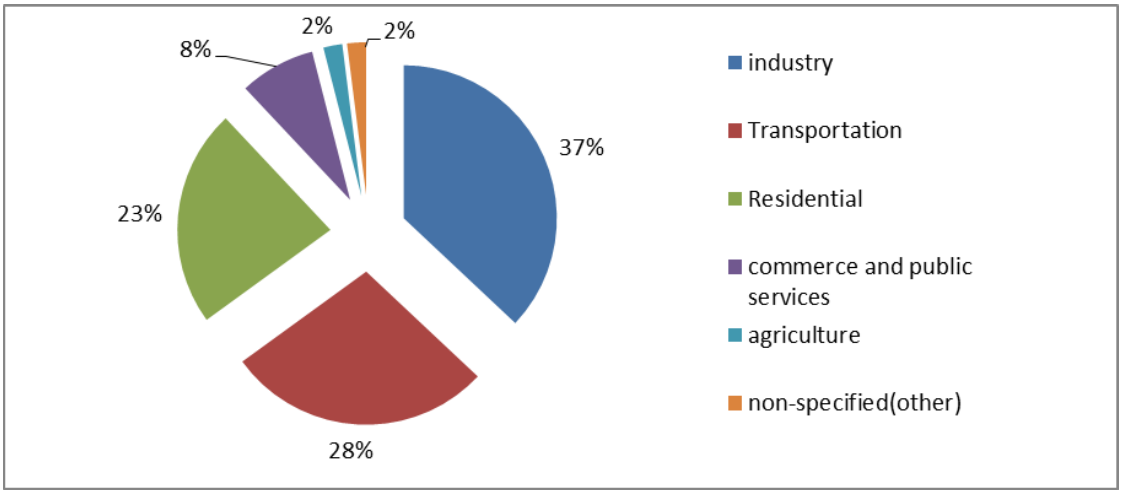


Figure 1.6: World electricity consumption between different sectors in 2014

1.2.2.2 State of electric power in Algeria

The Algerian electricity system is composed of many generation sources, such as gas, oil, solar, wind and other renewable sources. However, about 98% of Algeria's electricity generation rests on fossil fuel sources. Especially, over 92.4% of the Algerian electricity production are derived from natural gas and 6.5% from oil. The Algerian Ministry of Energy and Mines has set ambitious goals for electricity generation, aiming to generate 40% from renewable sources by 2030 [35]. The electricity market is almost entirely held by the national company SONELGAZ, which manages the electricity system and provides local electricity and gas distribution. Coverage of the country by the power grid is at 98% (34% in 1970) with capacity of 11.325 MW through 2009. This grid has over 6.5 million customers. Since 1995, electricity generation increased considerably in Algeria (as shown in Fig. 1.7). According to SONELGAZ, the country's public utility in charge of electricity generation and distribution, Algeria's electricity generation capacity reached 15.2 GW at the of 2015, up from 12.9 GW at the end of 2013 and 11.4 GW at the end of 2012.

The price of electricity in Algeria is one of the lowest prices in the Middle East and North Africa region (MENA), especially for residential customers, it was fixed to 2.2 dinar/kWh (equivalent to 0.027 $/kWh) in 2005 [28].

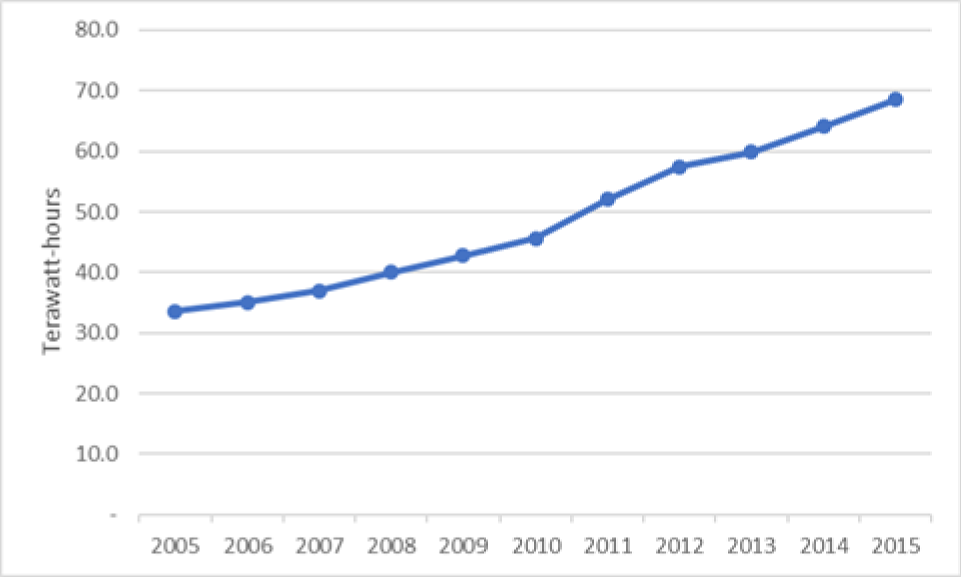


Fig 1.7: electricity generation in Algeria

The production of electricity is in progress, where 17% produced by steam-powered units, 31% by gas turbines, 49% by combined cycles, 1% by hydroelectricity, 2% by hybrid power plants, and 1% by diesel [26]. The park of electricity production was strengthening in 2015 by putting in service a capacity of 1470 MW, and require more additional capacity mainly gas turbines and diesel groups To face the considerable evolution of the demand 8,5%.

During the previous years, Algeria's electricity demand has been increasing rapidly, mainly due to expansion of economic activities and population growth. Net electricity consumption was 45 billion kilowatt hours in Algeria in 2015, is expected to average about 75–80 billion kilowatt hours in 2020 and 130–150 billion kilowatt hours in 2030. From 2008–2015, Algeria's electricity consumption has increased by an annual average of roughly 8% [36]. This underlines the importance of electricity consumption as a crucial component of the economic growth for Algeria [37]. Electricity consumption is divided into three main strands: the Industry Construction & Public Works (I.CPW); Transport (Tr); Residential and others including agriculture (R). In Fig. 1.8 is shown the distribution of the energy consumption in different sectors in 2015 [28]. The residential sector accounted for 36 % of all final energy used in Algeria and was the second largest energy-using sector, after the transport sector 41%. The agriculture and industrial sectors account for respectively 3% and 15%.

Electricity consumption during the 2010–2015 period is fast increasing for the three sectors. In figure 1.9 [19], which represents the evolution of energy consumption in residential sector, electricity consumption is increasing too fast, from 8.320 ktoe in 2010 to

12.730 ktoe in 2015, we can notice that the energy consumption in this sector is in constant growing with an increase of 65.26%. According to the WBG (2015), in 2011 per capita consumption reached 1091 kWh per person.

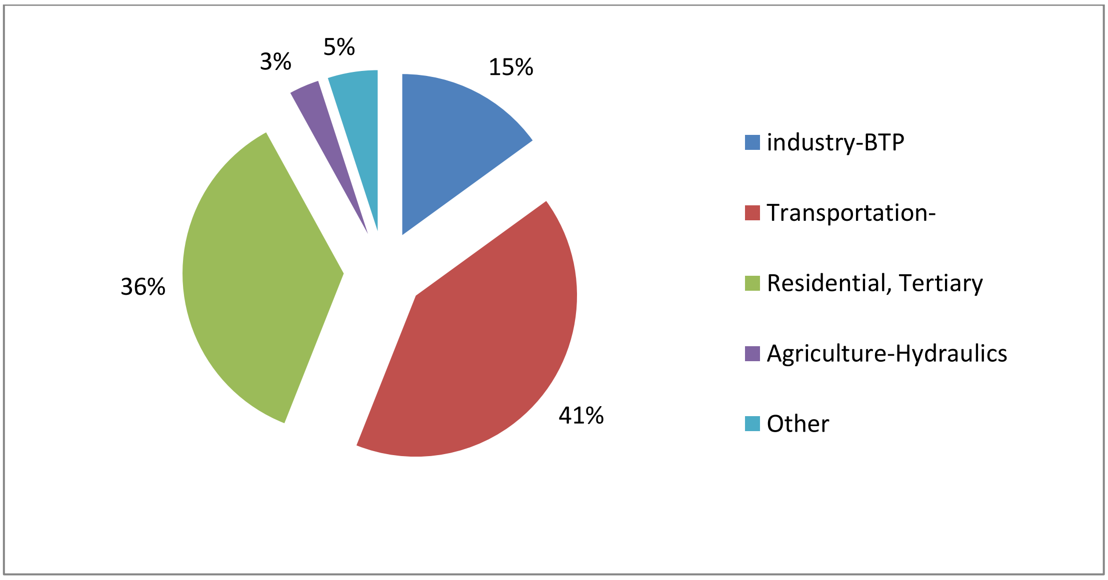


Fig 1.8: Distribution of final energy consumption by sector in 2015.

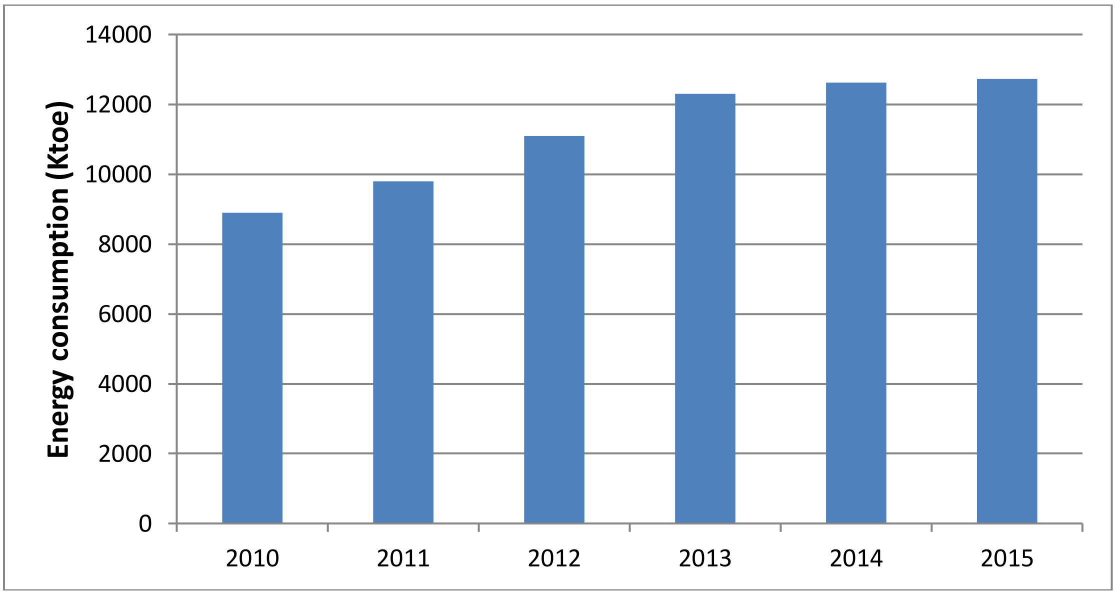


Fig 1.9: Energy consumption in the residential sector from 2010 to 2015

Like the developing countries where energy demand in the residential sector is the highest of all other sectors, in Algeria the residential sector is the greatest consumer of electricity. Despite the technical progress in equipment with low energy consumption, over 40% of total electricity in Algeria is consumed by the residential sector [19].

In order to meet the increasing electricity demand, one of Algeria's electricity sector main challenges is the ability to integrate renewable energies into the national energy mix and finance new generation projects amid fixed electricity prices and energy subsidies. Algeria is initiating a process of shifting to green power by launching a challenging program of development of renewable energy and energy efficiency.

1.2.3 Environmental impact of energy change in Algeria

The main sources of Greenhouse gas (GHG) emissions are represented mainly by fixed sources of combustion using fossil fuels (liquid, solid and gaseous fuels) such as power stations and other energy industries, road transport, fugitive emissions in industry oil and gas industry [38]. Globally, GHG emissions continue to increase despite the many policies implemented to mitigate climate change to date. These GHG emissions are estimated at 35 (± 4.5) billion tonnes of CO2 equivalent in 2012.

The over-use of electricity and intensive gas flaring to generate it, are the major causes of CO2 emissions in the country. At the data British group British Petroleum in 2016 [29], we are illustrated the evaluation GHG emissions, as shown in (Figure 1.10) underlines that since 1988, CO2 emissions increase in Algeria due to fossil fuel production and consumption. For example, in 2013, CO2 emissions reached 120 Million tons (MT) of CO_2.

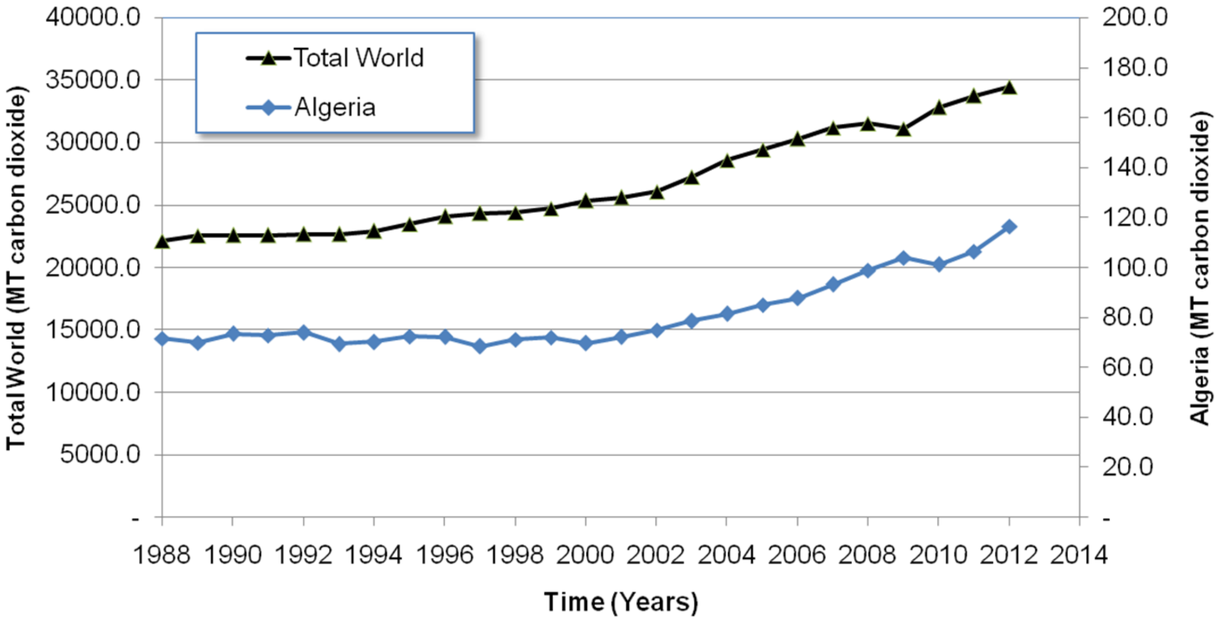


Fig 1.10: Total Greenhouse gas emissions in Algeria

Distribution of GHG emissions by business sector in 2012 of activity, shows a predominance of the transportation sector at 49%, followed by the residential sector, which accounts for a significant share of GHG emissions with 31%. The remaining 20% of emissions are in descending order between industry and construction, agriculture and hydraulics. The residential sector is a key sector to cope with the continued rise in GHG emissions.

1.3 RENEWABLE ENERGIES

Today, sustainable development is a new concept at the center of the debate, it is expressed as the solution to the tension between progress and new threats. Renewable energy policy represents a development that must meet the needs of the present without compromising the ability of future generations to meet their needs [39, 40].

The different branches of renewable energies are: solar energy namely passive solar, solar photovoltaic and thermal; geothermal energy at low, medium and high temperature; wind energy and biomass [41]. However, Algeria has a rich potential of renewable energy. The distribution of these potentials is [24]:

- ✓ Thermal solar: 169,440 TWh/year.
- ✓ Photovoltaic: 13.9 TWh/year.
- ✓ Wind energy: 35 TWh/year.

1.3.1 Solar energy

The history of using solar energy in Algeria goes back to 1954 with the solar furnace built by the French for ceramic fabrication purpose. Solar energy is considered the potential source of renewable energy, Algeria's geographical location has several advantages for a large use of solar energy. Algeria is situated at the center of North Africa in 38–35° North and 8–12° East with the surface 2,381,741 km2. According to the Development Center of Renewable Energies (CDER), the solar radiation is between 1530–1970 kW h/ m2/year for the north, and 1970–2410 kW h/m2/year for the Sahara. Hence, the solar resources and geographical location of Algeria provide a strategic position to play an important role in the electricity energy generation. A report of the International Energy Agency's (IEA) says that a country such as Algeria could be an exporting solar energy to Europe [16].

The insolation time over the quasi-totality of the national territory exceeds 2000 h annually and may reach 3900 h (high plains and Sahara) [42], as shown in Table 4. The daily obtained energy on a horizontal surface of 1m2 is of 5 kWh over the major part of the national territory, or about 1700kWh/m2/year for the North and 2263 kWh/m2/year for the South of the country [43].

Table 1.4
Solar potential in Algeria

Areas	Coastal area	High plateau	Sahara	Total
Surface (%)	4	10	86	100
Area (km2)	95.27	238.174	2048.297	2381.741
Mean daily sunshine (h)	7.26	8.22	9.59	25.07
Average duration of sunning (h/y)	2650	3000	3500	9150
Received average energy (kWh/m2/y)	1700	1900	2650	6250
Solar daily energy(Twh)	4.66	5.21	7.26	17.13
Potential daily energy(Twh)	443.96	1240.89	14870.63	16555.48

1.3.1.1 Photovoltaic energy

The interest in solar photovoltaic energy is growing worldwide. Today, more than 230606 MW of photovoltaic systems have been installed all over the world. Since 2000, the PV price has continuously dropped [44]. This price drop has encouraged worldwide application of small-scale residential PV systems. These recent developments have led researchers concerned with the environment to undertake extensive research projects for harnessing renewable energy sources including solar energy. The usage of solar photovoltaic as a source of energy is considered more seriously making future of this technology looks promising.

The amount of solar energy Algeria receives explains that it would be feasible to consider solar energy as a potential energy source for different applications in the form of individual PV solar panels or systems. Solar PV energy is being developed in Algeria mainly for six applications: domestic uses, water pumping, refrigeration, village electrification, lighting and telecommunication.

1.3.1.2 Thermal energy

Heat and power from thermal conversion were used as early as 1948. Recently, almost all countries with some industrial base are building solar water heaters. Europe saves about 4 percent oil importation by using solar water heaters in almost all their buildings. Turkey produces 1/4 of a million systems a year and Egypt legislated since 1990 that all newly built buildings must have solar water heaters as an integral part of the buildings. As for the electricity generation, desalination and processed heat, many applications exist in the USA, Asia and Africa. The main source book of Solar Engineering of Thermal Processes written by Duffie and Beckman (1991) gives a detailed discussion on these subjects [45]. There are several solar thermal power technologies (parabolic trough, central tower and parabolic dish) and despite the fact that most of them are in a development stage, their future potential decline in costs and technological advances are striking.

The demand for solar thermal installations is growing constantly in Algeria. The number of glazed solar collectors sold grew by 300 MW from 2010 to 2013. in other hand, Algeria is indeed aiming to be a major actor in the production of electricity from CSP, which will be drivers of sustainable economic development to promote a new model of growth.

The REs program for concentrating solar thermal power technology development is based on two stages [19]:

- ✓ From 2016 to 2020: 1200 MW of CSP will be installed.
- ✓ From 2021 to 2030: a capacity of about 600 MW per year will be installed.

A solar thermal power is considered as one of the most mature, successful, and proven solar technologies for electricity generation [46]. The first oil crisis in the early 1970s marked the beginning of modern development of CSP plants worldwide. R&D activities were started on several continents, and experimental and pilot solar power plants were erected and operated, but it was in the United States where technology reached its maximum maturity, with the solar energy generating systems developed by Luz International Ltd., at 354 MW, being the largest solar energy generating systems (SEGS) facility in the world [47].

1.3.2 Wind energy

Wind energy is the fastest growing energy source in the world, and the power of wind is one of the most widely used alternative sources of energy today. Algeria has a huge plan to develop this source. Studies of indigenous wind resources performed by the CDER during recent years, show that the climatic conditions in Algeria are favourable for WE utilization. The wind map, established by the CDER and MEM shows that 50% of the country surface presents a considerable average speed of the wind.

The wind resource has also been assessed by the developer, Sonalgaz, and at present, there are six pilot projects for electrification and telecommunication, which are identified and quantified. The region of Adrar receives the most wind in the country proved by the results of the preliminary survey. Evaluations of recoverable powers at height from 10 to 50 m could conclude in registering this region as a favourable site for the establishment of a windy farm.

1.3.3 Legal aspects (Legislative framework)

1.3.3.1 Laws and decrees

Algeria has incorporated the renewable energies development in its energy policy by adopting a legal framework in favour of their promotion and realization of relevant infrastructures. Renewable energies development is supervised by whole legislative texts [37], incentive and encouragement measures are particularly provided for in the law pertaining to energy control (financial, tax and customs duties benefits) for actions and projects that contribute at improving energy efficiency and promoting renewable energies. Among these legislative texts, there are:

- Law No. 99-09 dated 28th July, 1999 regulates the energy control
- Law No. 02-01 of 5 February 2002 on electricity and the public distribution of gas through pipelines;
- Law No. 04-09 dated 14th August, 2004, is about the promoting renewable energies under sustainable development
- Executive Decree No. 13-218 of June 2013: setting the conditions for granting bonuses for the costs of diversification of electricity production.
- Ministerial Decrees orders dated 02nd, February 2014 setting the purchase list prices guaranteed for power generating from facilities using the photovoltaic industry and the terms of the enforcement thereof.

This legal framework has been designed to achieve the following operational objectives: (a) to guarantee the power supply for all inhabitants of the country; (b) promote the conservation and efficient use of energy; (c) respect the environment; (d) progress towards energy diversification; (e) improve regional infrastructure related to energy production, transport and distribution; and (f) raise awareness of the use of renewable energies [58] [59] [60].

The goal of the aforementioned measures is to encourage local products and provide favourable conditions, particularly tax, for investors who are willing to involve in different renewable energies and energy efficiency industries.

1.3.3.2 National Program for renewable energy and energy efficiency

The National Renewable Energy Development Program, adopted in 2011, was revised in 2015 with the aim of achieving, by 2030, a production of 22,000 MW dedicated to local consumption alone, of which more than 4,000 MW will be realized, now until 2020. This program plans to implement a wide range of technological sectors, including the photovoltaic sector and the wind power sector, which will dominate with respectively 13,575 MW and 5,010 MW, the remainder being split between solar thermal, biomass and cogeneration. and geothermal energy.

Table 1.5 Capacities of the renewable energies program

Renewable energies capacities (MW)	1st phase 2015-2020	2nd phase 2021-2030	Total
Photovoltaic	3000	10575	13575
Wind	1010	4000	5010
CSP		2000	2000
Cogeneration	150	250	400
Biomass	360	640	1000
Geothermal	5	10	15
Total	4525	17475	22000

This revised program is characterized by a break with previous programs in the field of renewable energies. Because this ambitious program consists of installing a renewable power source of nearly 22 000 MW between 2015 and 2030, 12 000 MW will be dedicated to cover the national demand for electricity and 10 000 MW for export. Power generation is deemed to reach 90 TWh in 2020 and 170 TWh in 2030. About 40% of the electricity produced for domestic consumption will be from renewable energies in 2030 [28]. This strategic choice is motivated by the immense potential of solar energy; this energy constitutes the major axis of the program which devotes an essential part to the solar photovoltaic and solar thermal. Indeed, since the national potential in renewable energies is strongly dominated by solar power, Algeria regards energy as an opportunity and a lever for economic and social development. Table 1.5 gives combined capacities of the renewable energies program, per type and phase, over 2015 – 2030 periods [24].

The main renewable energy projects completed or in progress can be summarized as follows: [28, 48, 49].

- ✓ Solar photovoltaic: the rural electrification program provides for the electrification of 500 households per year at an average of 0.75 KW per household. The power to install would average 700 kW per year from 2015.
- ✓ Supplying electricity for more than 100 telecommunications stations (650 kW).
- ✓ 10 kW photovoltaic power stations connected to the national grid.
- ✓ 75 MW Condor PV module manufacturing plant was inaugurated in 2014 in Bordj Bou-Arreridj. These solar modules are intended for the production of electricity, public lighting and solar pumping. ENIE plant starts manufacturing Condor PV modules with an annual capacity of 120 MW in Sidi Belabbes.
- ✓ Solar thermal: Sonelgaz plans to build four solar / gas hybrid power plants with an installed capacity of around 1,300 MW by 2015.
- ✓ Wind: the program provides for the construction of 4 wind farms with a total installed capacity of 40 MW in 2015.
- ✓ Geothermal energy: the program foresees geothermal applications for the heating of agricultural greenhouses in 2015. More than 200 hot springs have been inventoried in the north of the country, the thermal gradient exceeds 5 ° C / 100m, with about a third having temperatures above average 45 ° C
- ✓ Construction of the first solar / gas hybrid power plant with a capacity of 150 MW in Hassi R’mel.
- ✓ Ghardaïa experimental solar power station (1,1 MW), designed for the experimentation of photovoltaic technologies.
- ✓ Solar energy supply program for 20 villages in the south of which the installation of one million km2 of photovoltaic area. Production more than 2 GWh.
- ✓ 13 photovoltaic plants with a capacity of 265 MW will be installed in the Hauts Plateaux region, and 10 others in the Great South for a total power of 78 MW.

1.3.4 Achievements state of photovoltaic systems in Algeria

The installation of photovoltaic systems (PV) isolated or connected to the grid, can be used in almost all places with an appropriate dimensioning. More specifically, in Algeria the solar capacity in operation is 108 PV installations and the solar connection capacity has exceeded 900 homes. Solar energy in the national energy balance accounts for 0.028% of national consumption with a renewable energy integration rate of 5%. in brief the total installed power is 11000 MW of which 275 MW for the hydraulic sector and 306 MW for isolated grid (off grid) of the South.

1.3.4.1 Isolated sites

According to the Ministry of Energy, there are over 260,000 villages not connected to the general electricity network [50]. Thereby, isolated houses tend to use engine-generators to cover their essential need in electricity. These engine-generators mainly use Diesel fuel to produce electrical energy that does not only have a bad effect on the environment, but it also costs a lot in means of transport. Therefore, solar photovoltaic energy represents a very attractive alternative instead of engine-generators. It has Manifold advantages like no gas releases nor greenhouse effect, free energy source for everyone, Modular design adaptable to all needs [24].

Sonelgaz (The National Gas and Electricity Society), has been contributing to the rural electrification of Algeria for years by deploying solar photovoltaic kits all over isolated villages which contain a limited number of houses. These villages (about 906 houses), are called “Solar Villages” and are mostly located in the south of Algeria [28, 50]. The regions that have benefitted from this program (first phase) were Tindouf (three villages), Adrar (two villages), Illizi (five villages), and Tamanrasset (eight villages). In its second phase [28], which started in 2010, rural electrification aims to deploy solar photovoltaic kits in 16 other isolated villages.

1.3.4.2 Decentralized photovoltaic power plants

The PV Systems connected to the grid, have been used in the early 1990 and spread rapidly in the developed countries. The main advantage of this configuration, in addition to reducing costs due to the absence of batteries, is that the energy generating surplus with respect to the consumption of the load is directly injected to the distribution grid. This last will ensure the extra on the other side (low energy generation). Thus, the integration of PV systems to the distribution grid is an important and strategic issue in future energy policies of the South countries including Algeria [24, 51].

Many photovoltaic power plants have been installed, and more are planned in the country. A photovoltaic plant was inaugurated in “Bousmail”, region of Tipaza, in the development unit of solar equipment (UDES) (2012). and new subsidiary of electricity generation, SKTM power generation company wishes is take in charge of the remote southern and renewable energy networks called Shariket Kahraba oua Takat Moutadjadida, abbreviated SKTM, is a new shareholding company with a capital fully subscribed by Sonelgaz and whose head office is located in Ghardaia. It is within the aim of optimizing the electricity generation means in the South and promoting new electricity subsidiaries that this company has been created. For the south of the province of Sidi-Bel-Abbes, in the town of “Dhaya”, a photovoltaic power plant with a capacity of 15 MW has been included in the program of the achievements of 2014. Just as the West, East, more precisely the city of “AinAzel” has benefited from a project of a solar plant power of 150 MW at the end of 2013 [52]. In the town of “Ain El Melh”, located in the steppe zone, a photovoltaic planted with a capacity of 20 MW was achieved in 2014. In 2015, the South Korean company “Hanwha Engineering” will deliver a power of 4.5 MW in the region of Biskra. In “Ras El Oued”, in the region of Bordj BouArreridj, the Chinese company Sino-Hydro installed a power of 20 MW photovoltaic powers at the end of 2014 [53]. At Ghardaia, south of Algeria, a photovoltaic plant power of 1.1 MW was put into operation for the experiment of the four existing solar cell technologies. Always in this region, the first mini photovoltaic solar power plant connected to the network using micro amorphous panels with a capacity of 28 kW was put into operation. This achievement is within the scope of research activities of the Unit for Applied Renewable Energy (URAER). At Adrar and Ain- Salah, seven photovoltaic plants were planned for the fourth quarter of 2014. In Sebdou, a plant with a capacity of 10–20 M VA (million volt-ampere) will inject energy into the national electricity grid.

The provision of sufficient infrastructure for the generation and transport of large amounts of renewable electricity in Algeria can only be achieved by a substantial, innovative upgrade and modernization of the Algerian power transmission system. Algeria has an extensive AC grid, not only covering the densely populated coastal areas, but also due to the presence of its oil and gas industry, reaching far into the largely unpopulated Centre of the country. Owner of grid is the state utility Sonelgaz, which is also responsible for operation, management and development of the grid. The grid is displayed in Fig. 1.11.

Currently, the stability of the grid is provided by centralized conventional control methods based on conventional power plants. Consequently, all PV systems will be disconnected from the grid under special conditions (faults in the network, weather ...etc.) and then reconnected in normal conditions. If PV systems connected to the electrical distribution networks take a significant place in the Park of production, automatic disconnections can actually be a problem of managing the stability of the grid, especially during peak energy demand.

In general, the introduction of decentralized approach in Algerian grids, which initially were not designed to accommodate them, is causes of the appearance of new phenomena that is necessarily to be identified and studied. In the coming years, the power grid manager must consider the distributed generation (PV, wind, etc.) as means of full production and integrate it into the Algerian grid management process.

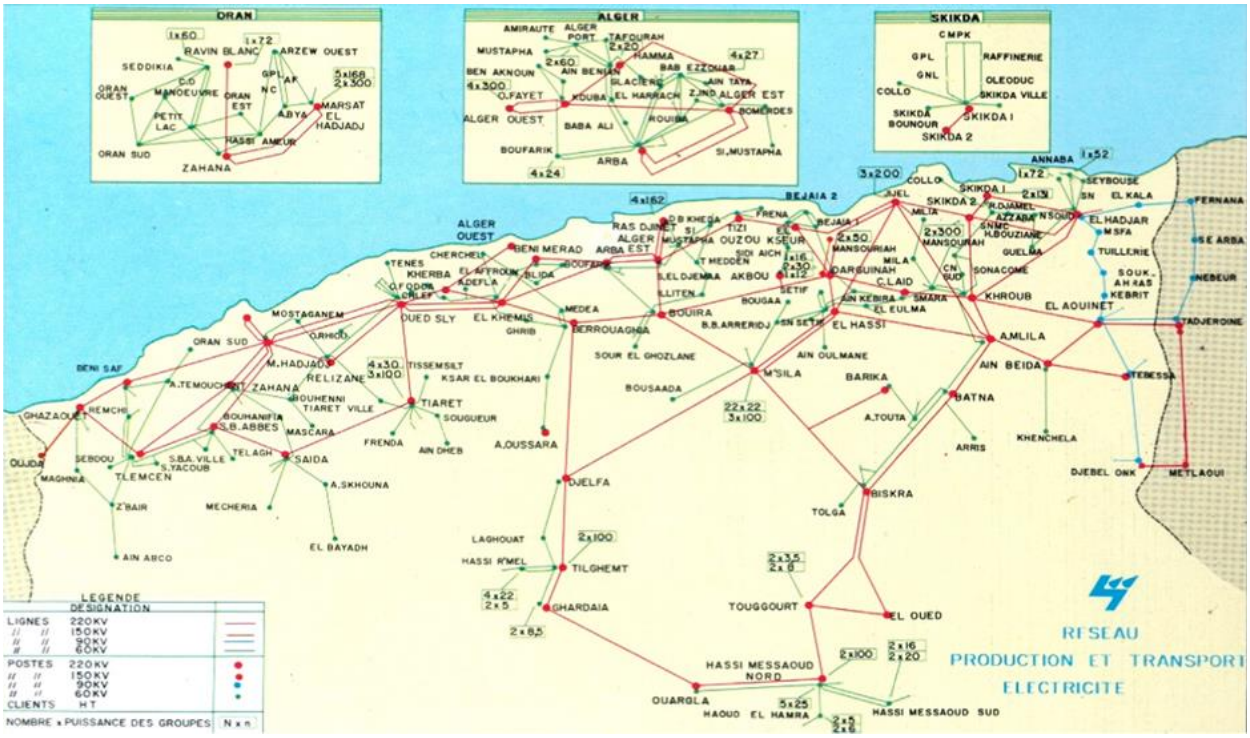


Fig. 1.11 Algerian electricity Grid (Sonalgaz)[24]

1.4 CONCLUSION

In this chapter, the energy situation of Algeria; has been outlined and data for renewable energies are presented. Algeria is an energy producing-exporting country. The main energy source is crude oil, flowed by natural gas. However, domestic fossil reserves are limited and harm the environment. In order to be less dependent on fossil fuel, meet the increasing energy demand and protect the environment, Algeria must diversify their energy resources. Indeed, government gives particular importance for promoting renewable energy and improving energy efficiency, with the aim to produce 40% of electricity from renewable energy by 2030.

Solar energy is considered as a promising source in the improvement of the energy balance and the protection of the environment. In fact, it is clear that Algeria is endowed with good solar energy potentials. There is also optimism for wind and geothermal, but further work is required for comprehensive determination of geothermal and wind resources. Despite the huge potential of renewable resources, the share of energy from renewable sources in energy balance is not significant. Finally, in the sense of resorting to the use of the PV system connected to the network for the electrification of sites in suburban areas, a detailed problem was presented.

CHAPTER 2

SOLAR ENERGY AND ENERGY EFFICIENCY IN HOUSING

Chapter 2:

Solar energy and energy efficiency in housing

2.1 INTRODUCTION

In the present day, the dwelling and habitat are invariably linked to making buildings as comfortable and convenient possible all over the world. The building sector is growing at a rapid pace by investing 30–40% of total global basic resources. The present-day buildings have become the third largest consumer of fossil energy after industry and agriculture. The Asia-Link program is an initiative by the European Commission to promote and spread the knowledge on sustainable built environment with nearly zero energy approach. In this sustainable built environment program, there is promotion toward the integration of proven renewable energy technologies with the building for various applications such as water heating, heating/cooling and electricity production. The operational energy use in the building is of growing importance all over the world [54].

The building labels have been introduced in European countries, such as ‘Passive House’ in Germany and ‘Minenergy’ in Switzerland to certify standardized low energy buildings [55]. Sources place the amount of energy expended in the building sector in Europe to about 40–45% of total energy consumption; about two-thirds of this amount is used in private buildings. Other sources claim, that in industrialized countries, energy usage in buildings is responsible for approximately 50% of carbon dioxide emissions [56]. Hence, sustainability assessment of buildings is becoming necessary for sustainable development especially in the building sector all over the world. The main goals of sustainable design were to reduce depletion of critical resources such as energy, water, and raw materials; prevent environmental degradation caused by facilities and infrastructure throughout their life cycle; and create built environments that are safe, productive and effective utility of the water and solar energy.

Hence, there exists a tremendous potential to conserve energy in buildings. Energy conservation measures are developed for newly constructed buildings and for buildings under refurbishment. However, to achieve a significant reduction in energy consumption in the building apart from the standard energy-efficiency methods, proven renewable energy technologies should be implemented and integrated with the passive building [57].

2.2 HIGH QUALITY ENERGY HOUSING

2.2.1 Managing an HQE building

The High Quality Environmental HQE is usually requested before the construction, during the design phase. Nevertheless, it can be also requested after the construction phase. Thus, the question of the existing building stock is put, the stock versus to the flow which is the case of new buildings. There is, thus, the rehabilitation need, and the current management/maintenance need, which must be ameliorative, two subjects on which the HQE Association opened recently the discussion.

The definition of the environmental quality of a building remains of course, the same, but the ways to reach that point, the levels of performance one can reach, must adapt to the starting situation. The quality of the physical diagnosis, the listening of the inhabitants, the observation of the former lived situation, come to enrich the step for the rehabilitation. As for the everyday management, it is a logical continuation of the HQE for the buildings built with the HQE step. It is not enough to produce a performant building, it is also necessary that its exploitation be performant, that all the potentialities are being carried out [58, 59].

The latter aims, in fact, to better control the impacts (visual, acoustic, olfactory, sanitary) of buildings on the quality of life of residents. For example, it is not a question of sacrificing the aesthetics of dwellings to their functional and ecological dimensions, of building homes that make the best use of natural light, and of reducing acoustic and olfactory nuisances thanks to insulating materials. Indeed, the primary objective of the HQE approach is to fight against the waste of natural resources. According to the HQE association, this approach may allow [59]:

- ✓ energy saving: From 30 to 50% of thanks to selected heating and insulation equipment,
- ✓ water saving: From 20 to 50% of thanks to water savers on faucets, rainwater recovery.

The HQE is not a state, it is still a dynamic there. The same reasoning can be considered for “not HQE” constructions. Each intervention can be the occasion of an improvement, with an overall plan, so that the accumulation of them draws the building quality towards the HQE. A great part of the building stock will probably never be the subject of a rehabilitation, consequently this method of continuous improvement can constitute a response to the need for modernizing the built heritage, to study in connection with projects the health records of a building.

2.2.2 Bioclimatic housing

The term “Bioclimatic Architecture” summarizes a number of differing general terms as the single planning definition-that is a group of design decisions that offer appropriate living conditions within buildings by the minimal use of technical units “the group of machinery” that require energy consumption of non-renewable resources. In other words, such relations should be formed between a building and its surroundings that allow the possibility of the desired change in the habitation interior, which depends on the habitation’s physical and morphological “formative” characteristics, as well as its dimensions and measurements. Considering conditions change according to the building location, and knowing that these conditions also change through time and building position, an ideal “bioclimatic habitation” should have the potential to adapt in a way that allows it to absorb the maximum amount of heat in cold days. Additionally, it should be able to absorb and retain solar energy throughout daytime during winter in order to use it when in need, and reflect solar radiation in hot climate zones. Hence, creating appropriate living conditions and maintaining the architectural spaces within the scope and limits of comfort “22-24 degree Celsius”. We can achieve such building behaviour, which is known as the “ideal or model behaviour” by making use of certain schemes and specific building patterns. And I hereby by would like to mention that this paper will only address the residential scene of the matter; however, proposed results can be applied on other architectural structures [60].

2.2.3 Algerian context in terms of HQE housing

The Algerian policy in terms of energy efficiency, mainly in the building sector is reflected in the actions of a few entities: APRUE supported by its financial arm the National

Fund for the Control of Energy (FNME) and the National Program of Energy Control (PNME). To this must be added the collaboration of research centers related to the field of buildings as the center for the development of renewable energies (CDER) and the National Center for Integrated Building Research and Studies (CNERIB) and of course the Ministry of Energy. Energy and Mines. It is a question of seeing in detail the state of the places of these policies and possibly the follow-up and the first fruits of result or the opposite case the obstacles which hinder their executions.

APRUE has a number of programs and initiatives aimed at controlling energy in the building sector [61]:

a) The ECO-BAT

The ECO-BAT program provides for the improvement of thermal comfort in dwellings and the reduction of energy consumption for heating and air conditioning by [62]:

- ✓ The mobilization of building stakeholders around the issue of energy efficiency.
- ✓ The realization of a demonstrative action, proof of the feasibility of high energy performance projects in Algeria.
- ✓ The provocation of a ripple effect of the practices of considering the aspects of energy control in the architectural design.

b) New national program on energy efficiency (2016-2030)

The new national program "2016-2030" comes from the Algerian Program for the Development of New and Renewable Energies and Energy Efficiency, adopted by the Council of Ministers in February 2015. The energy efficiency program is in line with Algeria's desire to promote a more responsible use of energy and to explore all avenues for the preservation of resources and the systematization of a useful and optimal consumption for program components [63].

c) Pilot project of housing with High Energy Performance (HPE)

This first pilot thermal insulation project is already launched by APRUE in partnership with the Ministry of Housing. For its implementation, agreements have been signed with the National Housing Fund (CNL) and the OPGI of 11 selected wilayas, covering all the climatic zones of the country. defining the conditions and the modalities for the integration of efficiency measures in the 600 pilot homes spread over eleven wilayas (departments): Laghouat, Béchar, Blida, Tamanrasset, Algiers (Hussein Dey), Djelfa, Setif, Skikda, Mostaganem, Oran and El Oued [64, 65].

For example, the El Oued HPE project (Figure 2.1) has 32 dwellings. Its construction is based on: The use of the vegetation, the reduction of the covers on the west facade and the extension of the projected shady facades. It is also characterized by the use of the dome to promote air movement, the use of moucharabiehs as sunscreen and combination of inertia and ventilation.

Figure 2.1: 3D illustration of HPE El Oued housings

d) Pilot project of housing with energy efficiency at CNERIB

The Mediterranean Energy Efficiency Project in the Construction Sector (MEDNEC Project), was formally launched on 2007 in Damascus to implement energy efficiency measures in the building through the application thermal regulation, the use of renewable energies and the development of new materials and constructive systems with high energy performance.

The main objective of this project is the introduction of the energy saving approach in the act of building at the design and implementation levels. This project differs from conventional constructions by the use of the following elements:

- ✓ Constructive system based on bonded masonry,
- ✓ Locally available construction material namely BTS (Stabilized Earth Concrete), the binder used for block stabilization is cement with a maximum concentration by weight of 5%

Table 2.1

below shows the characteristics of HPE dwellings in El Oued

External reference walls	Plaster, brick10cm blade air, brick15cm, cement coated	K= 0,74624 W / m2°C
Exterior walls with 10cm insulation	Plaster, brick10cm, polystyrene 05cm, brick15cm, cement-coated	K=0.21522 W / m2°C
Interior walls	Plaster, brick10, plaster	K=2.07815 W / m2°C
Floor	Plaster, hourdi 16cm, concrete, granito tile	2.70279 W / m2°C
Roof	Plaster, hourdi 20cm, concrete, felt and asphalt	1.89150 W / m2°C

2.3 ENERGY CONSERVATION IN BUILDING

There are four broad ways to reduce the energy consumption of building which ultimately results in mitigating emissions of CO2 emissions through energy conservation. These aspects are described as follows:

a. Comfort passive building design and its orientation for harnessing solar energy.

b. Low embodied energy materials for building construction.

c. Energy efficient domestic appliance to conserve the building operational energy.

d. Building integrated renewable energy technologies.

2.3.1 Passive building design

The most sustainable energy technique is to conserve energy as much as possible. Passive solar building design can aid energy conservation efforts because building design is directly related to energy use. Buildings with passive solar building designs naturally use the sun’s energy for free of charge heating, cooling and daylighting. This reduces the need to consume energy from other sources and provides a comfortable environment inside. The principles of passive solar design are compatible with diverse architectural styles and can be renovated with existing building for net zero energy use.

2.3.1.1. Passive solar design principles

Passive solar design integrates a combination of building features to reduce or even eliminate the need for mechanical cooling and heating and daytime artificial lighting. Designers and builders pay particular attention to the sun to minimize heating and cooling needs. The design does not need to be complex, but it should involve knowledge of solar geometry, window technology, and local climate. Given the proper building site, virtually any type of architecture can integrate passive solar design [54].

The basic natural processes that are used in passive solar energy are the thermal energy flows associated with radiation, conduction, and natural convection. When sunlight strikes a building, the building materials can reflect, transmit, or absorb the solar radiation. Additionally, the heat produced by the sun causes air movement that can be predictable in designed spaces. These basic responses to solar heat lead to design elements, material choices and placements that can provide heating and cooling effects in a home. Passive solar energy means that mechanical means are not employed to utilize solar energy. There are some rules of thumb which must be considered for effective solar energy utilization through passive solar systems. The building energy management can be achieved smartly using the nearly zero energy building concept.

2.3.1.2 Passive solar heating

The goal of all passive solar heating systems was to capture the sun's heat within the building's elements and release that heat during periods when the sun is not shining. At the same time that the building's elements (or materials) are absorbing heat for later use, solar heat is available for keeping the space comfortable (not overheated). Two primary elements of passive solar heating required are as follows:

- ✓ South facing glass for northern region and vice versa.
- ✓ Thermal mass to absorb, store, and distribute heat.

There are three approaches to passive solar heating systems: (direct gain, indirect gain, and isolated gain).

a) Direct gain:

In this system, the actual living space is a solar collector, heat absorber and distribution system. South facing glass admits solar energy into the house where it strikes directly and indirectly thermal mass materials in the house such as masonry floors and walls as shown in Fig. 2.2. The direct gain system will utilize 60–75% of the sun's energy striking the windows. In a direct gain system, the thermal mass floors and walls are functional parts of the house. The thermal mass absorbs solar radiations during daytime and radiates the heat energy during night-time into the living space [66] as shown in Fig. 2.2.

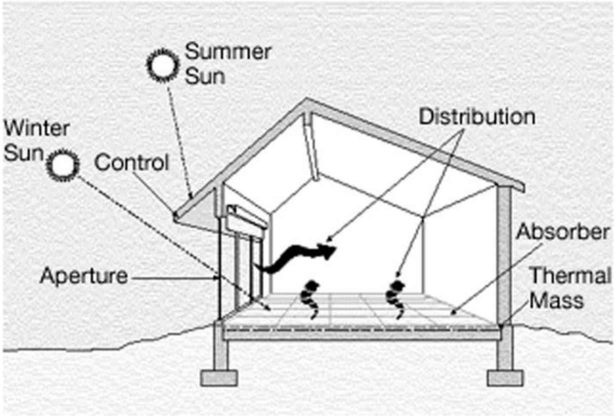


Figure 2.2. Direct gain: thermal mass absorbs heat in day through window and radiates in night [66].

b) Indirect gain:

In an indirect gain of solar passive heating system, thermal mass is located between the sun and the living space. The thermal mass absorbs the sunlight that strikes it and transfers it to the living space by conduction. The indirect gain system will utilize 30–45% of the sun's energy striking the glass adjoining the thermal mass. There are three types of indirect gain systems:

- ✓ Thermal storage wall systems (or Trombe wall).
- ✓ Water wall.
- ✓ Roof pond systems.

c) Isolated gain:

An isolated passive solar heat gain system has its integral parts separated from the main living area of a house [66]. Isolated gain involves utilizing solar energy to passively move heat from or to the living space using a fluid, such as water or air by natural convection or forced convection [54]. Examples are sunroom and convective loop through flat plate air collector to a storage system in the house as shown in Fig. 2.3. The ability to isolate the system from the primary living areas is the point of distinction for this type of system. The isolated gain system will utilize 15–30% of the sunlight striking the glazing toward heating the adjoining living areas. Solar energy is also retained in the sunroom itself.

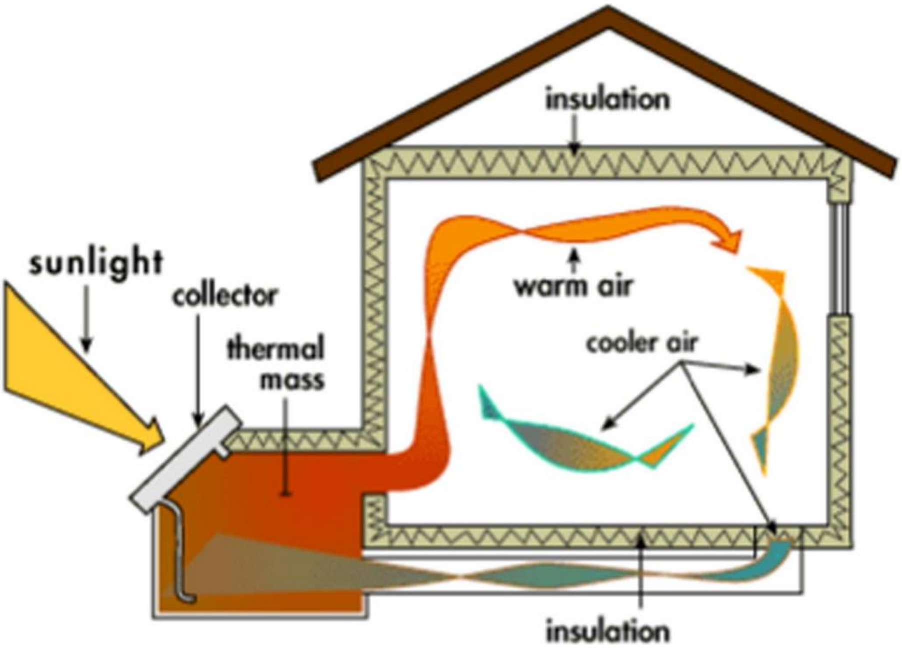


Fig. 2.3. Isolated heat gain system through integrated solar collector for isolated heat gain [54].

2.3.1.3. Passive solar cooling

A combination of proper insulation, energy-efficient windows and doors, daylighting, shading, and ventilation will usually keep homes cool with a low amount of energy use [54]. The approaches include use of operable windows, wing walls and thermal chimney. Natural ventilation can be created by providing vents in the upper level of a building to allow warm air to rise by convection and escape to the outside. At the same time cooler air can be drawn in through vents at the lower level. This lower vent is provided where there are trees planted besides the building to provide shade for cooler outside air [67].

a) Ventilation and Operable Windows

- ✓ Place operable windows on the south exposure.
- ✓ Casement windows offer the best airflow. Awning (or hopper) windows should be fully opened or air will be directed to ceiling. Awning windows offer the best rain protection and perform better than double hung windows.

- ✓ If a room can have windows on only one side, use two widely spaced windows instead of one window [67].

b) Wing Walls

Wing walls are vertical solid panels placed alongside windows perpendicular to the wall on the windward side of the house. Wing walls will accelerate the natural wind speed due to pressure differences created by the wing wall [67].

c) Thermal Chimney

A thermal chimney employs convective currents to draw air out of a building. By creating a warm or hot zone with an exterior exhaust outlet, air can be drawn into the house ventilating the structure.

2.4 BUILDING INTEGRATED RENEWABLE ENERGY TECHNOLOGIES

Renewable energy is derived from natural processes that are continuously replenished. The various forms of renewable energy are derived directly from the sun, or from heat generated deep within the earth. The electricity and heat generated from solar, wind, ocean, hydropower, biomass, geothermal resources, and biofuels and hydrogen derived from renewable resources are also included in this definition [66]. The renewable energy technologies include solar power, wind power, hydroelectricity, micro-hydro, biomass and biofuels.

Significant amount of heat and electricity needs of buildings can be effectively covered by using solar thermal collectors and photovoltaic. In the coming years, other renewable energy sources (RES) such as wind turbines, biomass and hydrogen (produced only from RES) can be also applied, minimizing the use of the conventional energy sources. RES and nuclear energy can be considered the alternative energy sources to avoid greenhouse effect. Between these two energy sources, only RES are clean and compatible with the environment, are almost uniformly distributed globally, can be easily used from all people with minimum market trust and ownership undertaking and of course are inexhaustible [54].

Renewable energy technologies have several benefits such as sustainability and security of energy supply, increased employment, and long lifetime of energy systems. Even if the cost of solar energy systems remains in high levels it seems to follow European and international commitments. This is due to the fact that solar technology is a very friendly one in environmental terms for buildings and urban applications. This kind of technology is also highly important for the economy of most countries as they can replace the expensive and imported conventional energy sources (oil, gas, coal and nuclear fuels). Solar Energy Systems can be applied in a very harmonic way on buildings to cover the heating, cooling, electricity and lighting needs. The facades and the horizontal or inclined roofs of houses, hotels, athletic centres, etc, constitute appropriate surfaces for an expanded use of solar thermal collectors and photovoltaic panels.

Buildings can be designed according to the bioclimatic architecture for the minimization of the energy needs and the environmental impact of them, using new heat-insulating materials and special glasses (e.g. smart windows), which reduce effectively thermal losses during the winter and energy consumption for cooling during the summer. Under these aspects, the prospective energy savings in the buildings (especially in the new buildings) can be more than 50% of the energy consumption of standard buildings and become a regular procedure for the built environment construction [54].

2.4.1 Active solar system

The installation of devices and active solar energy units is related to their cost increase and their harmonization with building’s architecture and the environment. Solar energy systems are also preferred for aesthetic reasons, in order to avoid the negative phenomena of diesel engines for heat and electricity (e.g. smokes, chimneys). It is also important to apply them if they are harmoniously implemented into the existing, local, and natural particularities of the environment through good planning and wise environmental studies.

The exploitation of solar energy systems toward sustainable development applications could take the form of the creation of innovative buildings, equipped with bioclimatic features aiming at the saving of energy. As it is known that the sector of buildings is responsible for about 35% of the final energy consumption and for the 40% of the gas emissions, it is estimated that the saving of energy can arrive at 60% when solar energy systems are used for heating and cooling purposes. Besides, a new directive from European

Commission (EC) has been placed into force with regard to the obligation of energy saving in the newly constructed buildings. Thus, RES application to buildings with improved performance and aesthetic integration can result in the rising of the standards of living [54, 68].

Solar energy systems integrated into the building that can be transformed into heat by means of thermal solar panels or electricity by means of photovoltaic cells [68].

2.4.1.1 Systems using solar thermal

Active solar technologies aim to take advantage of the thermal energy of solar radiation to transmit it to a coolant [69]. Although there are a variety of systems that operate using this technology based on different thermal sensors:

- ✓ **Individual solar water heater (CESI)**

The solar water heater for the production of domestic hot water (see Figure 2.4): in a conventional Solar Water Heater (CESI) solar installation, a heat transfer fluid circulates through a solar collector pump to recover solar energy. In the hot water storage tank (DHW), an exchanger is then essential to transmit the recovered energy. This heat transfer is effected via an exchanger. The consumption of DHW constitutes the discharge of the storage tank.

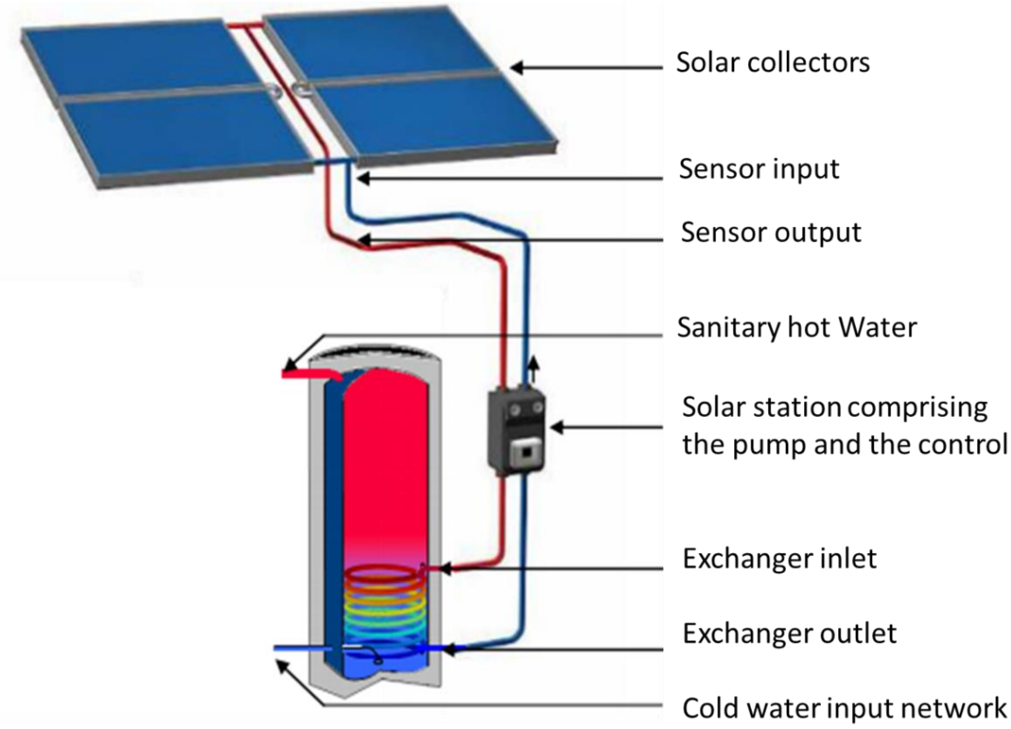


Figure 2.4: Overall representation of a CESI [70].

- ✓ **Flat Plate Thermosyphon Units (FPTU) and Integrated Collector Storage (ICS)**

These systems are small size solar water heaters, aiming to cover domestic needs of about 100–200 liters of hot water per day [71]. ICS solar systems are simpler and have lower cost than FPTU systems, as they consist of solar collector and water storage tank mounted together in the same device.

- ✓ **Solar Collectors with Colored Absorbers**

The solar collectors with absorbers of different colors than black could be an interesting solution for the wider application of solar energy systems [71] .

- ✓ **Solar Collectors with Booster Reflectors**

There are many buildings which have horizontal roof and solar collectors can be installed in parallel rows, placed at a proper distance, in order to avoid collector shading during winter. This type of installation is suitable for collector operation in higher temperatures, adapting therefore space cooling requirements [54, 71].

2.4.1.2 Solar Photovoltaic systems

Based on the photovoltaic effect, solar energy photovoltaic power generation is a novel power generation approach. The photovoltaic effect refers to the phenomenon that some special semiconductor materials under the light irradiation can internally generate electromotive force. Photovoltaic systems can be grouped into stand-alone systems and grid-connected systems as illustrated in Fig. 2.5. In stand-alone systems the solar energy yield is matched to the energy demand. Since the solar energy yield often does not coincide.

In time with the energy demand from the connected loads, additional storage systems (batteries) are generally used. If the PV system is supported by an additional power source, for example, a wind or diesel generator this is known as a PV hybrid system. In grid-connected systems the public electricity grid functions as energy store [72].

a) Stand-alone Systems

The first cost-effective applications for photovoltaics were stand-alone systems, wherever it was not possible to install an electricity supply from the mains utility grid (UG). The range of applications is constantly growing. There is great potential for using stand-alone systems in developing countries where vast areas are still frequently not supplied by an electrical grid. These systems can be seen as a well-established and reliable economic source of electricity in rural areas, especially where the grid power supply is not fully extended [73]. Solar power is also on the advance when it comes to mini-applications: pocket calculators, clocks, battery chargers, flashlights, solar radios, etc., are well-known examples of the successful use of solar cells in stand-alone applications. Stand-alone PV systems generally require an energy storage system because the energy generated is not usually required at the same time as it is generated (i.e., solar energy is available during the day, but the lights in a stand-alone solar lighting system are used at night). Rechargeable batteries are used to store the electricity.

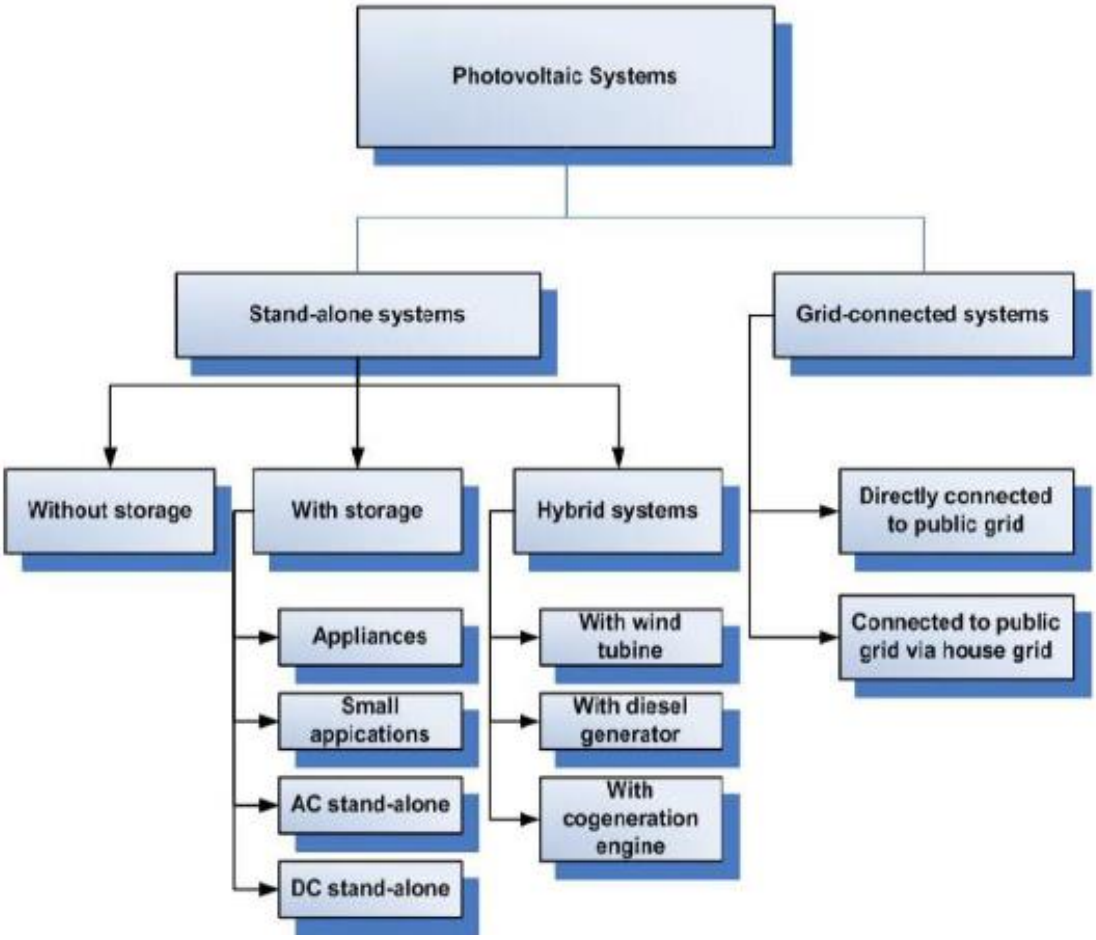


Fig. 2.5 photovoltaic system classification

However, with batteries, in order to protect them and achieve higher availability and a longer service life it is essential that a suitable charge controller is also used as a power management unit. Hence, a typical stand-alone system comprises the following main components [73, 74]:

- PV modules usually connected in parallel or series-parallel;
- Charge controller;
- Battery or battery bank;
- Loads;
- Inverter (i.e., in systems providing AC power).

b) Grid-Connected Photovoltaic Systems

Grid-connected PV systems (GCPVS) account for more than 99% of the PV installed capacity compared to stand-alone systems (which use batteries). In grid-connected PV systems, batteries are not needed since all of the power generated by the PV plant is uploaded to the grid for direct transmission, distribution, and consumption. Hence, the generated PV power reduces the use of other energy sources feeding the grid, such as hydro or fossil fuels, whose savings act as energy storage in the system, providing the same function of power regulation and backup as a battery would deliver in a stand-alone system. Since grid-connected systems do not need batteries, they are more cost-effective and require less maintenance and reinvestment than stand-alone systems. This concept together with the cost reduction, technology development, environmental awareness, and the right incentives and regulations has unleashed the power of the sun.

The typical configuration of a grid-connected PV system is represented [74-76]. In a conventional PV system, the PV cells (arranged in a single module, a string of series-connected modules, or an array of parallel-connected strings) generate a dc current that greatly depends on the solar irradiance, temperature, and voltage at the terminals of the PV system. This dc power is transformed and interfaced to the grid via a PV inverter. Additional elements include a grid connection filter, a grid monitor or interaction unit (for synchronization, measurements, antiisland detection, etc.), and a low-frequency transformer (which is optional depending on local regulations, the converter topology, and the modulation used to control it [76]). Another option is an intermediate dc–dc power stage between the PV modules and the grid-tied inverter. This optional stage decouples the PV system operating point from the PV inverter grid control. Additionally, it can boost the PV system dc output voltage if required or provide galvanic isolation and perform maximum power point tracking (MPPT) control.

2.5 CONCLUSION

Modern day buildings are highly energy intensive with a significant consumption of energy right from the construction phase to the operation and maintenance stage, owing to global energy crisis suitable strategies needed to be developed to address energy conservation in buildings.

There are various methods to reduce the use of conventional energy from fossil fuels to meet the energy requirement for the building. The combination of various solar passive design aspects can easily be integrated in new buildings based on the site, orientation of building and local climatic conditions. The retrofit of Trombe wall as solar passive heating design concepts in honey storage building had shown promising results for winter heating. Similarly, the use of proper design of daylighting can lead to tremendous reduction in use of artificial lights during daytime and thereby reduces the energy consumption by building for lighting. Hence, integration of solar passive features into the building leads to reduction in energy consumption of building which ultimately reduces the CO2 emissions and helps in sustainable development.

The second important aspect is to reduce energy consumption of building for operation using energy derived from fossil fuels. So, as a feasible alternative the focus is on the promotion of renewable energy technology in meeting building energy requirements. When the building energy is completely met by renewable energy system then it is known as a highly energy efficient or zero emission green building. The economics of various renewable energy systems is given for the acceptance of these technologies as compared to the conventional energy source.

CHAPTER 3

PHOTOVOLTAIC SYSTEMS CONNECTED TO THE GRID

Chapter 3:

Photovoltaic systems connected to the grid

3.1 INTRODUCTION

Photovoltaic (PV) power supplied to the utility grid is gaining more attention, while the world's power demand is increasing [77]. Not many PV systems have so far been placed into the grid due to the relatively high cost, compared with more traditional energy sources such as oil, gas, coal, nuclear, hydro, and wind. Solid-state inverters have been shown to be the enabling technology for putting PV systems into the grid. The power capacity of the grid-connected PV system ranges from small residential and commercial rooftop systems to large utility-scale solar power plants. Unlike a grid-connected PV system without battery backup, a grid connected PV system with an integrated battery backup includes more components and batteries [78]. The grid-connected PV system can contribute strongly to reduce the electrical energy purchased from the grid by suppling the PV excess power, beyond consumption by the connected load, to the utility grid especially when weather conditions are favourable. It can also reduce the energy losses of the grid and avoid or delay upgrades to the transmission and distribution grid where the average daily output of the PV system corresponds with the utility's peak demand period [79-81]. Furthermore, the main advantage of a grid-connected PV system compared to stand alone PV system is the absence of storage batteries that decreases significantly the unit cost of the PV energy produced.

The cost of the grid-connected inverter is, therefore, becoming more visible in the total system price. A cost reduction per inverter watt is, therefore, important to make PV-generated power more attractive [82, 83]. Focus has, therefore, been placed on new, cheap, and innovative inverter solutions, which has resulted in a high diversity within the inverters, and new system configurations.

The main aim of this chapter is divided in two parts, the first parts gives the classifications of grid-connected PV systems. Then, we discussed recent work that has studied the interest of the introduction of the grid-connected PV systems in the residential building. It has been completed on the application of PV systems in the residential building, which has positive effects by reducing the energy taken from the grid during the day and injecting the surplus of the PV energy under favourable climatic conditions. The second parts are to present the grid-connected photovoltaic systems overview and concept of research work done in this thesis. First, the chapter studies the rooftop photovoltaic system technology and discusses. Then, overviews of PV systems are presented. Secondly, connection topologies of photovoltaic systems are discussed. Also, the relationship between the grid-connected technology and the renewable source with different topologies of solar inverter configuration are presented. Finally, the international codes and standards for grid connected PV system.

3.2 LITERATURE REVIEW

3.2.1 Classification of grid-connected PV systems

The PV systems comes in different forms sizes, such as grid connected, stand alone, large scale and roof-top systems. The core of presentation concentrates on the development and trends of converters for grid connected PV-systems. The novel multi-string converter is being widely used in recent times as it is seen to be one of the major trends in PV system technology towards modular PV-system design based on string converter technology with low specific costs and optimal energy yield. Castro, M [84] presented an overview on the PV systems capacity connected to the grid installed worldwide, they concluded that the worldwide market tended to classify the grid-connected PV systems in three main categories. Low-scale PV systems (1–5 kW) for private homes, medium-scale PV systems integrated in commercial, industrial and office buildings (usually 10–250 kW) and large-scale PV power plants (100 kW up to 5 MW) for supplying electricity energy to a number of units.

3.2.1.1 Low-scale PV systems

Kjaer, S [78] presented an overview focuses on inverter technologies for connecting photovoltaic (PV) modules to a single phase grid. The inverters are categorized into four classifications: a) the number of power processing stages in cascade; b) the type of power decoupling between the PV module(s) and the single-phase grid; c) whether they utilize a transformer (either line or high frequency) or not; and e) the type of grid-connected power stage. Various inverter topologies are presented, compared, and evaluated against demands, lifetime, component ratings, and cost. Finally, some of the topologies are pointed out as the best candidates for either single PV module or multiple PV module applications.

Marina Bertolini et al [85] provided a theoretical framework modeling prosumers' decision to invest in photovoltaic power plants, assuming that they are integrated in Smart Grids. To capture the value of managerial flexibility, a real option approach is implemented. The model was calibrated and tested with data from the Italian energy market. Our findings show that the possibility of selling energy via the Smart Grid increases investment values. The connection to Smart Grids increases managerial flexibility. The opportunity to sell energy in the market encourages prosumers to invest in a larger plant compared with that needed for self-consumption, and there is a positive relation between optimal size and (optimal) investment timing. Okello et al [86] presented a comparison between measured and simulated performance parameters of a 3.2 kWp grid-connected PV system in the Nelson Mandela Metropolitan University, Port Elizabeth, South Africa. The PV system consists of14 poly crystalline silicon modules connected in two strings of 7 series-connected modules. The performance of the system was simulated using PVsyst software using measured and Meteonorm derived climate data sets. The measured data showed that the PV system supplied 5757 kWh to the local electric utility grid in the year 2013. They conclude that simulation results gave good approximation to measured energy output.

Allouhi et al [87] presented investigates the performance analysis, economic and environmental assessment of two 2 kWp grid-connected PV systems installed on the roof of an administrative building at the High School of Technology of Meknes (Morocco).the simulation results were compared to the monitored data in the period of February-November 2015. Generally, the monthly computed and measured energy output at the inverter show an acceptable concordance except for August and October months when the relative error is significantly high.

Wang et al. (2011) [88] proposed a grid-interfacing system topologies with enhanced voltage quality for microgrid applications. Two three-phase four-leg inverters, together with DC microsources and nonlinear loads, are employed to construct a general series–parallel grid-interfacing system. With the reconfigurable functionalities, the proposed systems have been compared with conventional series–parallel systems and shunt-connected systems, showing flexible applicability. The system also shows the possibility to achieve auxiliary functions such as voltage unbalance correction and harmonic current compensation. The proposed methods have been verified by experimental tests on a laboratory setup.

Hartner et al [89] present analyzed optimal sizing of grid connected rooftop photovoltaic systems from a household's perspective.. This study has done for various scenarios on prices, tariffs, cost curves, and subsidies. They assessed the optimal PV system size for a sample of more than 800 households in Austria and estimated that for a minimum system size of 5 kW total investment costs for subsidized residential photovoltaic systems from 2008 to 2013 could have been 2.2% lower for the same amount of installed capacity.

3.2.1.2 Medium-scale PV systems

Fantidis et al [90] examined the potential of a 20 kW photovoltaic (PV) power plant connected to the grid at each of the 46 locations in Greece to predict energy production, cost of energy and reduction of greenhouse gasses (GHGs) emissions by using HOMER software. The study demonstrated that the PV power plant connected to the grid can play an important role in Greek energy generation and considerable quantity of CO2 is not released into the atmosphere each year. The financial analysis showed that the PV power plant could operate profitably in these 46 locations. Besides, Kumar et al [91] studied a grid connecting a 20 kWp solar photovoltaic installed on a flat rooftop and connected to the grid in Tiruchirappalli (India). The 20 kWp system is divided into four strings with an average PV output voltage of about 600 V in loaded condition. They highlight the operational performance and economic calculations of a grid connected solar photovoltaic. The results showed that the efficiency of the PV module varied between 10.14% and 12.6% and the inverter efficiency varied between 88.90% and 96.54%. The economic analysis shows that solar PV installation is a good investment. Oko et al. (2012) [92] presented a design analysis of PV system to supply a Laboratory at the Department of Mechanical Engineering, University of Port Harcourt, Nigeria. An automated MS Excel spreadsheet was developed for the design and economic analyses of PV system. Their results show that, unit cost of electricity for the designed PV system is high compared to the current unit cost of the municipally supplied electricity, but will be competitive with lowering cost of PV system components and favorable government policies on Renewable Energy (RE). Bansal and Goel (2000) [93] discussed the integration of 25 kWp solar PV system in an existing building of cafeteria on the campus of Indian Institute of Technology, Delhi by creating a solar roof covering an area of about 250 m2. The system was found to be optimum if integrated with an angle of 15° tilt with relation to north–south axis, in Delhi's climatic conditions, therefore giving it higher efficiency.

In [94], Kymakis et al calculate the final yield (FY), the reference yield (RY), the performance ratio (PR) and the capacity factor (CF) in order to evaluate the performance of PV park system of 171.36 kWp connected to the local power grid on the island of Crete. The PV park supplied 229 MWh to the grid during 2007, ranging from 335.48 to 869.68 kWh.

The final yield (FY) ranged from 1.96 to 5.07 h/d, and the performance ratio (PR) ranged from 58 to 73%, giving an annual PR of 67.36%. The study gave the following results, the average annual PV park energy output in 2007 was 1336.4 kWh/kWp, the average annual performance ratio of the park was 67.36% and the average annual capacity factor was 15.26%. Haas et al. (1999) [95] investigated the socioeconomic aspects about an Austrian 200 kWp-rooftop program (100 PV systems with an average capacity of 2.28 kWp) to promote small grid-connected PV systems in Austria.

3.2.1.3 Large scale PV power plants

Zafar et al [96] explored the economic and technical impact of 750 MW PV power plant connected to the national grid of Pakistan. The results positively confirm that connection of this PV plant does not cause any load flow violations and the recommended short circuit current levels of the system is preserved. Also Kumar et al [97], have studied the performance results of a 10 MW photovoltaic grid connected power plant at Ramagundam (India) and compared them with the simulation values obtained from PV system and PV-GIS software. The plant operates with a seasonal tilt. They concluded that the actual performance closely matches with the simulated performance of PV system and Solar GIS over the entire year. The study found that the total amount of energy injected in to the grid for the entire year is 16 047 MWh. The maximum energy is generated in the month of December (1589 MW h) and minimum energy is in the month of July (926 MWh). The final yield (FY) of plant ranged from 1.96 to 5.07 h/d, and annual performance ratio (PR) of 86.12%. Cheikh et al [98] investigated the performance of power plants with capacities greater than 5 MW. They have presented and evaluated the performance of the grid-connected PV power plant of 15 MWp, which was implemented to supply 10% of the electrical needs of Nouakchott (The capital of Mauritania (18.15° N, 15.98° W). The PV plant, which is composed of seventeen arrays connected to inverters, supplies the 33 kV electricity grid through nine transformers. The results showed that spring, summer and autumn months had the highest values of daily average energy output, while the lowermost ones occurs during winter months. Furthermore, Muneer et al. (2011) [99] proposed an optimization model to facilitate an optimal plan for investment in large-scale solar PV generation projects in Ontario, Canada. The optimal set of decisions includes the location, sizing, and time of investment that yields the highest profit. They considered various relevant issues associated with PV projects such as location-specific solar radiation levels, detailed investment costs representation, and an approximate representation of the transmission system.

Similarly, Sundaram et al [100] studied the performance characteristics of a 5 MWp grid connected PV system located in South India during 2011–2012. The comparison between the measured annual average energy generated by a 5 MWp system which is 24116.61 kWh/d, and the predicted annual average energy by employing a RETscreen software which was found to be 24055.25 kWh/d showed that they are appropriately close. The study showed also the following results: The module efficiency (6.08%), inverter efficiency (88.20%) and system efficiency (5.08%). Padmavathi et al [101] conducted an investigation on the performance of a 3 MWp grid-connected PV plant located in Karnataka State (India) using monitored data for the year 2011. The 3 MWp PV plant has three independent segments of 1 MWp. The following conclusions could be drawn: The annual average energy generated by the plant was 1372 kWh per kWp of the installed capacity and the performance ratio (PR) was found to be less than 0.6 from August to November due to high inverter failure losses estimated to be 818 MWh.

3.2.2 Grid-connected PV system application in the residential building

In the literature, several researchers focused on the investigation of the different categories of the grid-connected PV system. Concerning the small PV system size supplies in a residential building Energy efficiency refers to reducing the consumption of a home without causing a decrease in the level of comfort and quality of life of the inhabitants [102]. Missoum et al [20] investigated two ways to improve the energy performance of a typical rural house in the district of Chlef. The first way consists of using the passive solar by integration the adequate orientation of the house, insulation of the envelope house, efficient glazing and increased windows size with the use of shading device in summer. Second way consists of using the active solar by integration of PV systems to supply the house with electricity. The study analyzed the energy performance of 1 kW grid-connected PV system in a typical rural house in the Chef district. The results showed that 219 GWh of electricity and 26,508 t of butane gas could be saved annually in rural housing built.

Mehleri et al. (2013) [103] presented an optimization based approach for evaluation of RES on a Greek residential sector taking into account site energy loads, local climate data, utility tariff structure, characteristics of RE technologies (technical and financial) as well as geographical circumstances.

Al-Salaymeh et al. (2010) [104] proposed a design of PV system to produce energy for basic domestic needs. The proposed design studied the feasibility of utilizing PV systems in a standard residential apartment in Amman city in Jordan to conduct energy and economic calculations. It was found that the calculated payback period high in a stand-alone system, to decrease payback period a grid-connected PV system was suggested. The output results of this study show that installation of PV system in a residential flat in Jordan may not be economically rewarding owing to the high cost of PV system compared to the cost of grid electricity.

Danny Parker [105] presented annual performance data from a dozen low-energy houses in northern America. A lot of design combines greater energy efficiency and the use of solar photovoltaic energy in an attempt to get a zero energy home. The results indicate that low-energy buildings can be easily constructed in North America. Semache et al [21] presented an energy behavior study of a rural housing in three areas in Algeria. The energy performances of a reference house (Pilot project of Algiers) is analyzed and compared to these obtained for a traditional building in three regions of Algerian South, Then, a grid connected PV system is proposed on the roof of the REF building. The simulation of its electrical performances in Homer software indicates a positive energy balance of 62kWh/yr, 148kWh/yr and 93kWh/yr in the regions of Laghouat, Bechar, and El Oued respectively.

The integration of photovoltaic modules in the building envelope allow one to consider a multifunctional frame and then to reduce the cost by substitution of components.
G. Fraisse et al. [106] investigated the energy performance of water hybrid Photovoltaic /Thermal (PV/T) collectors applied to combisystems of Direct Solar Floor type. The recovered heat energy can be used for heating systems and domestic hot water. A. combination with a Direct Solar Floor is studied. The results show that the research led on the hybrid solar collectors are interesting and promising. However, it is required that both photovoltaic and thermal field maintain a strong, partnership in order to conceive a unique industrial component which integrates the thermal absorber and the photovoltaic module.

Li et al. (2012) [107] studied a grid-connected PV system installed in an institutional building in Hong Kong. The analysis was based on two years measured data made in Hong Kong from 2008 to 2009. Technical data including available solar radiation and output energy generated were systematically recorded and analyzed. It was found that with Feed-in-tariff schemes, high electricity selling price can shorten the payback period for grid-connected PV system to a reasonable time period that should be less than the lifetime (e.g. less than 20 years).

Dragana et al [108] estimated the performance and energy efficiency of the 2 kW (rooftop) solar PV plant installed on the building of the Faculty of Sciences and Mathematics (FSM building) in Niš (Republic of Serbia) for the period from January 1, 2013 to January 1, 2014. Based on the experimental determination results, the solar PV plant works efficiently on the real climate conditions. The measurement data showed that the greatest amount of electrical energy (291.47 kWh) was generated in August when the global solar energy was 206.19 kWh/m2. However, in the same period, the greatest amount of electrical energy (11.787 kWh/day) was generated on April 17, 2013. They concluded that the integration of PV systems into the transmission network was considered satisfactory.

L. Wang et al. [109] discussed the possibility of the zero energy building solution in the United Kingdom. The EnergyPlus software was used to study the design of a façade by considering insulation materials, window dimensions and their orientations. Dynamic Thermal Simulation Software, TRNSYS has been used to examine the feasibility of zero energy buildings with renewable electricity. The results show that theoretically it is possible to achieve zero energy homes in the United Kingdom. Missoum et al [22] estimated the energy performance of a typical individual bioclimatic dwelling equipped with a heating system in northern Algeria (Algiers). Thus, he examined the passage of this dwelling to a zero energy dwelling via the installation of a PV system connected to the electrical network. For this, he developed a digital model of this house which he then validated experimentally. The results show that the transition from a bioclimatic home to zero energy using a PV system connected to the grid has a high level of feasibility. But the return on investment is important which is essentially the high price of solar components and the low price of conventional energy in Algeria. Caroline Hachem et al [110] examined the energy performance of multi-historic buildings in terms of the demand for energy for heating and cooling and the generation of electricity by using photovoltaic systems. Ren et al. (2009) [111] dealt with the problem of optimal size of grid-connected PV system for residential application and developed a simple linear programming model for optimal sizing of grid-connected PV system. The objective of the study is to minimize the annual energy cost of a given customer, including PV investment cost, maintenance cost, utility electricity cost, subtracting the revenue from selling the excess electricity. It would be seen that the adoption of PV system offers significant benefits to household (reduced energy bills) and to the society (reduced CO2 emissions) as a whole.

3.2.3 Rooftop Photovoltaic System Technology

In the next years, there will be an explosion of solar PV rooftops across the world, big and small. Fifteen or 20 years from now, a “bare” rooftop will seem very strange to us, and most new construction will include PV as routine practice. This will lead to a parallel explosion in micro-grids (both residential and commercial), community-scale power systems, and autonomous-home systems. The grid will become a much more complex hybrid of centralized and distributed power, with a much greater variety of contractual models between suppliers and consumers [112]. Development of rooftop PV technologies has received much attention and introduction of a subsidy for the system cost and energy production especially in Germany and Japan has encouraged the demand for rooftop PV systems [113], where German PV market is the largest market in the world, and Germany is a leading country in terms of installed PV capacity. One of the most suitable policies for introducing rooftop PV systems to the market is Feed-in Tariff mechanism. According to this approach, eligible renewable power producers will receive a set price from their utility for all the electricity they generate and deliver to the grid, where grid interactive PV systems derive their value from retail or displacement of electrical energy generated. The power output of a PV system depends on the irradiance of Sun, efficiency and effective area of PV cells conducted. Therefore, it is compulsory to choose the optimal size of PV system according to the application. Algeria has abundant solar energy resource, which is extensively applied to buildings. Therefore, solar energy utilization in buildings has become one of the most important issues to help Algeria optimize the energy proportion, increasing energy efficiency, and protecting the environment. Solar PV system can easily be installed on the rooftop of education, governmental as well as on the wall of commercial buildings as grid-connected solar PV energy application. Energy efficiency design strategies and RE are keys to reduce building energy demand. Rooftop solar PV energy systems installed on buildings have been the fastest growing market in the PV industry. The integration of solar PV within both domestic and commercial roofs offers the largest potential market for PV especially in the developed world [113].

3.2 GRID-CONNECTED PHOTOVOLTAIC CHAIN

The basic building blocks of a grid-connected PV system are shown in Fig. 3.1. The system is mainly composed of a matrix of PV arrays, which converts the sunlight to DC power, and a power conditioning unit (PCU) that converts the DC power to an AC power.

The generated AC power is injected into the grid and/or utilized by the local loads. In some cases, storage devices are used to improve the availability of the power generated by the PV system. In the following subsections, more details about different components of the PV system are presented. A grid connected PV system eliminates the need for a battery storage bank resulting in considerable reduction of the initial cost and maintenance cost. The PV system, instead, uses grid as a bank where the excess electric power can be deposited to and when necessary also withdrawn from. When the PV system is applied in buildings, the PV modules usually are mounted on rooftop, which can reduce the size of mounting structure and land requirements.

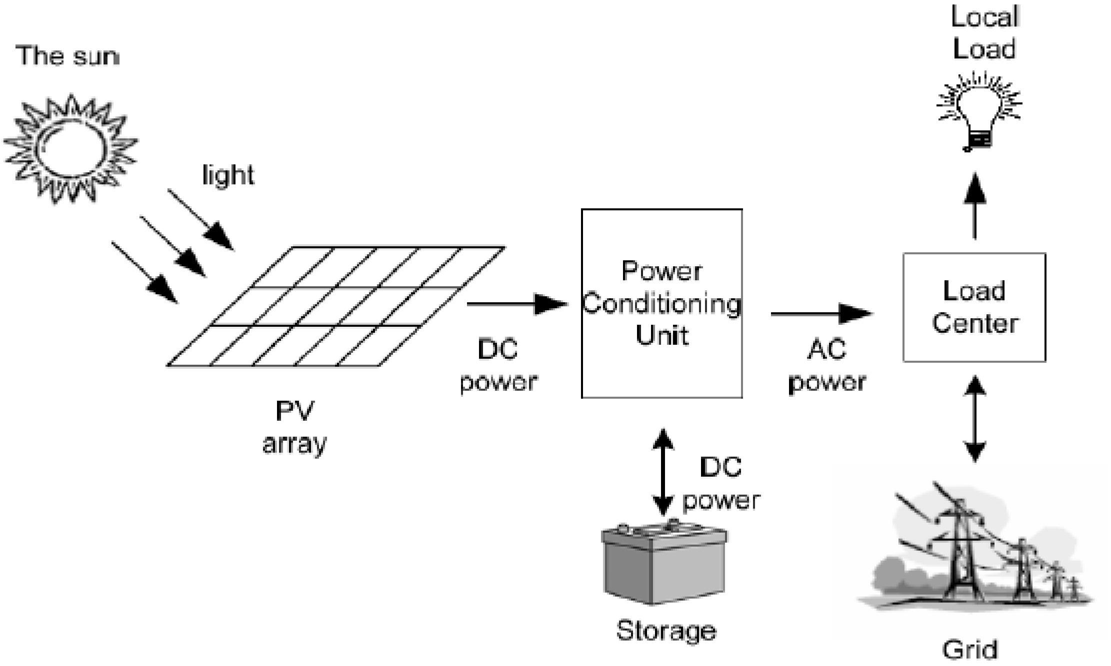


Fig.3.1 Main components of grid-connected photovoltaic system [114]

3.3.1 Solar irradiation

Information concerning available solar irradiation is required for most practical applications of solar energy in active and passive systems. Solar system and building design as well as thermal performance analysis require irradiation values on inclined surfaces. However, for most areas these data are not available and must be estimated, generally through models that use as input daily and hourly global irradiation data on the horizontal surface, G_d and G_h, respectively. For the North Mediterranean Belt area, horizontal global irradiation data have indeed been recorded at some stations, but the corresponding diffuse radiation records, D_d and D_h, are scarce. Thus, the diffuse values must also be estimated through models and correlations [115].

The sizing of a photovoltaic system for a given site requires the knowledge of the solar irradiance on the plane of the photovoltaic generator. However, the collection of a maximum of solar irradiation is conditioned by an adequate angle of incidence. By using a simulation program under Matlab, it is necessary to have broad sequences of daily irradiation values. Unfortunately, many localities in Algeria do not have these irradiation data or they are not sufficiently representative. In our present study, models for the estimation of clear sky solar irradiance on the inclined plane were used for two different sites in order to optimize the choice of the tilt of the photovoltaic generator. To validate these models, experimental data were used. These data were measured on plans with the same inclinations chosen for the two sites (Algiers and El Oued).

3.3.2 Photovoltaic conversion Cell/Module/Array

The basic element of photovoltaic generators is the photovoltaic cell, as shown in Figure 3.3. This element is a light sensor that receives light energy and converts it into electrical energy in the form of direct current (DC) thanks to the photovoltaic effect. The production of photovoltaic cells is done using semiconductor materials. Thin-film cells, organic cells, and crystalline silicon cells are the best known and the most commercialized. Photovoltaic cells that are manufactured by crystalline silicon technology are often the most used for the realization of photovoltaic modules. The silicon may be monocrystalline or multi-crystalline.

The photovoltaic cell is actually a generator of very low power. An elementary cell of a few tens of square centimetres delivers a maximum of a few watts at a voltage of about 0.6 V (voltage of the PN junction) [116]. To have a larger power generator, several photovoltaic cells must be associated. Association of cells in series increases the voltage of the assembly, while the parallel association of cells increases the current. The set is then called photovoltaic module, where its power can be up to 200 Watt peak or more (it all depends on the number of cells connected and the technology used). The surfaces of the photovoltaic modules are generally of the order of one square meter.

The serial/parallel wiring of photovoltaic modules is used to obtain a generator called photovoltaic Array as shown in Figure 3.2. The latter is mounted so as to have the desired characteristics. Several photovoltaic arrays connected together form what is called photovoltaic field whose power can be of the order of megawatts [117].

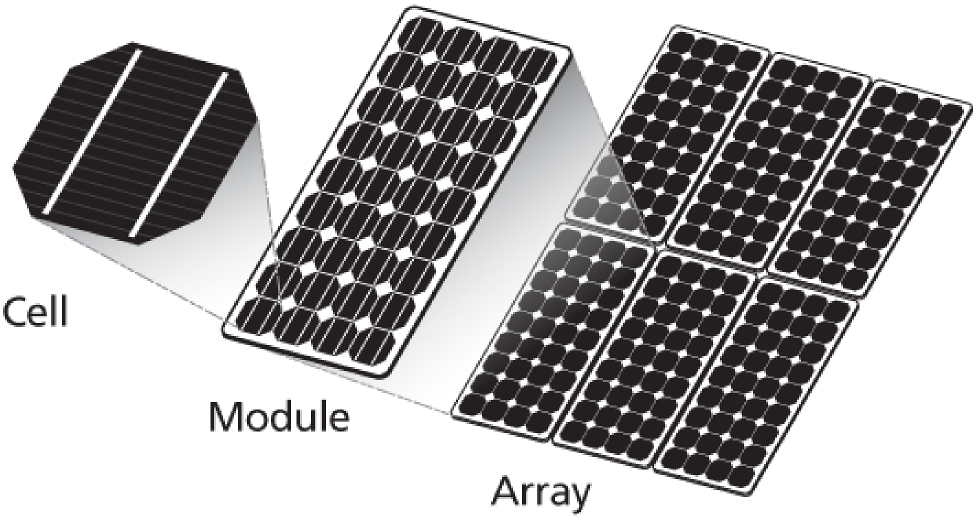


Fig.3.2 Relation between the PV cell, a module and an array

3.3.3 Power Conditioning Units

Power conditioning units are used to control the DC power produced from the PV arrays and to convert this power to high-quality AC power before injecting it into the Grid. PV systems are categorized based on the number of power stages. The past technology used single-stage centralized inverter configurations. The present and future technology focus predominantly on the two-stage inverters, where a DC–DC converter is connected in between the PV modules and the DC–AC inverter as shown in Fig. 3.3.

In single-stage systems, an inverter is used to perform all the required control tasks. But, in the two-stage system, a DC–DC converter precedes the inverter and the control tasks are divided among the two converters. Two-stage systems provide higher flexibility in control as compared to single-stage systems, but at the expense of additional cost and reduction in the reliability of the system [78]. During the last decade, a large number of inverter and DC–DC converter topologies for PV systems were proposed [78, 118], In general, PCUs have to perform the following tasks:

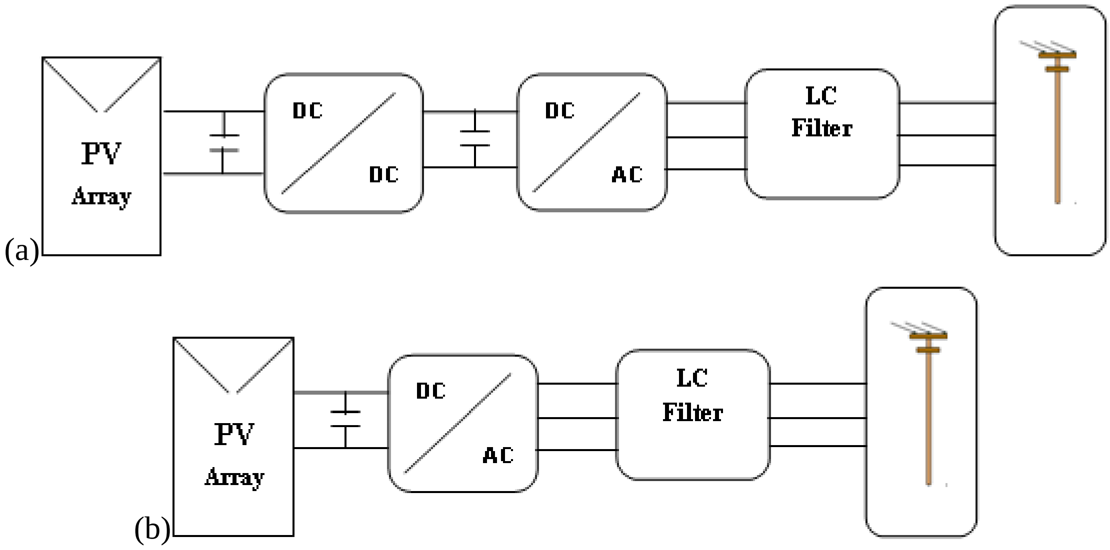


Fig 3.3. Classification of system configurations (b) single stage (a) two stages

3.3.3.1 Maximum Power Point Tracking (MPPT)

One of the main tasks of PCUs is to control the output voltage or current of the PV array to generate maximum possible power at a certain irradiance and temperature. There are many techniques that can be used for this purpose [118-121] with the Perturb-and-Observe (P&O) and Incremental Conductance (IC) techniques being the most popular ones [122].

3.3.3.2 Control of the Injected Current

Power Conditioning Units should control the sinusoidal current injected into the grid to have the same frequency as the grid and a phase shift with the voltage at the point of connection within the permissible limits. Moreover, the harmonic contents of the current should be within the limits specified in the standards. The research in this field is mainly concerned with applying advanced control techniques to control the quality of injected power and the power factor at the grid interface [123-125].

3.3.3.3 Voltage Augmentation

Usually, the voltage level of PV systems requires to be boosted to match the grid voltage and to decrease the power losses. This task can be performed using step-up DC–DC converters or MLIs. 3L-VSIs can be used for this purpose as they provide a good tradeoff between performance and cost in high voltage and high-power systems [126].

3.3.3.4 Islanding Detection and Protection

Islanding is defined as a condition in which a portion of the utility system containing both loads and distributed resources remains energized while isolated from the rest of the utility system [127].

3.3.3.5 Additional Functions

The control of PCUs can be designed to perform additional tasks such as power factor correction [128], harmonics filtering [129], reactive power control [130], and operating with an energy storage device and/or a dispatchable energy source such as diesel generator as an uninterruptible power supply [131].

3.3.4 Connection Topologies of Photovoltaic Systems

There are different techniques and topologies available for grid connected PV systems which are categorized based on the number of power stages. In PV plants applications, various technological concepts are used for connecting the PV array to the utility grid. Each technology has its advantage and/or disadvantages compared to other, interns of efficiency and maximum power point tracking and the cost.

3.3.4.1 Centralized inverters

The topology illustrated in Figure 3.4 was based on centralized inverters that interfaced a large number of PV modules to the grid. The PV modules were divided into a string, each generating a sufficiently high voltage to avoid further amplification. These series connections were then connected in parallel, through string diodes, in order to reach high power levels [78]. For this architecture, the PV arrays are connected in parallel to one central inverter.

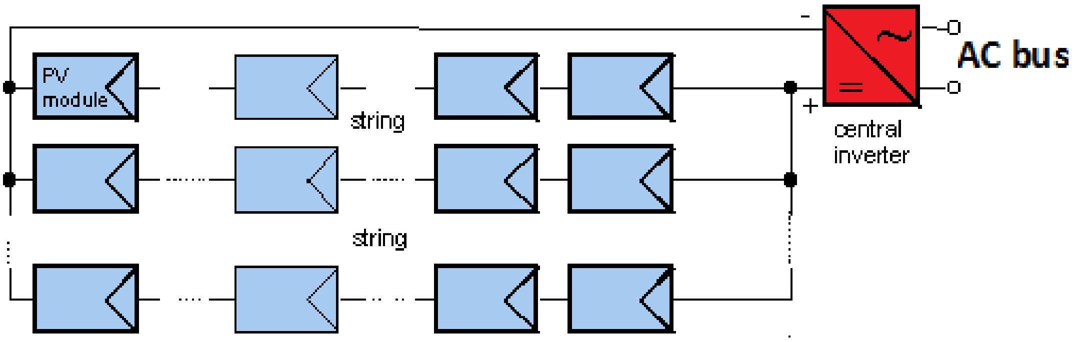


Fig.3.4 PV Central Inverters [132]

The organization is used for three-phase power plants, with power ranges between 10-1000 kW. The main advantage of central inverters is the high efficiency (low losses in the power conversion stage) and low cost due to usage of only one inverter. The drawbacks of this topology are the long DC cables required to connect the PV modules to the inverter and the losses caused by string diodes, mismatches between PV modules, and centralized maximum power point tracking [132, 133].

3.3.4.2 String Inverters

The present technology consists of the string inverters and the ac module. The string inverter, shown in Figure 3.5 is a reduced version of the centralized inverter, where a single string of PV modules is connected to the inverter. The input voltage may be high enough to avoid voltage amplification [78]. This configuration emerged on the PV market in 1995 with the purpose of improving the drawbacks of central inverters. Compared to central inverters, in this topology the PV strings are connected to separate inverters. If the voltage level before the inverter is too low, a DC-DC converter can be used to boost it. For this topology, each string has its own inverter and therefore the need for string diodes is eliminated leading to total loss reduction of the system. The configuration allows individual MPPT for each string; hence the reliability of the system is improved due to the fact that the system is no longer dependent on only one inverter compared to the central inverter topology [132].The mismatch losses are also reduced, but not eliminated.

This construction increases the overall efficiency when compared to the centralized converter, and it will reduce the price, due to possibility for mass production [78, 133]. The photovoltaic modules in the given topology are linked in a structure whereby they end up forming a string; the voltage from the PV array ranges between 150-450 V [134].

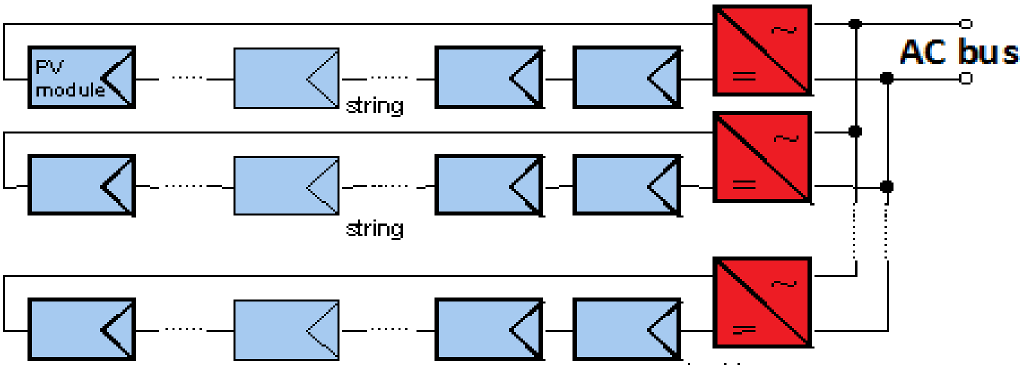


Fig.3.5 String Inverters [132]

3.3.4.3 Multi-String inverters

As this current and future topology, multi-string inverter configuration became available on the PV market in 2002 being a mixture of the string and module inverters [132]. The multistring inverter depicted in Figure 3.6 is the further development of the string inverter, where several strings are interfaced with their own dc–dc converter to a common dc–ac inverter. This is beneficial, compared with the centralized system, since every string can be controlled individually production [78, 133]. The power ranges of this configuration are maximum 5 kW and the strings use an individual DC-DC converter before the connection to a common inverter. The topology allows the connection of inverters with different power ratings and PV modules with different current voltage (I-V) characteristics. MPPT is implemented for each string, thus improved power efficiency can be obtained [132]. This gives a flexible design with high efficiency, and will probably become standard where centralized and string converters are used today.

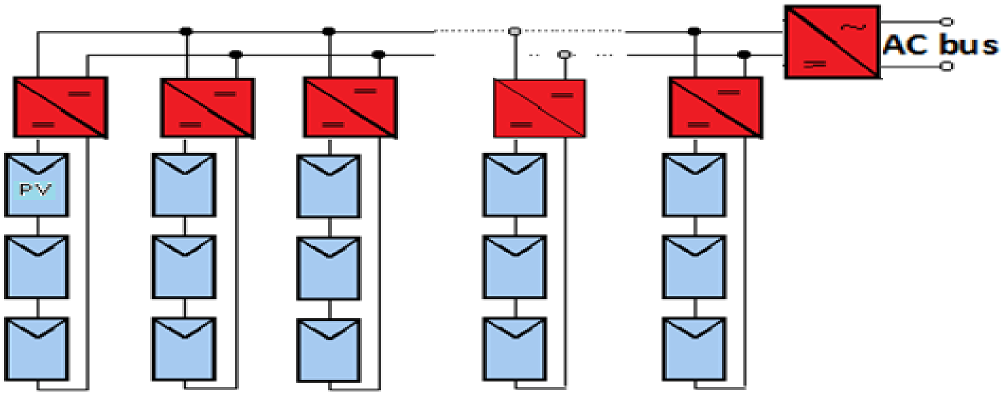


Fig.3.6 Multi-String Inverters

3.3.4.4 Module Inverters

Module Inverters topology shown in Figure .3.7 is the present and future technology consists of single solar panels connected to the grid through an inverter. A better efficiency is obtained compared to string inverters as MPPT is implemented for every each panel [132]. By incorporating the PV module and the converter into one device, the possibilities of creating a module based "plug and play" device arises, and it can then be used by persons without any knowledge of electrical installations. In this configuration the mismatch losses between the PV modules is removed and it is possible to optimize the converter to the PV module, and thus also allowing individual MPPT of each module. Since there will be need for more devices then with the previous mentioned configurations, it will give the benefit of large-scale production, and thus lower prices. On the other hand the input voltage will become low, requiring high voltage amplification, which may reduce the overall efficiency [78].

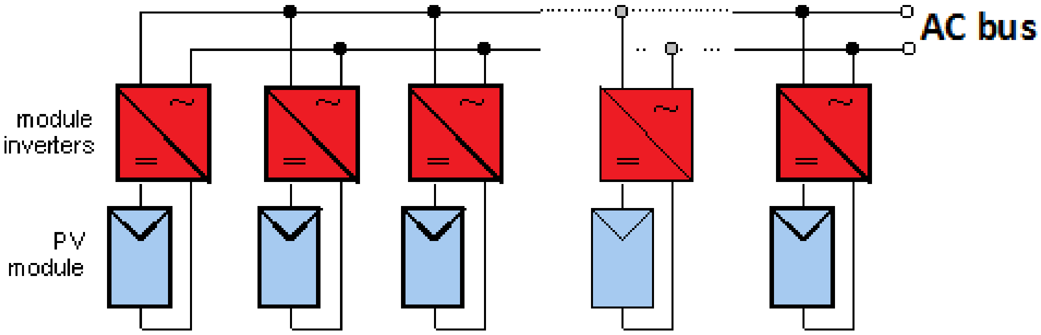


Fig 3.7 Module inverters

3.3.5 International Codes and Standards for Grid Connected PV system

In the grid connected photovoltaic systems there are many standards on the market dealing with the interconnection of distributed resources with the grid [133]. In this context PV system is of importance where all practice for wiring, design and installation has been explained. This thesis is limited to International Electro technical Commission (IEC), Institute of Electrical and Electronics Engineers (IEEE) and National Electrical Code (NEC). Standards and codes governing the design of the proposed PV system at NTNU electro building is based on PV electrical installations practices and interfacing with grid. In the standard [135].

IEEE 929-2000: Recommended Practice for Utility Interface of Photovoltaic (PV) Systems which gives the guidance to PV system practices. These practices include power quality and protection functions [136]. The IEEE 929 standard also containing UL 1741 standard which has been used as the key to select inverters used in this design. The IEC standard has been discussed in [133], and they show to give out the characteristics of PV system and grid interface at the point of common coupling (PCC).

National Electrical Code in article 690 Photovoltaic power systems [137] as well as explain in literatures [138] shows the necessity and important information for proper installation of PV system. The 690 code explain most of the important information in both design aspects and installation. Some of this important information includes;

- ✓ PV system conductors and coding.
- ✓ Grounding system and Module connection
- ✓ PV source circuits, PV Inverter output circuits and circuit routing.
- ✓ Identification of equipment used and system circuit requirements i.e. Open Circuit voltage and short-circuit current.

3.4 CONCLUSION

The main aim of this chapter is separate in two parts, the primary parts provides a literature review about previous work. The survey includes the following aspects power quality improvement of grid-connected PV systems and design and sizing of PV systems. Before introducing renewable energy systems into a building, it is essential to first reduce energy requirements. in other hands, the climatic conditions have a significant impact on the annual energy demand of the residential building, the integration of photovoltaic systems connected to the network in the residential building to cover the energy needs are reliable, efficient and cost-effective at the same time with durations of Depreciation lower than their life cycles. Is the most cost-effective energy efficiency measure in the building.

In the next part, a small overview for the photovoltaic systems and grid-connected PV system have been discussed, the characteristics and the behaviour for climatic changing of the PV system have been explained and also the deferent topology and structures for the grid connected PV inverter are described. Importance of grid-connected and the relationship with the renewable energy sources have been detailed, and also explained the conditions and international standards for the grid connected PV inverters.

Chapter 4

Methodology and Modelling of Grid-Connected PV system

Chapter 4:

Methodology and Modelling of Grid-Connected PV system

4.1 INTRODUCTION

Power cuts in Algeria have been escalated in recent years due to the shortage of fuel necessary to run power plants due to the rapid depletion of fossil fuels and continual instability of their prices and overconsumption of loads especially in summer season, which negatively affected various levels of social and economic activities. On the other hand, Algeria has some of the highest GHG emissions in the world. To solve problems of power cuts and emissions,

Algeria is taking impressive steps to rationalize consumption and optimize the use of electricity in addition to develop and encourage PV system projects that can be deployed on rooftop of institutional and governmental buildings. As a result, Algeria government intends to implement about program for Renewable Energies and Energy Efficiency, in between the objective of this program installation grid-connected PV systems on the roof of buildings.

This chapter presents an approach for optimum design of rooftop grid-connected PV system installation for house is situated in the north of Algeria in a village named Souidania, Algeria as a case study. The approach proposed in this chapter is based on optimal configuration of PV modules and inverters according to not only MPP voltage range but also maximum DC input currents of the inverter.

In order to ensure acceptable operation at minimum cost, it is necessary to determine the correct size of grid-connected PV system considering meteorological data, solar radiation, and exact load profile of consumers over long periods. The next limitation to consider is the area available for mounting the array. For the majority of grid-connected PV systems, this area is the roof of the house or any other building.

4.2 MODELLING OF PROPOSED ENERGY SYSTEM

The photovoltaic power systems connected to the grid may change in size depending on the power demand; however, they have the same components.

The proposed system model for a grid-connected PV system for residence building is shown in Fig. 4.1 shows a block diagram of the grid-connected photovoltaic system which is integrated into the building [139, 140]. It is comprised of a PV array, an inverter and a meter to measure the energy exported to the grid and the energy imported from the grid. All electrical appliances in the house are served by both the photovoltaic system and the grid. During the daytime, the electricity is supplied by the photovoltaic system and during the night (absence of the sun) or in extra demand of energy, the electrical power is supplied from the grid. In the case of surplus of energy, the extra energy is injected to the grid. The house meter is used to calculate both of the produced and consumed energies. The photovoltaic panels supply a DC voltage bus through a converter designed to carry out the DC-AC conversion and to ensure that the PV generator is always operate at its optimum point of operation (MPPT: Maximum Power Point Tracking). Since the electrical characteristics of the photovoltaic panels are related to weather conditions, this converter improves the overall system's profitability. The grid can permanently accept the energy that is produced by the photovoltaic panels, allowing a relatively rapid return on investment. Therefore, there is no production shedding in this type of system. Indeed, the grid whose mission is to permanently ensure the match between production and electricity consumption. For a well-planned PV installation, the power of the inverter must be adapted to the connected photovoltaic generator [141].

In order to perform this operation, the power ratio acts as a reference value. It defines the interface of the two systems based on the ratio between the maximum input power of the inverter and the peak power of the PV array.

- If maximum efficiency is to be achieved, the configuration must have a power ratio of about 110%. In other hand, it is a configuration with an optimized profitability that is sought; the improvement of the profitability or the reduction the duration of damping. Also, it depends on the sunshine; the operating efficiency at a partial load of the inverter and the level of purchase rates.
- If the orientation of the PV generator deviates from ideal values (e.g. on a PV facade), this must be taken into account by considerably reducing the dimensioning of the inverter.

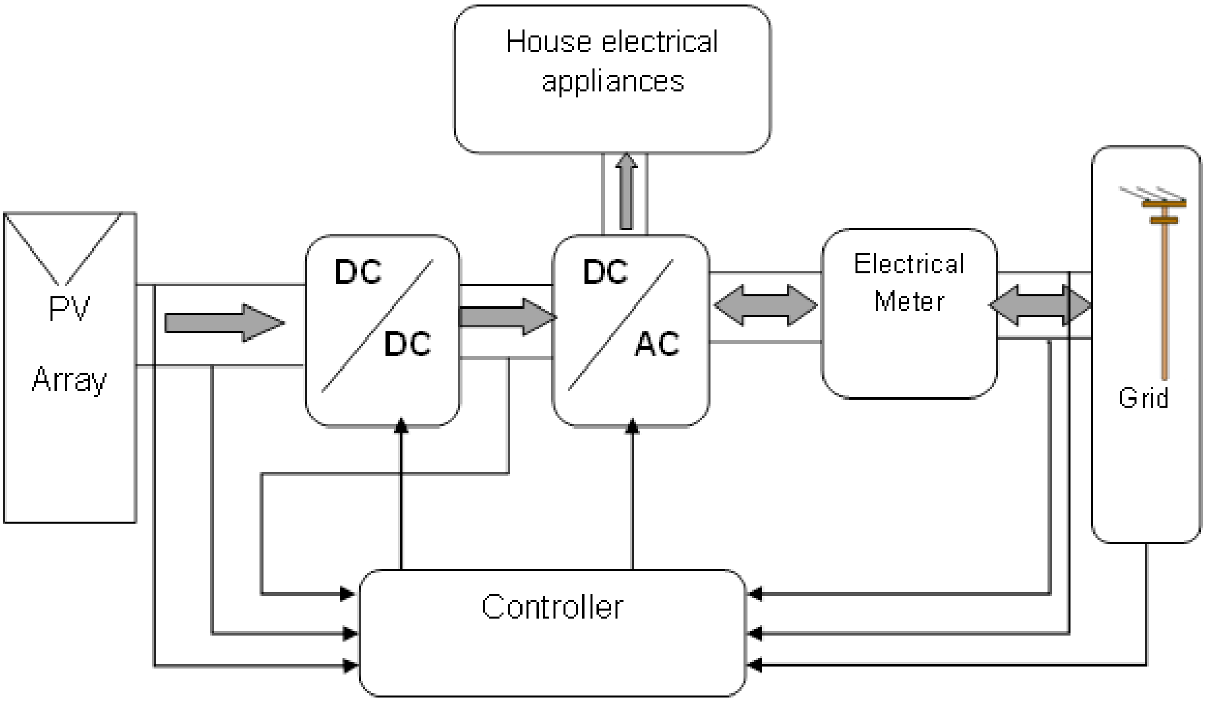


Fig. 4.1. Block diagram of the grid connected photovoltaic system

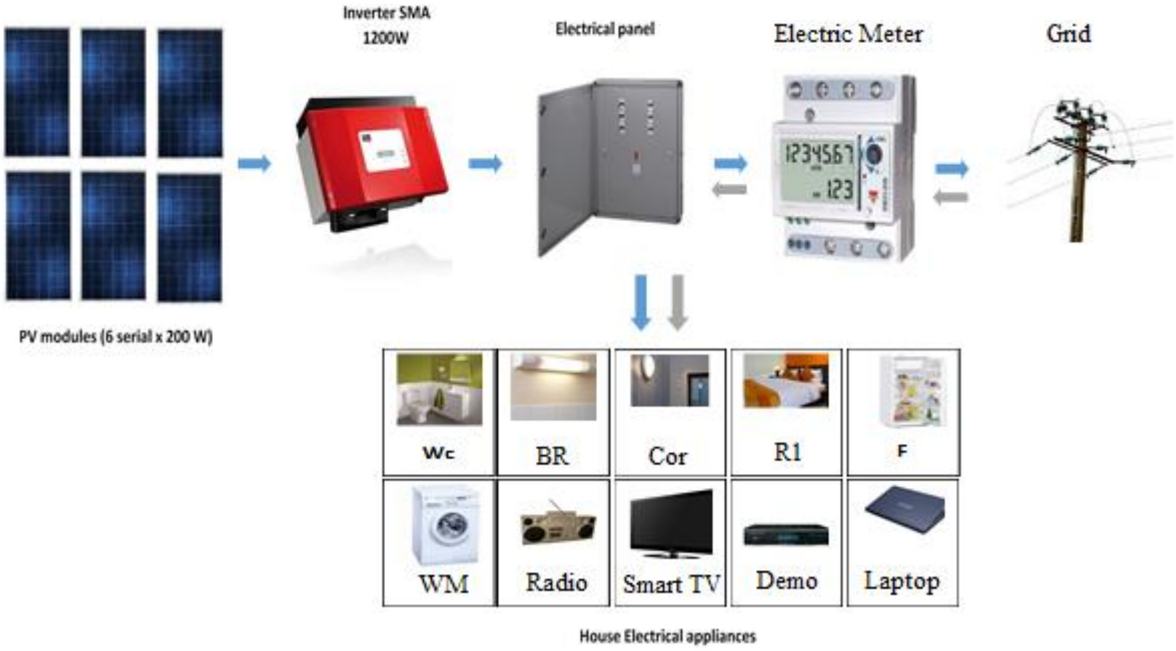


Fig. 4.2. The general scheme of the proposed grid-connected PV system

In Fig. 4.2, it is shown that the system contains 6 PV modules mono-crystalline arranged in series, the whole module area is 7.66 m². The detailed technical specifications of this model are presented in Table 4.1. It contains also an inverter SMA-1200 which guarantees the supervision and the safety of the grid. Furthermore, the system assures the DC/AC conversion with a power of 1.2kVA. The nominal productivity of this inverter is 92.1% and its specifications are reported in Table 4.2.

Table 4.1
Technical specification of solar PV module (Condor, CEM200M-72)

Settings	**Value**
Nominal maximum power (W)	200
Optimum operating voltage (V)	36.5
Optimum operating current (A)	5.48
Open circuit voltage (V)	44.5
Short circuit current (A)	5.92
Operating temperature	−40 ◦C ∼ + 85 ◦C
Normal operating cell temperature	45 ± 2 ◦C
Dimension (mm)	1580 mm × 808 mm × 45 mm

Table 4.2
Technical characteristics specifications of the inverter SMA (SB 1200 Sunny Boy)

Settings		**Value**
DC Input	Maximum power (W)	1320
	Maximum voltage (V)	400
	Maximum current (A)	12.6
	MMPT voltage range (V)	From 100 to 320
AC Output	Maximum power (W)	1200
	Nominal voltage range (V)	From 180 to 260
	Maximum current (A)	6.1
	Nominal AC frequency (Hz)	50 / 60
Efficiency (%)		92.1

4.2.1 Modelling of solar radiation

The sizing of a photovoltaic system for a given site requires the knowledge of the solar irradiance on the plane of the photovoltaic generator. However, the collection of a maximum of solar irradiation is conditioned by an adequate angle of incidence. By using a simulation program under Matlab, it is necessary to have broad sequences of daily irradiation values. Unfortunately, many localities in Algeria do not have these irradiation data or they are not sufficiently representative. In our present study, models for the estimation of clear sky solar irradiance on the inclined plane were used for two different sites in order to optimize the choice of the tilt of the photovoltaic generator. To validate these models, experimental data were used. These data were measured on plans with the same inclinations chosen for the two sites (Algiers and El Oued).

The global radiation incident on tilted surface on the terrestrial surface G (β) can be calculated as the sum of direct radiation B (β), diffuse D (β), and reflected R (β) (Equation (4.1)) [142]:

$$G(\beta) = B(\beta) + D(\beta) + R(\beta) \tag{4.1}$$

a) Direct Radiation on Tilted Surfaces

The direct component B (β) (Equation (4.2)) can be obtained by using the angles of incidence θs and zenith of the sun θz:

$$B(\beta) = \frac{\mathrm{B}(0).\cos\theta_s}{\cos\theta_z} \tag{4.2}$$

b) Diffuse Radiation on Tilted Surfaces

The model of Liu and Jordan used considers the sky as a source of diffuse radiation characterized by an isotropic emission (the diffuse radiation emanating from the sky is uniformly distributed) [142]. The model of diffuse illumination on an inclined surface is expressed by a simple equation (4.3) as a function of illumination on horizontal plane and angle of inclination.

$$D(\beta) = D(0)\left[\frac{1 + \cot(\beta)}{2}\right] \tag{4.3}$$

Where β is the angle of inclination of the PV generator.

c) **Reflective Radiation on Tilted Surfaces**

Reflected light or albedo on an inclined surface is given by the equation (4.4) [142]:

$$R(\beta) = \frac{1}{2}\rho\, G(0)[1 - \cos(\beta)] \tag{4.4}$$

Where ρ is the reflectivity of the soil, in the absence of specific information its value is about 0.2 for ordinary or grassy soil and up to 0.8 for soil covered with snow [142].

4.2.2 Modelling of PV Module/ Array

The mathematical modeling of physical phenomena of photovoltaic origin is essential, allows to characterize the behavior of a photovoltaic system, from the capture organs to the organs of restitution of the energy, in order to establish a direct relation between the various system components and to induce a relationship between the energy produced by the installation and the energy demand and to predict the characteristics of each part of the system based on meteorological data.

The photovoltaic system modeling depends on the choice of the equivalent electrical circuit of a photovoltaic cell. It is therefore necessary to understand the physical configuration of the elements making up this cell and their electrical characteristics in order to choose the appropriate mathematical model. The mathematical models that are based on the Shockley diode equation represent a non-linear behavior resulting from semiconductor junctions. These models are differentiated by the mathematical procedures and the parameters number involved in the calculation of the voltage and current of the photovoltaic module. In the literature, several mathematical models exist to describe photovoltaic cells, from simple to more complex models ranging that account for different reverse saturation currents. The single diode model is used in this study to represent a photovoltaic cell, which offers a good compromise between accuracy and simplicity [143-147].

The modelling of photovoltaic cells necessarily involves a judicious choice of equivalent electrical circuits. To develop a precise equivalent circuit for a PV cell, it is necessary to understand the physical configuration of the elements of the cell as well as the electrical characteristics of each element, taking more or less details.

The mathematical modelling of the equivalent circuit of a solar cell is idealized by a junction diode PN with an I_{ph} current source, a series resistor R_s, which models the power losses, a parallel resistor R_{sh}, which represents the internal losses [148]. There are numerous mathematical models but the only difference between them is the mathematical procedures and the number of parameters involved in the calculation of the voltage and current of the photovoltaic module. These models differ from each other by the mathematical procedures and the number of parameters involved in the calculation of the voltage and current of the photovoltaic module, both are based on Shockley's well-known diode equation. Two models of GPV will be presented [149], model with a single diode (or simple exponential), and model with two diodes (or double exponential).

a) Model with single diodes

By employing the Kirchhoff law at the equivalent circuit below Fig. 4.3 to find the ratio between the output current I and the output voltage V across the load resistor Rc [149-151]. The application of the laws of Kirchhoff allows at first to write the relation between the currents:

$$I + I_{sh} - (I_{ph} - I_d) = 0 \tag{4.5}$$

It remains to explain the different currents:

Ish, shunt current:

$$I_{sh} = \frac{V + R_s I}{R_{sh}} \tag{4.6}$$

Rs: Resistance series of the module

Rsh: Shunt resistance of the module

Iph, photo-current:

$$I_{ph} = \frac{G}{G_{ref}}\left(I_{ph,ref} + u_{I,sc}\left(T - T_{ref}\right)\right) \tag{4.7}$$

Iph, ref: Short-circuit current in reference conditions [A].

G: Solar irradiance [W / m²].

Gref: Solar irradiance under reference conditions [W / m²].

$\mu_{I,\,sc}$: Temperature coefficient of the short-circuit current [A / ° K].

T: Operating temperature of the cell [° K].

Tref: Operating temperature in reference conditions [° K].

Id, diode current:

$$I_d = I_{sat}\left[exp\left[\frac{V + R_s I}{nV_{th}}\right] - 1\right] \tag{4.8}$$

Isat: Saturation current of the diode [A].

Vth: Thermal residual voltage [V].

n: Ideal diode factor of the solar cell.

The saturation current of the Isat diode is expressed by:

$$I_{sat} = I_{sat,ref}\left[\frac{T}{T_{ref}}\right]^{3/n} exp\left[\frac{E_g}{nV_{th}}\left[\frac{T}{T_{ref}} - 1\right]\right] \tag{4.9}$$

Isat, ref: Diode current in reverse under reference conditions [A].

Eg: Semiconductor gap energy band [V].

Vth: Voltage [V].

The saturation current Isat, ref is expressed by:

$$I_{sat,ref} = \frac{I_{sc,ref}}{exp\left[\frac{V_{oc,ref}}{nV_{th}}\right] - 1} \tag{4.10}$$

The expression of Vth:

$$V_{th} = \frac{kT}{q} \tag{4.11}$$

k: Boltzmann constant k = 1.38e-23 [J / ° K].

T: Operating temperature of the cell [° K].

q: Faraday constant q = 1.60e-19 [C].

Equation (1) is written finally:

$$\mathrm{I} = \mathrm{I_{ph}} - \mathrm{I_{sat}}\left(\exp\left(\frac{\mathrm{V} + \mathrm{R_s I}}{\mathrm{nV_{th}}}\right) - 1\right) - \frac{\mathrm{V} + \mathrm{R_s I}}{\mathrm{R_{sh}}} \tag{4.12}$$

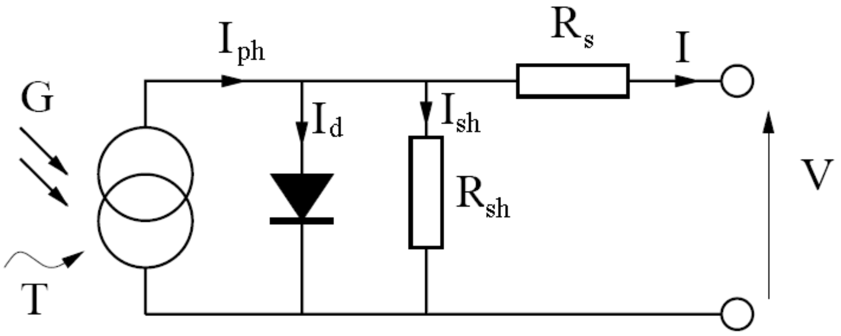


Fig. 4.3. Equivalent circuit of a solar cell, model of single diodes

b) Model with two diodes

In this study, the two diodes model is considered. A supplementary diode is positioned in parallel with the circuit of the single diode model as shown in Fig. 4.4. This diode is included to provide more accurate I-V characteristic curve [152]. Equation (4.13) shows the relation between the output PV current I and the output PV voltage V [149]. This two-diode model is more accurate than the simple model of a diode, but because of the difficulty of solving the current equation, the simple model of a diode is preferred.

$$I = I_{ph} - I_{sat1}\left(\exp\left(\frac{V + R_s I}{n_1 V_{th}}\right) - 1\right) - I_{sat2}\left(\exp\left(\frac{V + R_s I}{n_2 V_{th}}\right) - 1\right) - \frac{V + R_s I}{R_{sh}} \tag{4.13}$$

Where R_s is series resistor, R_{sh} is shunt resistor, I_{ph} is photo-current, V_{th} is thermal voltage of the diode, I_{sat1} and I_{sat2} are saturation current of the diode D_1 and D_2, n_1 and n_2 are ideality factors of the diode D_1 and D_2.

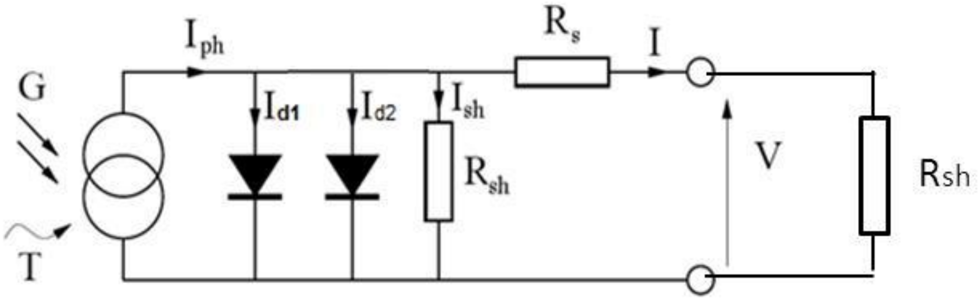


Fig. 4.4. Equivalent circuit of a solar cell, model of two diodes

A value of the ideality factor n different from the unit is associated with a predominant recombination mechanism and depends on the nature and position of the traps.

n = 1: The space charge area is depopulated (ideal case).

1 <n <2: The trap level is shallow in the space charge zone and n depends on the polarization [11].

n = 2: The recombination centers are uniformly distributed in the space charge area and on one level in the middle of the band gap.

2 <n <4: The recombination centers are unevenly distributed with a reduced density at the center of the space charge area relative to the surface

4.3.3 Photovoltaic array parameters

Voltage and Current outputs of the PV modules is affected by temperature and irradiance [138, 153]. Power electronics components of a photovoltaic system, such as grid-direct inverters have maximum and minimum voltage inputs. through rating of power electronics equipment, the variations of the temperate and the irradiance should be taken into account especially for the maximum power point tracking range of inverters.

a) Effect Temperature on Voc s

A Photovoltaic module's voltage output is actually a variable value that is primarily affected by temperature. The relationship between module voltage and temperature is actually an inverse one. As elaborated in Fig. 4.5, the module's temperature increases, the voltage value decreases and vice versa. It is important to put into consideration the cold and hot temperatures during PV design as shown in PV calculations in [138, 154]. If the temperature of the module is less than the STC value of 25°C, the module's open circuited voltage, Voc value will actually be greater than the value listed on the module's listing label.

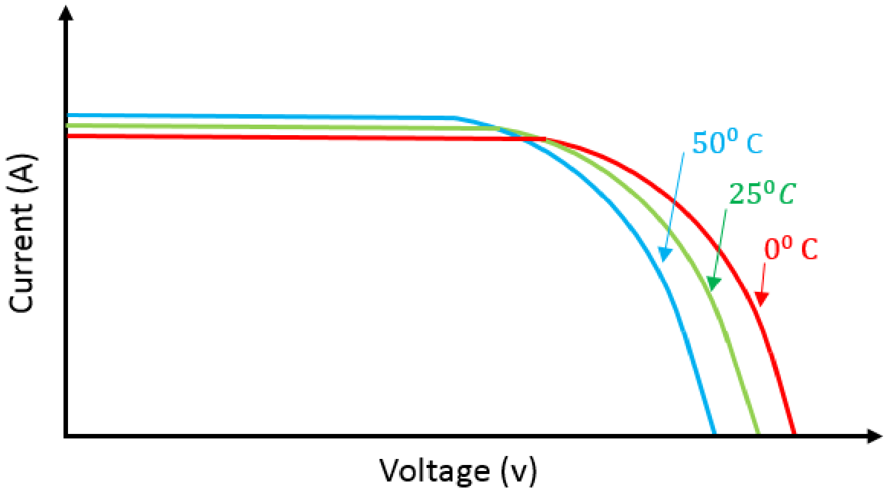


Fig. 4.5: I-V characteristics of a PV module with temperature variation

Photovoltaic module manufacturers will description the amount of change their modules testing in the form of temperature coefficients, most often in terms of a percentage per degree Celsius. For example, SM-55 solar modules at SIEMENS, the open circuited voltage temperature coefficient is $-0.077V/^{0}C$

This means that for every degree change in temperature, the module’s open circuited voltage, Voc will change in the opposite direction by 7.7%. For example, if the PV module got colder by 1°C, the PV voltage would increase by 7.7%.

The rule in [138, 154] can be used to decide the averaged maximum and minimum voltages of the modules at these temperatures. Since the string voltage in this design will have a voltage, Voc is obtained to be 42 V. If we assume the working environment of the PV modules as recorded in, the functioning temperatures of the modules are assumed to be from -20°C to 40°C.

$$V_{OC} = V_{OC\_STC} - [{}_{\gamma} * (T - T_{STC})] \tag{4.15}$$

Therefore, using equation 4.15 for the worst ecological conditions we have the minimum and maximum Voc as 41.45 V and 42.18 V correspondingly. This gives the voltage change of approximately to ∆V=0.73 V.

b) Effect Irradiance on Ics

The quantity of current produced by a PV module is directly proportional to how bright the sun. Higher levels of irradiance will cause more electrons to flow off the Photovoltaic (PV) cells to the load attached. However, the amount of voltage produced by the PV module is affected by the irradiance value, but the effect is very small. As demonstrated in Fig. 4.6 the PV module’s voltage changes very small with changing levels of irradiance. the SM-55 solar module has coefficient of current of $+0.0012\ A/^{0}C$.

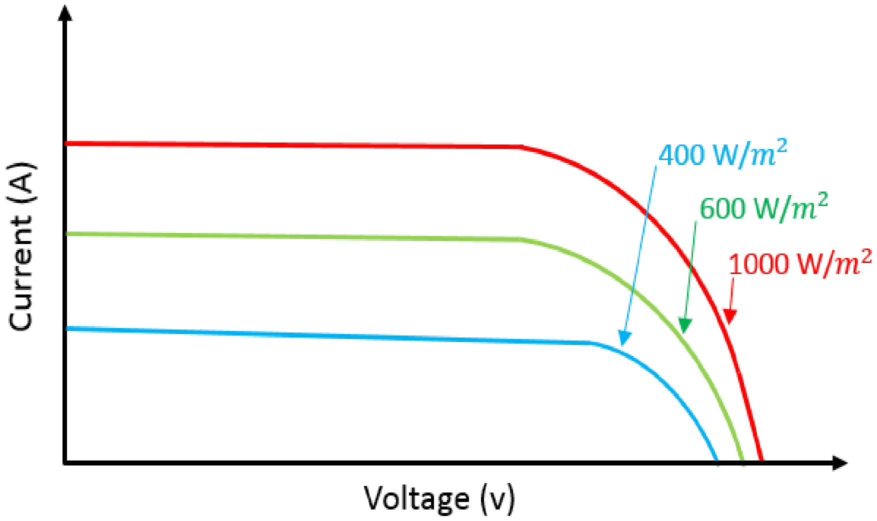


Fig. 4.6: I-V characteristics of a PV module with irradiance variation

4.2.4 MPPT Control System (Maximum Tracking Point)

Many MPPT methods have been reported, such as perturb and observe (P&O), incremental conductance (IC), neural network based (ANN) and fuzzy logic control as it has been said in [133, 134, 155]. Together with the efficiency, each method has its advantage and disadvantage for the tracking the maximum power. These approaches have been effectively used in standalone and grid-connected PV solar energy systems and operation well under sensibly slow and smoothly changing illumination conditions mainly caused by climate fluctuations.

In order to utilize the maximum power produced by the PV modules, the tools of power conversion have to be prepared with a maximum power point tracker (MPPT). This is a device which tracks the voltage at where the MPP is utilized at all times. It is generally implemented in the DC-DC converter, but in systems without a DC-DC converter the MPPT is included in the inverter control. Maximum power point tracking will ensure that, PV modules operate in such away maximum voltage, Vmp and maximum current, Imp of the modules will be attained and produce maximum power, Pmax point, this illustrated on the Fig. 4.7 are specified in the PV module data sheet of attached to it. The values are at standard test condition (STC) and they are called PV performance parameters.

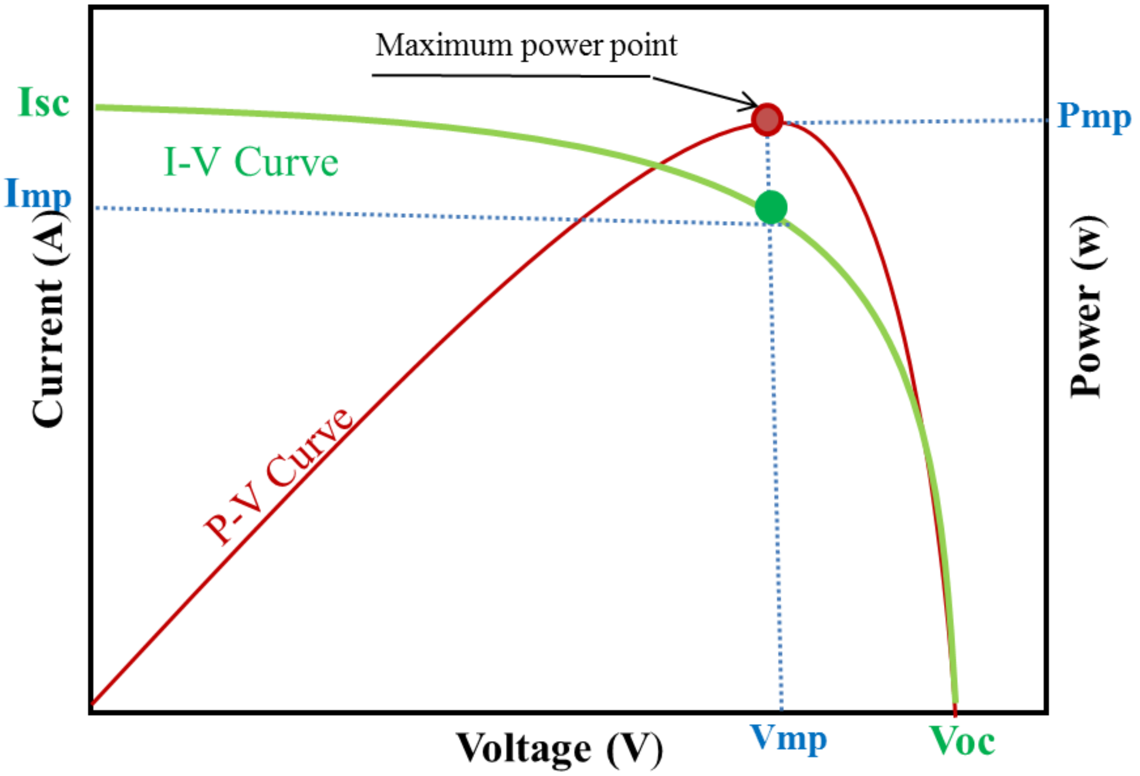


Fig. 4.7: current, Voltage and Power characteristics of a PV module

The MPPT controller in the proposed system uses the P&O technique. Figure 4.8 illustrates the flowchart of the P&O MPPT algorithm. As shown in the flowchart, the algorithm changes the operating voltage in the required direction and samples dP/dV. If dP/dV is positive, then the algorithm increases the voltage value towards the MPP until dP/dV is negative. This iteration is continued until the algorithm finally reaches the MPP. This algorithm is not suitable when the variation in the solar irradiation is high. The voltage never actually reaches an exact value but perturbs around the maximum power point (MPP) with fixed step.

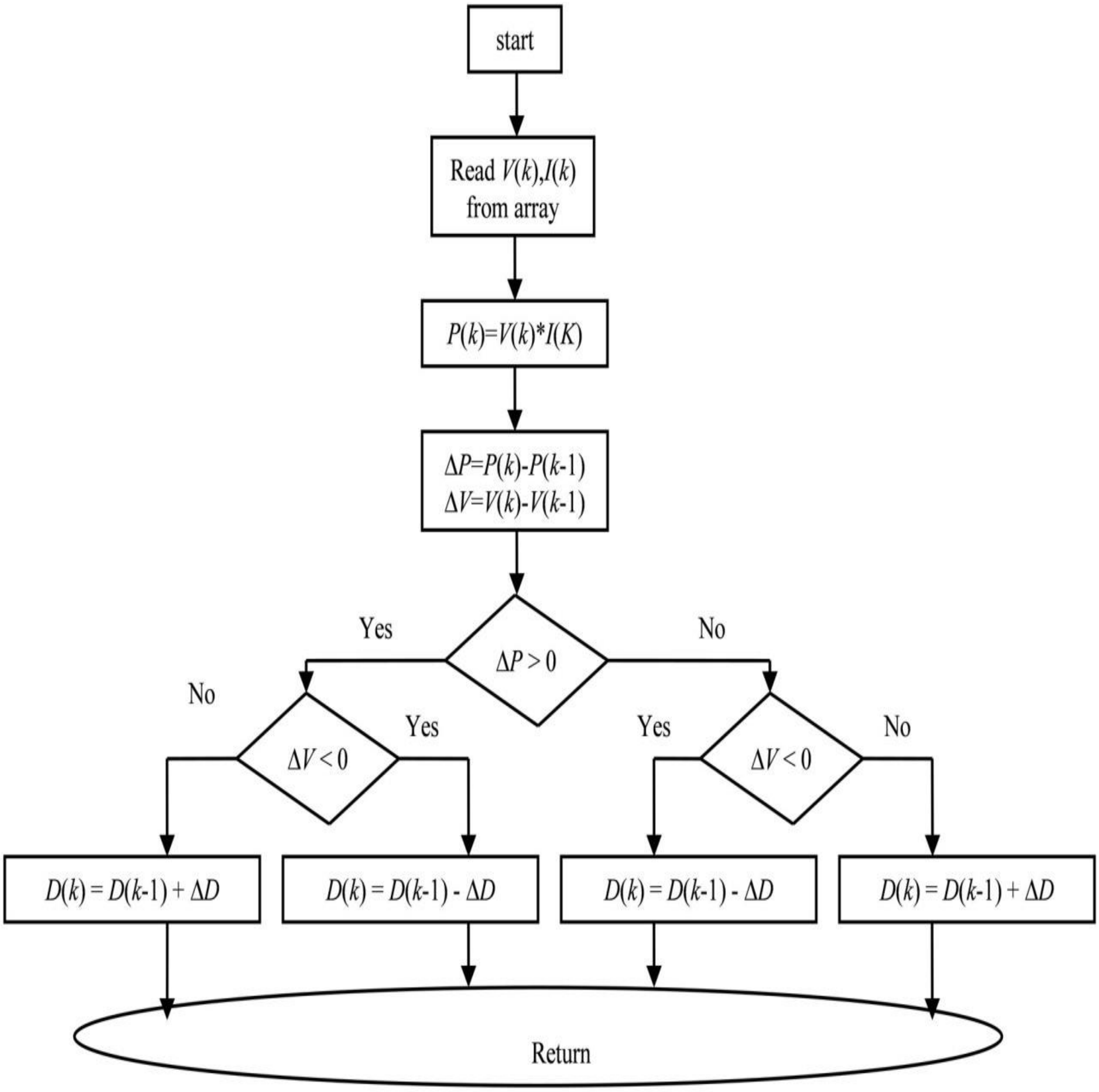


Fig 4.8 Flowchart of the P&O MPPT algorithm

4.2.5 Optimization of inclination angle of the PV generator:

In many cases, PV applications do not have a sun tracking system. For this, the PV generator must be inclined relative to the horizontal so that it receives a maximum energy density. In the ideal case, the PV module must always be perpendicular to the incident solar rays. However, this cannot be achieved for a fixed installation because the declination and the height of the sun vary during the year. A compromise is adopted such that the chosen slope for the module is that which allows obtaining a maximum annual energy. To find the optimal tilt of a photovoltaic generator for a given site, we evaluate the annual global irradiation on the inclined plane for different inclinations with respect to the horizontal. This variation of inclination is illustrated in Figure 4.9, where the optimal inclination for the selected site is close to the latitude of the place.

The solar radiation on a tilted surface is calculated using Hay model correlations [156]. Based on the model and the irradiance data, the yearly optimization angle for the grid PV system is 35°. However, for our case winter optimization was preferred. Therefore, a 45° of inclined angle is used in the installation of the PV array on the inclined roof and the performances evaluation of the grid PV system.

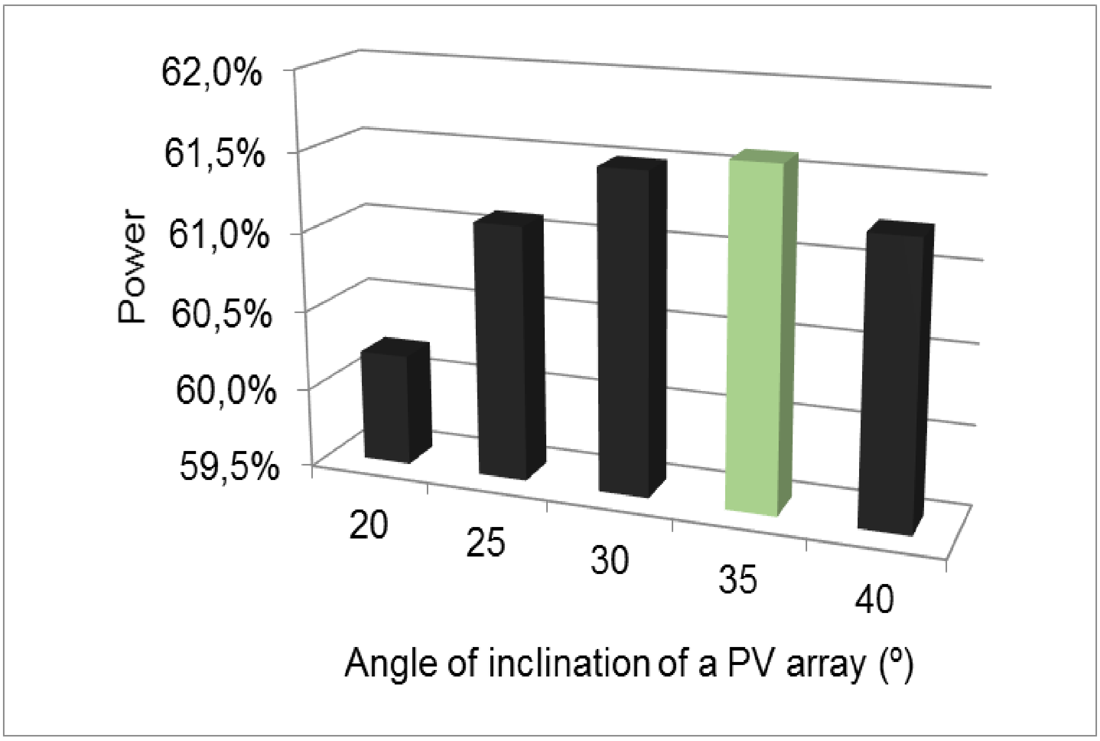


Fig. 4.9. PV proportion in the electrical balance as a function of the angle of inclination

4.2.6 Modelling of the inverter

In this work we can classify the models into three main modelling methods according to their level of complexity: numerical, analytical and empirical. Numerical modelling is preferred in case of studies of physical phenomena. Analytical modelling most often resolves simplified mathematical formulations by hypotheses that are valid within study case limits that may be stricter. This method reduces the complexity of the problem and the model to limit the description of the system to the bare necessities and thus also speeds up the calculation speed. Finally, in empirical modelling, the model defines a relation deduced from the incoming and outgoing data of the physical object, in combination with the modeller's experience. Because of its simplicity and pragmatism, this type of model is widely used in the industry. However, this method is only valid in very specific applications and does not allow for example to imagine parametric studies such as sizing.

In this section, an empirical model was introduced by SANDIA Laboratories (Sandia National Laboratories), the model was valid to all commercial inverters employed in PV systems. It is a simple model which allows the calculation, with precision, the output power (P_{ac}) according to the input power (P_{dc}) of the inverter. This model will be used to model the dynamic behaviour of single-phase inverter (SMA1200) connected to the grid. The model requires an adjustment of the performance parameters (coefficients) under real conditions.

The equations below describe the model of the inverter developed by the SANDIA laboratories. The DC voltage (V_{dc}) and DC power (P_{dc}) are considered as independent variables to calculate the output power of the inverter (P_{ac})[157]. Parameters with index "o" are constant values which are defined in reference conditions or nominal operation. The C_0, C_1, C_2 and C_3 are constant coefficients of the inverter model. The relationship between P_{ac} as a function of V_{dc} and P_{dc} is given by the following equation (4.16).

$$P_{ac} = \left[\frac{P_{ac0}}{A-B} - C(A-B)\right] \cdot (P_{dc} - B) + C(P_{dc} - B)^2 \tag{4.16}$$

Where:

$$A = P_{dc0}\left[1 + C_1(V_{dc} - V_{dc0})\right] \tag{4.17}$$

$$B = P_{S0}\left[1 + C_2(V_{dc} - V_{dc0})\right] \tag{4.18}$$

$$C = C_0\left[1 + C_3(V_{dc} - V_{dc0})\right] \tag{4.19}$$

The Table 4.3 shows the SMA 1200 performance parameters values, which are provided by the SANDIA database. The accuracy of the model depends on the accuracy of the performance parameters of the PV inverter model. These parameters can be obtained from the manufacturer's data sheets by considering the default values of the coefficients or test databases carried out in recognized international laboratories.

The self-consumption of the inverters used was determined by previous experimental measurements by a power analyser. In the remainder of our approach, the performance parameter Pso is considered constant and equal to 3.5W.

Table 4.3
Performance parameters of SMA1200

Performance settings	Default setting	Laboratory SANDIA
P_{aco} (W)	1200	1200
P_{dco} (W)	1320	1320
V_{dco} (V)	400	400
P_{so} (W)	15	3.5
C_0 (W^{-1})	0	-1.44e-8
C_1 (V^{-1})	0	1.385
C_2 (V^{-1})	0	-0.00284
C_3 (V^{-1})	0	1.074

Performance Parameter Definitions

Pac = ac-power output from inverter based on input power and voltage, (W)

Pdc = dc-power input to inverter, typically assumed to be equal to the PV array maximum power, (W)

Vd = dc-voltage input, typically assumed to be equal to the PV array maximum power voltage, (V)

Paco = maximum ac-power “rating” for inverter at reference or nominal operating condition, assumed to be an upper limit value, (W)

Pdco = dc-power level at which the ac-power rating is achieved at the reference operating condition, (W)

Vdco = dc-voltage level at which the ac-power rating is achieved at the reference operating condition, (V)

Pso = dc-power required to start the inversion process, or self-consumption by inverter, strongly influences inverter efficiency at low power levels, (W)

Pnt = ac-power consumed by inverter at night (night tare) to maintain circuitry required to sense PV array voltage, (W)

Co = parameter defining the curvature (parabolic) of the relationship between ac-power and dc-power at the reference operating condition, default value of zero gives a linear relationship, (1/W)

$C1$ = empirical coefficient allowing Pdco to vary linearly with dc-voltage input, default value is zero, (1/V)

$C2$ = empirical coefficient allowing Pso to vary linearly with dc-voltage input, default value is zero, (1/V)

$C3$ = empirical coefficient allowing Co to vary linearly with dc-voltage input, default value is zero, (1/V)

4.3 CONCLUSION

In this chapter, the modelling of various components of the photovoltaic system (PV) connected to the grid used in this thesis was presented. The aim of this chapter was to perform a dynamic model of a grid-connected PV system was modelled using a specific “Type” from the library of the MATLAB software. We started with a mathematical description of a model proposed energy system. The models represented in this chapter have been used in the context of an approach to optimizing the management of loads in a home and also for the optimization of sizing of the PV system connected to the network with the use of the proposed management. Then, a modelling of radiation models on an inclined surface and the PV generator of the system was presented. in addition, the optimization of the inclination angle of the PV generator. The second part was devoted to modelling of the inverter and performance evaluation criteria,

Finally, the energy balance between the PV system and the grid has been modelled using a MATLAB-Simulink. The model developed in this chapter will be used later in this work for the assessment of the energy demand of case studies houses.

Chapter 5

Solar Photovoltaic integration in the housing and their impact on the energy balance

Chapter 5:

Solar Photovoltaic integration in the housing and their impact on the energy balance

5.1 INTRODUCTION

This chapter analyses the impact of the integration of solar energy on the energy performance of housing in north of Algeria. For energetic analysis, the model developed in the previous chapters is applied on case study of a single-family typical house located in the region of Algiers, in the village of Souidania. Also, we have other analyse in the North of the Algerian Sahara is carried out for the El Oued region in order to improve the energy performance of the habitat. For this, we chose the pilot project of Souidania, Algiers, as reference housing. It is a high-quality environmental housing 'HQE'. Initially, a comparative study of the energy needs of the HQE housing and a standard 'STH' dwelling made of concrete and cinderblock and having the same dimensional characteristics for the El Oued region were carried out. The aim is to show the positive effect of energy efficiency measures on the energy balance of the habitat.

As mentioned before, the model includes of a PV array, an inverter and a meter to measure the energy exported to the grid and the energy imported from the grid. All electrical appliances in the house are served by both the photovoltaic system and the grid. The recommended model has been implemented in Matlab-Simulink, the energy balances are calculated with the methodology adopted is based on actual consumption profiles, actual weather conditions, the peak power of the PV generator, the presence and absence of the power grid.

The energy requirements for the reference house are reduced first by passive mean through the integration of a set of energy efficiency measures (EEMs). Then, by active mean, with the use of a solar heating system to provide heat for space heating demand in winter season and DHW preparation over all the year. A grid-connected PV system is designed to produce electricity for household need and electrical energy required for electrical heater (auxiliary energy for solar heating system). In all cases, a parametric study is conducted to optimize the energy efficiency measures and determine the optimum sizes of solar systems. Then, based on the energy balance of the reference house, the overall energy saving and the reduction of CO2 emissions at the energy balance of housing in north of Algeria due to this energy conservation are investigated.

Finally, in order to get information about the profitability of EEM and solar systems on housing, an economic analysis is performed. In this direction, we investigate yearly revenue, investment cost and return on investment due to the installation of a grid connected PV system, a solar heating system and EEM in housing of north Algeria.

5.2 DESCRIPTION OF THE CASE HOUSING STUDY

The case study is essentially based on two housings with the same dimensional characteristics. A house with high environmental quality 'HQE', the pilot project of Souidania on Algiers which serves as the reference building (REF) and a traditional one (TRAD) site in the region of El Oued (Far North-East of Sahara). This part presents the architectural of two houses as well as the meteorological data [160].

5.2.1 Location and design architectural

The REF housing, on the architectural level, the house was designed respecting some principles of bioclimatic architecture (see table 5.1) [158] :

- ✓ Use of local materials for the construction of 'BTS' stabilized earth concrete brick walls. It is an interesting system because of its energy consumption, its seismic properties and the local availability of the raw material.
- ✓ Insulation of exterior walls and floors. Insulation has an extremely beneficial role. In winter it reduces heat losses, while in summer it allows to keep a certain comfort by limiting the heat input.
- ✓ Use of double-glazed windows. The interest of double glazing is double, it allows to improve the thermal insulation as well as the sound insulation.
- ✓ Use of low-power appliances.
- ✓ The house is facing South.

A separate home floor area was used in order to study the performance of the grid-photovoltaic system on the house energy performances in Mediterranean climate conditions. The experimental house was built as part of a European MED-ENEC program and scientific collaboration between Renewable Energy Centre (CDER, Algeria) and National Center for the Study and Integrated Research of Buildings (CNERIB, Algeria).

The house that is the subject of this study has a living area of 90 m², it is located in the region of Algiers, specifically in the village of Souidania (Figure 5.1). This region is part of climate zone A (Latitude 36.70N, Longitude 03.20E) which is characterized by a cool winter and a hot and humid summer. An important limitation to consider in the design of rooftop PV system is the area available for mounting the arrays on the buildings.

The house contains seven parts specifically, two rooms, living room, kitchen, restroom, and corridor [21, 22]. It is supposed to be occupied by 7 people, the average number of occupants of a household in Algeria. The height of the house is approximately 2.74 m. Its technical characteristics are as follows:

- Walls with stabilized earth blocks;
- PVC doubles glazed windows (4/6/4);
- Thermal insulation of external walls and floors;
- The house is oriented along the E-W axis has a compact shape.

Fig 5.1 General view of the housing studied (Souidania, Algiers) and the photovoltaic array installed on the roof.

The TRAD housing corresponds to any modern construction (international style) representing the model generally adapted in Algeria and especially through the region selected in this work. Its construction does not respect bioclimatic techniques (see Table 5.2) [158]:

- ✓ Use for the construction of walls and floors, cinder block and concrete.
- ✓ Use of single glazed windows
- ✓ Use of energy-intensive appliances such as incandescent lamps.
- ✓ The house is facing north.

In this part we will study house located in the Southeast region of Algeria specifically in the El Oued home town (see Figure 5.2). El-Oued region is characterized by an arid climate of Saharan desert type (Latitude 33.37N, Longitude 06.86E and Altitude 80m), in winter the temperature drops below 0°c, whereas in summer it reaches up to 50°c. The housing studied is a representative housing of average number of occupants in an Algerian family, both by its type and by its level of equipment, including electrical equipment. This aspect greatly contributed to the choice made. this house has a living area of 90 m², the house is an F3 occupied by a family consisting of a couple and five children, ie 7 people.

The house is connected to the electricity Grid and natural gas, in Algeria, In the harsh winter, citizens use natural gas to warm up. In summer too hot, they use low-end and cheaper (energy-consuming) air conditioners, or mechanical ventilation. This increases alarmingly the consumption of electricity especially in the southern regions.

Fig.5.2. general view on Google Earth of the housing studied (El Oued)

Table 5.1:

Technical and thermal specification of the walls and windows of the HQE housing

Construction	**Building materials**	**Value of Unite ($W\ m^{-2}\ K^{-1}$)**
Roofing	Mortar (3 cm) + Expanded Polystyrene (16 cm) + Heavy concrete (8 cm) + Plaster (4 cm)	022
Exterior wall	Stabilized concrete (14 cm) + Expanded polystyrene (9 cm) + Stabilized concrete (29 cm)	0,35
Interior wall 1	Stabilized concrete (14 cm)	4,43
Interior wall 2	Stabilized concrete (29 cm)	2,37
Floor	Heavy concrete (5 cm) + Expanded polystyrene (6 cm) + Heavy concrete (15 cm) + Mortar and sand (3 cm) + tiling (2 cm)	0,54
Window	Double glazing	1,76

Table 5.2:

Technical and thermal specification of the walls and windows of the STH housing

Construction	**Building materials**	**Value of Unite ($W\ m^{-2}\ K^{-1}$)**
Roofing	Mortar (3 cm) + Heavy Concrete (12 cm) + Plaster (4 cm)	2,64
Exterior wall	interior coated plaster (2 cm) + breeze block (20 cm) + exterior coating cement (2 cm)	2,3
Interior wall	interior coated plaster (2 cm) + breeze block (10 cm) + exterior coating cement (2 cm)	2,67
Floor	Heavy concrete (15 cm) + Heavy concrete (3 cm) + (mortar + sand) (3 cm) + Tiling (2 cm)	4,41
Window	Single glazing	5,74

5.2.2. Meteorological data

The disparity in solar irradiance and temperature between winter solstice and summer is remarkable. At the studied site Algiers and El Oued, the evolution of the ambient temperature and the solar irradiation of the two regions of study are shown in Figures 5.3 and

5.4, during one day in January and one day in June. January is one of the coldest months and June is one of the hottest months of the year in Algeria. This meteorological data is extracted from the Meteonorm V7.0.22.8 software. These figures allowed us to make the following comments:

For the Algiers area, and according to Figure 5.3, the highest solar irradiance is about 990 Wh/m2 at noon in June. While the temperatures vary between 17.9 °C and 21.5 °C. solar irradiance values are low in winter. They can hold 670Wh/m2. While temperatures vary between 7.5°C and 9.6 °C in the month of January.

About the region of El Oued, and according to Figure 5.4, it can be noted that the solar irradiance it may around 1030 Wh/m2 at noon in the month of June. While the temperatures vary between 23.9 °C and 36.6 °C. Solar irradiance values are less important in winter. They can hold 670 Wh/m2. While the temperatures vary between 5.5 °C and 15.6 °C in the month of January. The daily global horizontal irradiation and average ambient temperature are illustrated in Fig. 5.5. It can be noticed that winter days are less sunny than summer days, which influence really the proper functioning of the PV system (decrease in power yield with low irradiances).

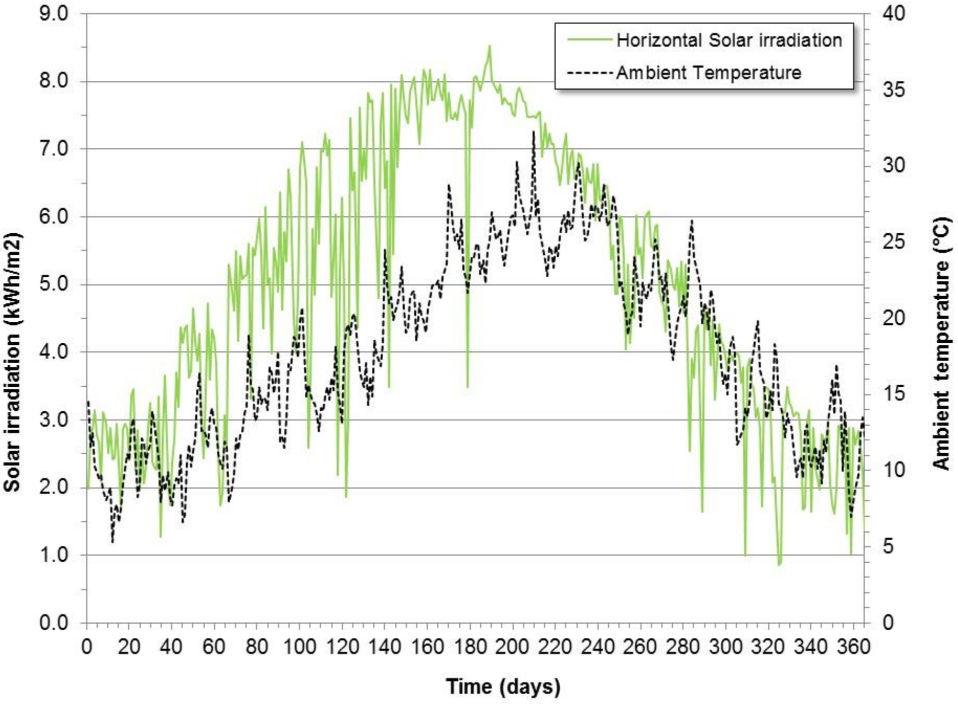
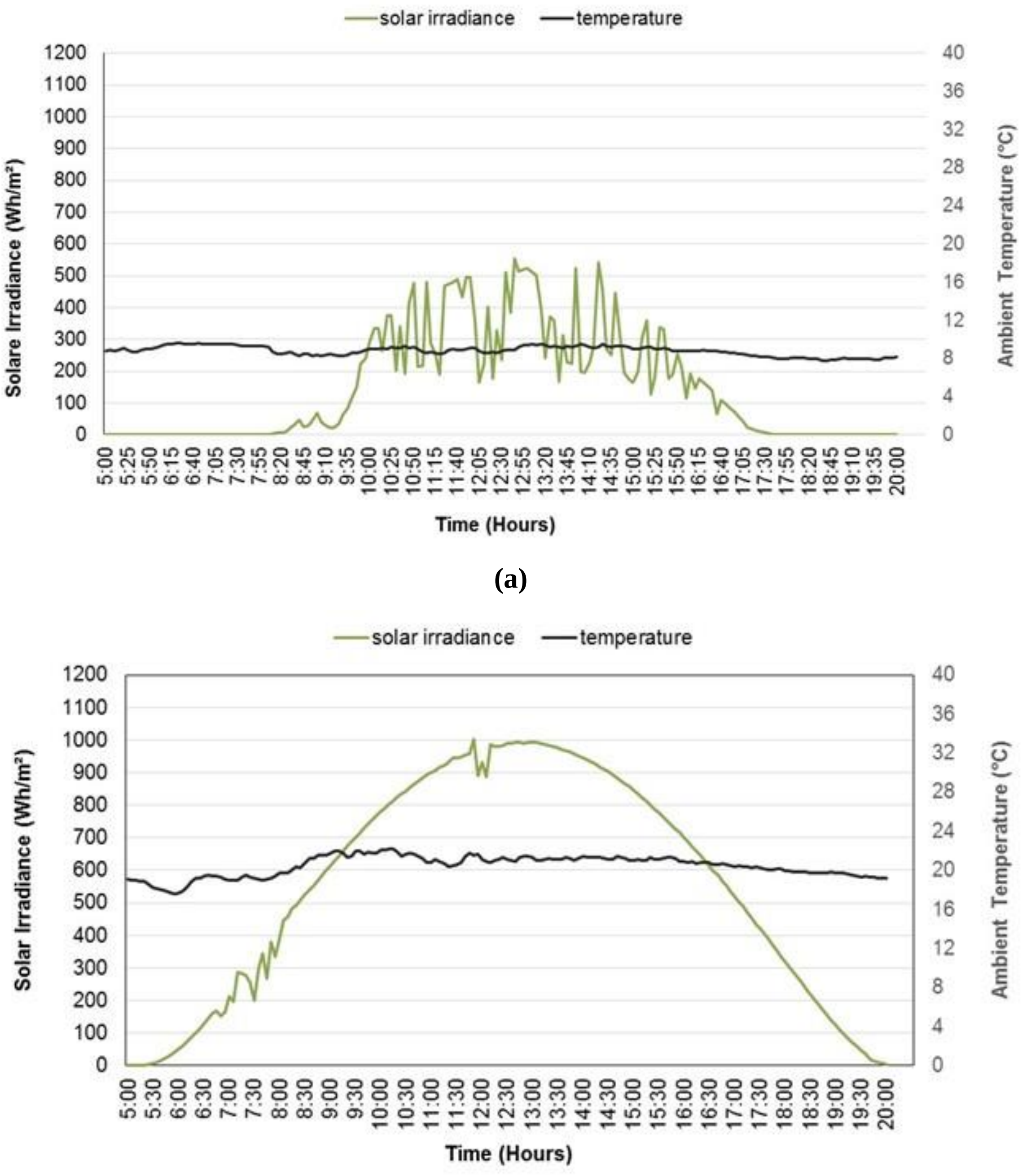


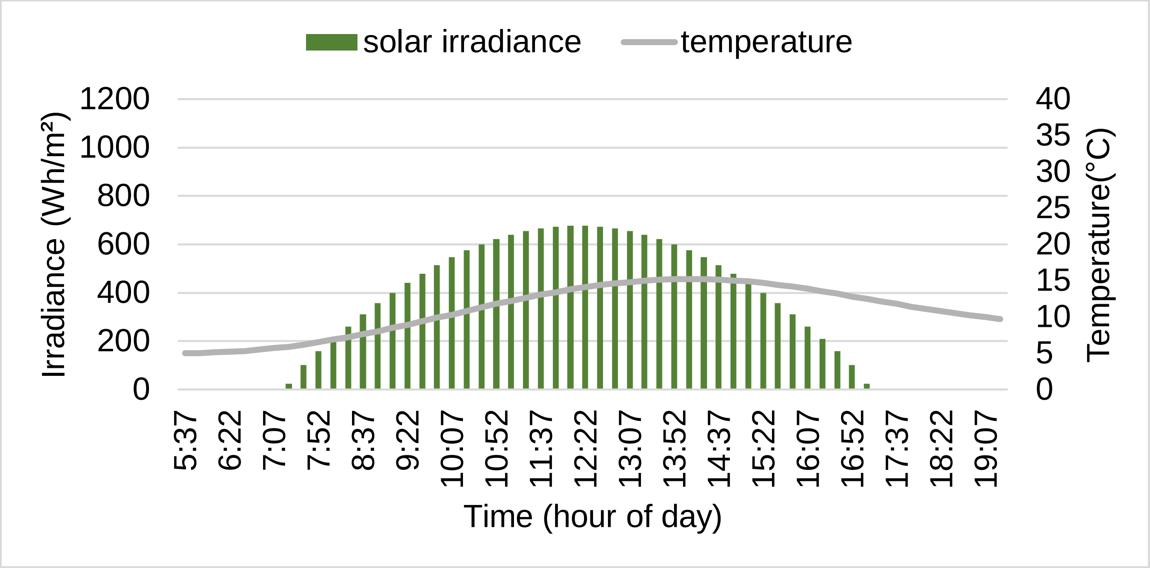
Fig. 5.5. Daily Global Horizontal irradiation and average ambient temperature in Algiers



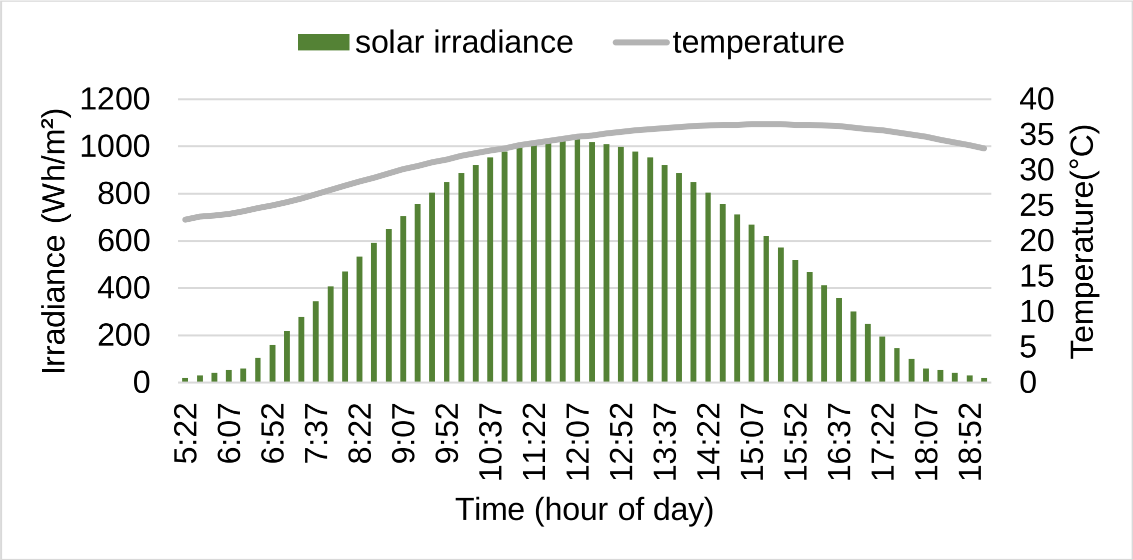
(a)

(b)

Fig. 5.3. Evolution of the solar radiation and the ambient temperature of Souidania. (a) at winter, 01 January 2016 and (b) at summer, 21 June 2016



(a)



(b)

Fig. 5.4. Evolution of the solar radiation and the ambient temperature at the studied site El Oued. (a) at winter, 01 January 2016 and (b) at summer, 21 June 2016

5.3 Simulation program of a grid-connected residential PV system

The energy performance of reference building in the study area improved by adopting the active method. It has been used by the use of low energy consumption lamps, and efficient electrical equipment as well as by the use of solar photovoltaic energy to be able to meet the daily needs of the house in electrical energy (lighting and power supply of appliances electric except heating and air conditioning).

The proposed PV system simulation to be installed on the roof of the HQE was performed separately in the MATLAB-Simulink environment for the study area [159]. MATLAB-Simulink, developed by MathWorks, is a graphical programming environment for modeling, simulating and analyzing multidomain dynamical systems. Its primary interface is a graphical block diagramming tool and a customizable set of block libraries. So Matlab Simulink can be used for a model photovoltaic system connected to the grid and measure its impact on the level of energy performance of the home. The methodology of electrical simulation in the model of study is presented in Figure 5.6. The annual, monthly and hourly results of the energy balance of the HQE housing are extracted in the form of an Excel file.

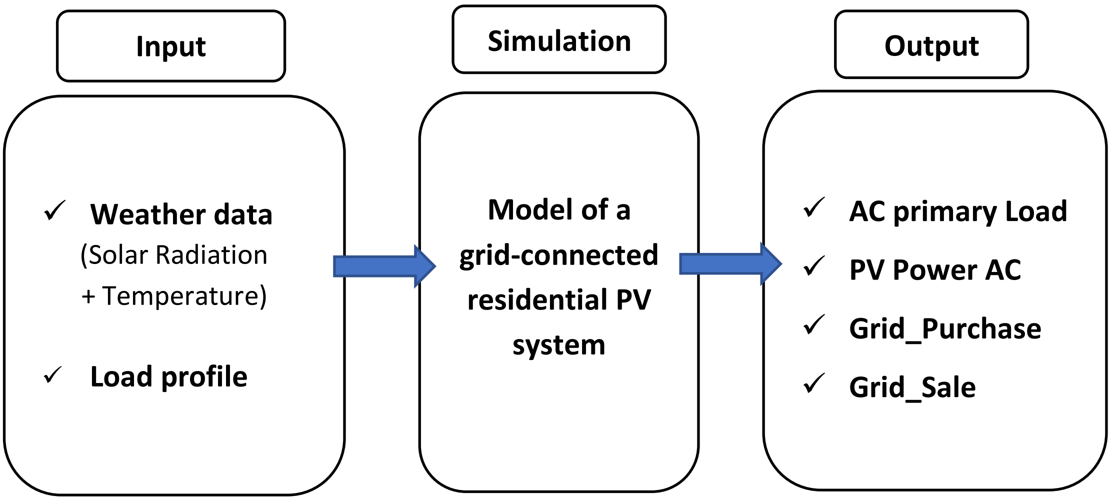


Figure 5.6. Inputs and outputs of a grid-connected residential PV system

At the input: the parameters of the system are fixed (Solar Radiation, Temperature, and load profile). For a given radiance and temperature, after considering the consumer's electrical energy demand, the quantity of energy produced by the photovoltaic generator is evaluated at time (t), the losses in the inverter are deduced; hence the power demanded by the electrical network can then be calculated by the difference between the injected production and the demanded consumption on the AC bus.

At simulation: The simulation program (see Figure 5.7) was developed under Matlab-Simulink. This program contains the models of a grid-connected PV system which has been described above. The simulation time step (Δt) used in this study is 5 minutes depending on the data acquisition process used experimentally. In the stimulating, the capacity for the PV array and inverter considered in the model was 1.2 kWp. This simulation was performed with a real daily profile of data input from Algeria site, exactly in Souidania town (the temperature, irradiance and the developed load profile). On the other hand, in the modelling, the demand side management was also considered.

At Output: The annual energy balance is obtained by adding the energy exchanges between a photovoltaic system connected to the grid and the distribution grid every hour. The hourly energy balance for the year is given by:

$$\boldsymbol{P_{PV} + P_{Grid\_purchese} - P_{Grid\_sale} - P_{load} = 0} \qquad \mathbf{5.1}$$

With:

$\boldsymbol{P_{PV}}$ is the energy produced by the PV system;

$\boldsymbol{P_{Grid\_purchese}}$ is the energy purchased from the electricity grid;

$\boldsymbol{P_{Grid\_sale}}$ is the energy injected into the electricity grid;

$\boldsymbol{P_{load}}$ is the energy consumed by the home;

The electrical power produced by the PV system for a given hour is compared to the corresponding hourly electrical load of the habitat to be covered. In the case where the PV production is greater than the electrical load of the house, the majority of the electrical energy consumed is provided by the photovoltaic in addition a surplus of production is injected into the electricity grid. The energy injected into the grid is given by:

$$\boldsymbol{P_{Grid\_sale} = P_{PV} - P_{load} \quad and \quad P_{Grid\_purchese} = 0} \qquad \mathbf{5.2}$$

On the other hand, in the case where the photovoltaic production is insufficient and the majority of the electrical energy consumed is withdrawn from the electricity grid, the energy purchased from the electricity grid is expressed as follows:

$$\boldsymbol{P_{Grid\_purchese} = P_{load} - P_{PV} \quad and \quad P_{Grid\_sale} = 0} \qquad \mathbf{5.3}$$

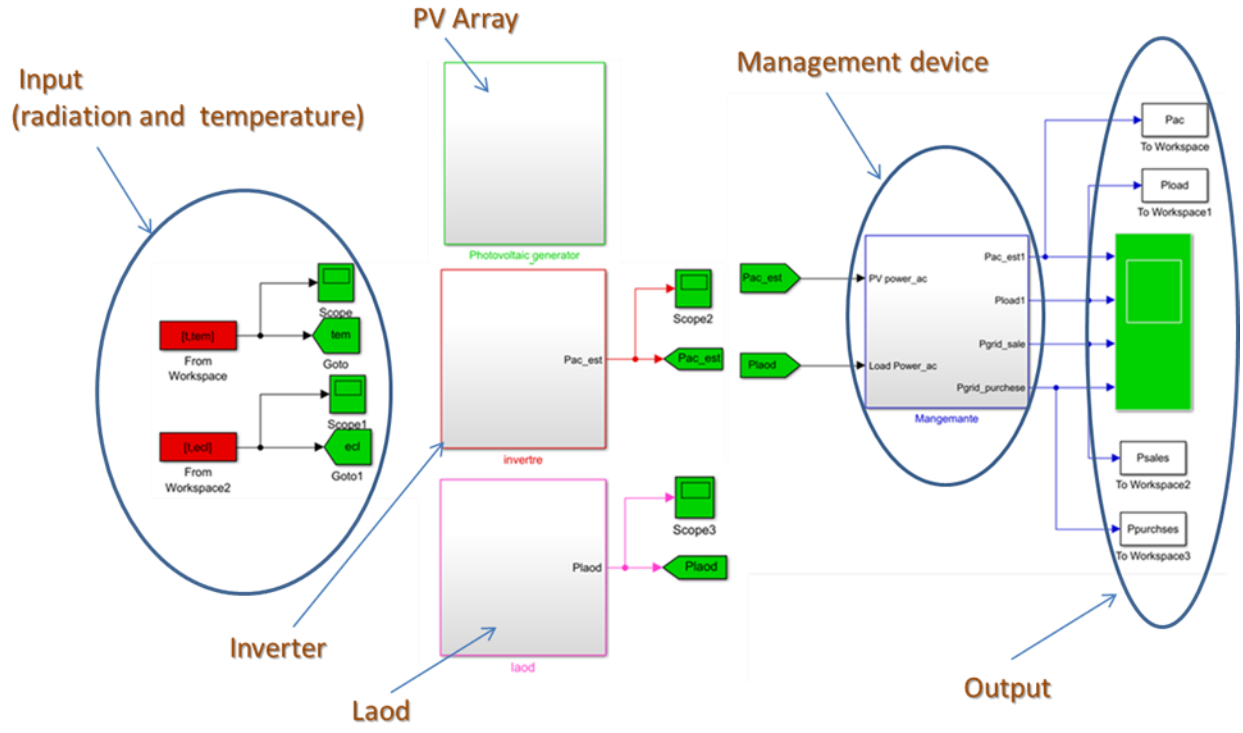


Fig 5.7. Matlab-Simulink program of the proposed grid-connected PV system

5.4 ENERGY CONSUMPTION PROFILE

The maximum power required and the daily energy consumed by the house must be determined in order to dimension the electrification infrastructure. We estimated the mean hourly load profile of the habitat to be electrified. The consumption profile adopted in this study corresponds to the load profile generally encountered in suburban regions [159-161].

The house is equipped with efficient appliances to offer comfort to the occupants. The characteristics of this house are:

- Number of rooms: three rooms, corridor and courtyard.
- Lighting: rooms, kitchen, toilet, bathroom, courtyard and corridor.
- Appliances: refrigerator, TV, radio, computer, laptop, washing machine, air conditioner and fan. The detailed characteristics of appliances are given in Table 5.3.

The proposed profile considered the same consumption for the winter and summer period. The time of use of the equipment is defined by means of a survey of suburban houses in Algeria. The number of hours of lighting depends on the hours of getting up and sleeping of family members that correspond to sunrise and sunset. The power of the lighting changes from one place to another and it is related to the surface of the rooms and the frequency of use. It is assumed that the fan is used only during the hot period (April-September) for a 5h/day. For the laptop, computer, television and radio, the number of hours of use of this equipment is estimated to be 6h/day in winter and 3h/day in summer.

In Fig. 5.8, it is presented the winter and summer daily energy estimations, based on the power consumed by the equipment given in Table 5.3. The peak of consumption noticed at 9 o'clock is due to the washing machine, considering in this time that the grid consumption is very low (or consumption of the grid is average). At noon, the electrical equipment is turned on as needed: television, computer, lighting and others. As a result, a peak of consumption is observed between 12 hrs and 14 hr [159].

Table 5.3.
List of home appliances

Name	**Power (W)**	**Type of service**
Refrigerator	40	permanent service
Lighting (one lamp)	15	timed service
TV	95	
Sat. receiver	40	
Radio	30	
Computer	120	
Laptop	90	
Washing machine	2000	
Fan	75	

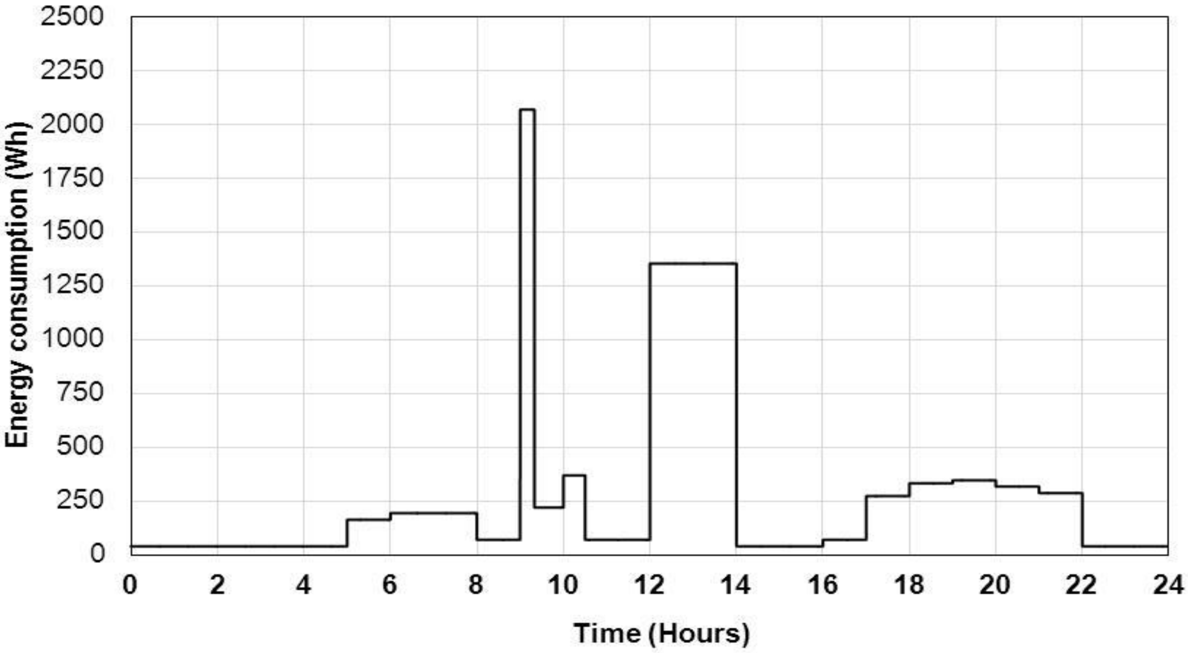


Fig. 5.8. Daily energy consumption profile of the residential building

In the house proposed for this study, we have no occupant living in the house so we developed an experimental electronic device that automatically ensures the power consumption of a house following a well-known profile.

5.5 EXPERIMENTAL ELECTRONIC DEVICE FOR LOAD PROFILE

In this thesis, we present the realization of an experimental electronic device that automatically ensures the consumption of electricity for consumption profiles well known for the energy balance of high energy quality housing in Algeria.

Knowing the profile of home consumption is important when energy production is decentralized, which requires demand control and the distribution of consumption across different types of appliances. For example, today the electricity company in Algeria has quarterly data on electricity consumption that does not contain much information on the exact consumption of homes. For this, we realized an experimental electronic device that automatically ensures the electrical consumption of a house following a specific profile. This profile takes into account the periods of use during the day of the various domestic equipment.

The aim is to optimize the electricity consumption profile in the energy balance of a house with grid connected photovoltaic system. Our instrument device was fixed in an electronic box that we made based on a PIC microcontroller 16F877A with their control circuits and also based on a Triac electronic component equivalent to the parallel setting of two Thyristors mounted head- spade.

An electronic circuit has been realized, it allows to trace the profile curve of the load of the house at different seasons of the year. This electronic control method is used to power household equipment (lighting, refrigerator, television, washing machine). It is an alternative source via an inverter connected to the public network.

a) The microcontroller

We chose the PIC 16F877A with a number of inputs / outputs adaptable to our application in addition to the A / D converter and an eight-way analog multiplexer. This PIC controls the supply of household equipment from an estimated usage of equipment per hour during the day.

b) The power circuit

We used Triac, which is an electronic component equivalent to the paralleling of two thyristors mounted upside down. The Triac is used to control the passage of the two alternations of an alternating current. Thus, an opto-coupler has been used, which is an electronic component capable of transmitting a signal from one electrical circuit to another, without there being any galvanic contact between them. Thus, with this opto-coupler we separated the control circuit and the power circuit. Figure 5.9 shows a cell that controls a single alternating load.

Domestic equipment is electrical equipment. In our application we have several types of load, so it must be installed on each equipment a proposed control cell to ensure the detailed profile of each electric load. When associated with an electronic device, they also provide the electrical load profile of a home. Figure 5.10 (a and b) represents experimental charge with the electronic device that manages the system.

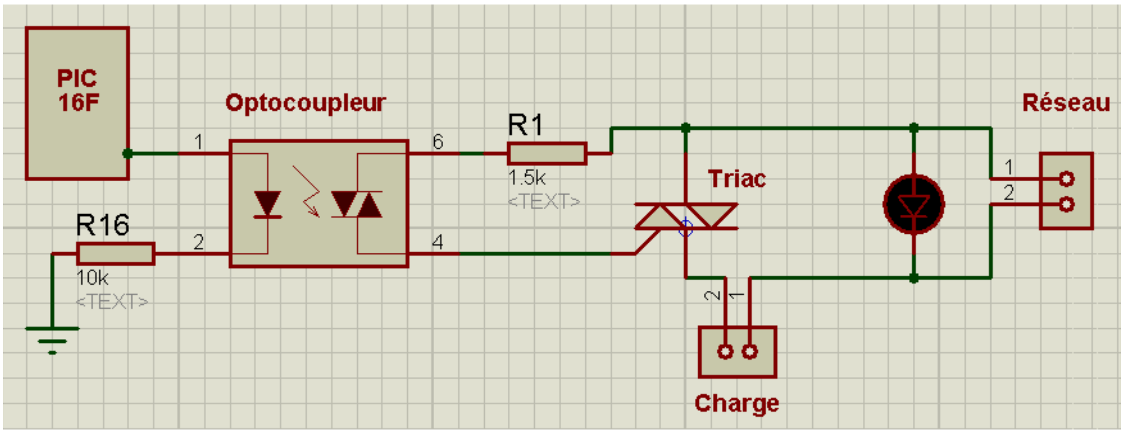


Fig. 5.9 Cell that controls a single charge Alternative

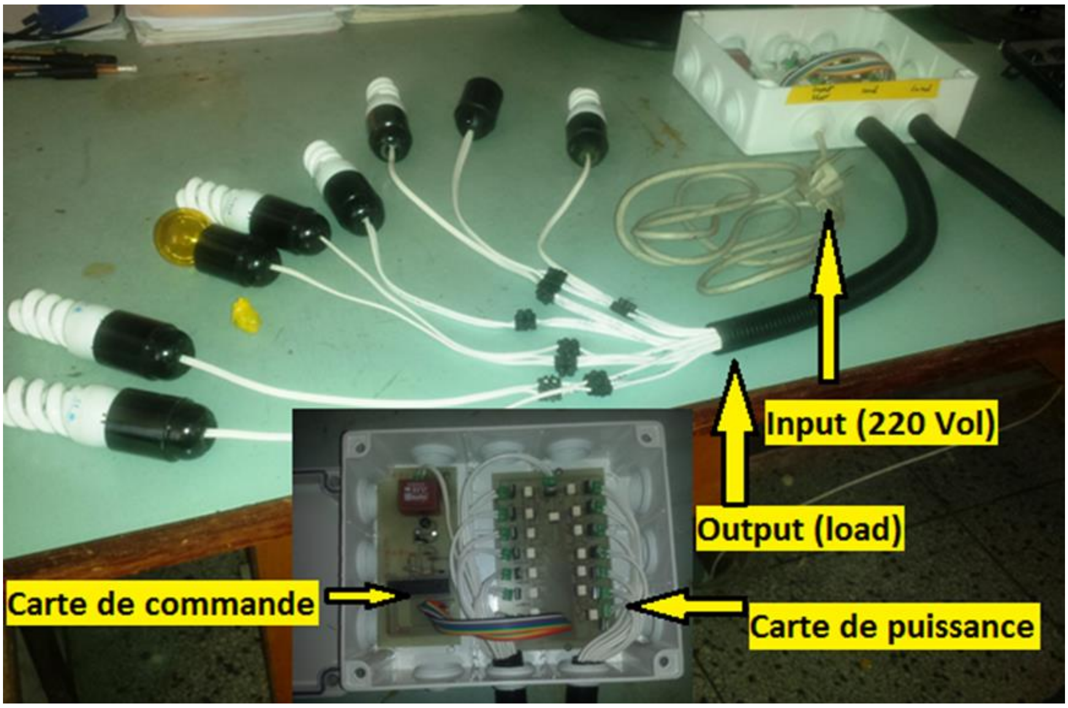


Fig.5.10 (a) Photos of the electronic device that has been realized

Figure 5.10 (b) Experimental load with the electronic device that manages the system

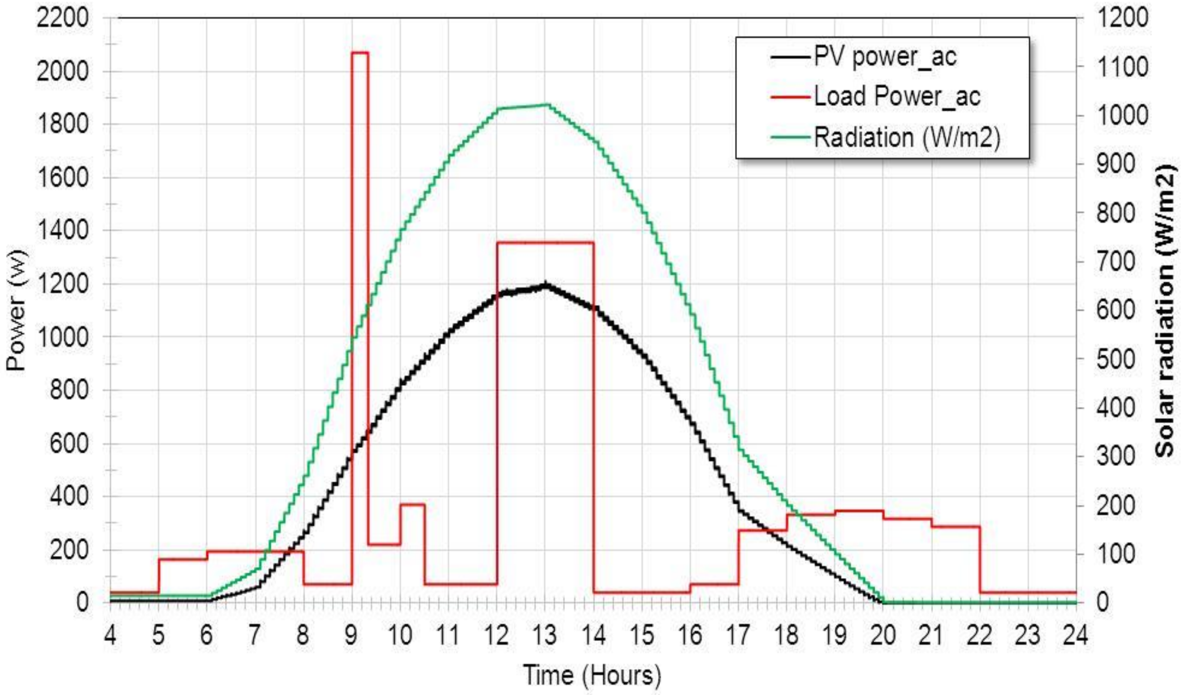
5.6 RESULTS AND DISCUSSION

5.6.1 Daily Energy

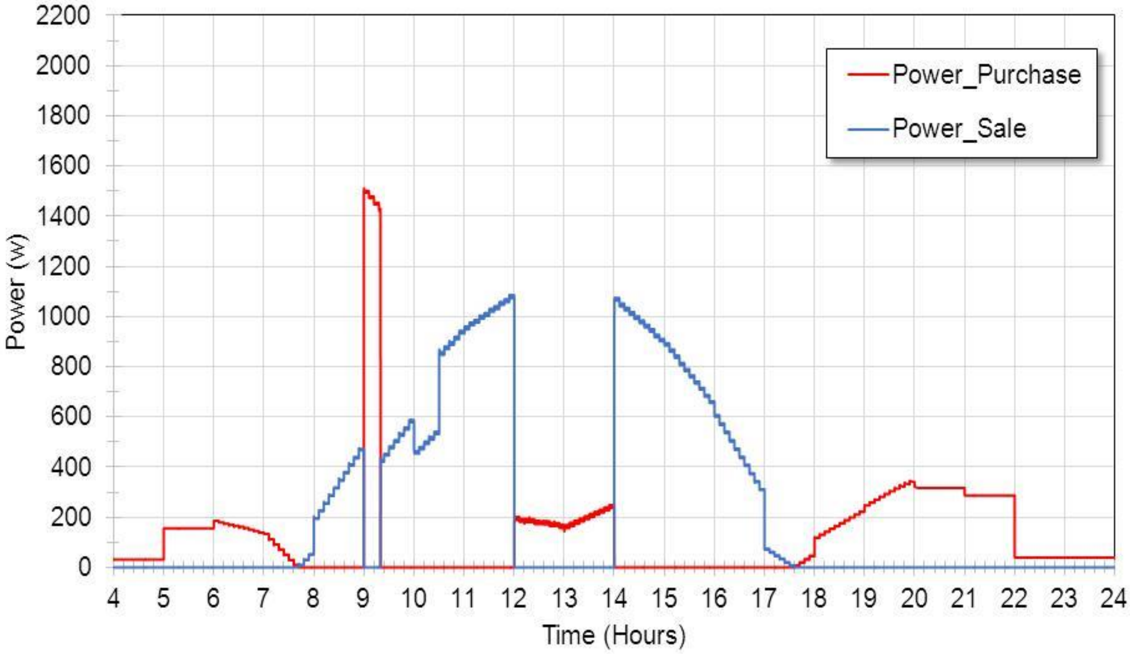
The daily electrical results for the 1.2 kWp PV system for two different days (one day was in summer and the other one was in winter) are reported in Fig. 5.11 and 5.12. The different results are: the produced energy from PV array, the load power, the purchased energy, and the PV electricity exported to the grid for each hour during the day. We can notice that the PV system continues in generating the electricity on winter days (for example cloudy days), but not as much as on a summer day.

Fig. 5.11 shows that in the considered summer day, the PV electricity which is generated before 8 O'clock in the morning cannot meet the energy consumption requirement because the sun's irradiance was not sufficient. The PV energy begins to increase after 8 O'clock. Therefore, when the power is produced from the sun, it can effortlessly meet the need of the house's energy requirement. The extra energy generated by the PV system will be injected to the grid. After 19 O'clock, the PV array did not produce any energy, thus, all the energy is bought from the grid. Fig. 5.12 presents the production of the electricity in the considered winter day where the power produced by the PV system could not encounter the energy consumption required between 9 O'clock to 18 O'clock. During the winter period, especially when it is cloudy, the energy consumption is utterly purchased from the grid [159,161].

The daily electrical power production and consumption are given in Fig. 5.13 and 5.14 [159,161].. The total daily electricity consumption in the house from both PV system and the grid is 6439 Wh/day (load_ac). The total daily energy imported from the grid (Grid purchases), which arises when the PV array gives less power, is 2593Wh/day in summer and 4054 Wh/day in winter. The total daily energy produced by the PV array in summer is 8483Wh/day and 3911Wh/day in winter. In this case, the PV array produces extra energy ‘‘grid sales’’, which is injected into the grid (4636 Wh/day in summer and 1525 Wh/day in winter).

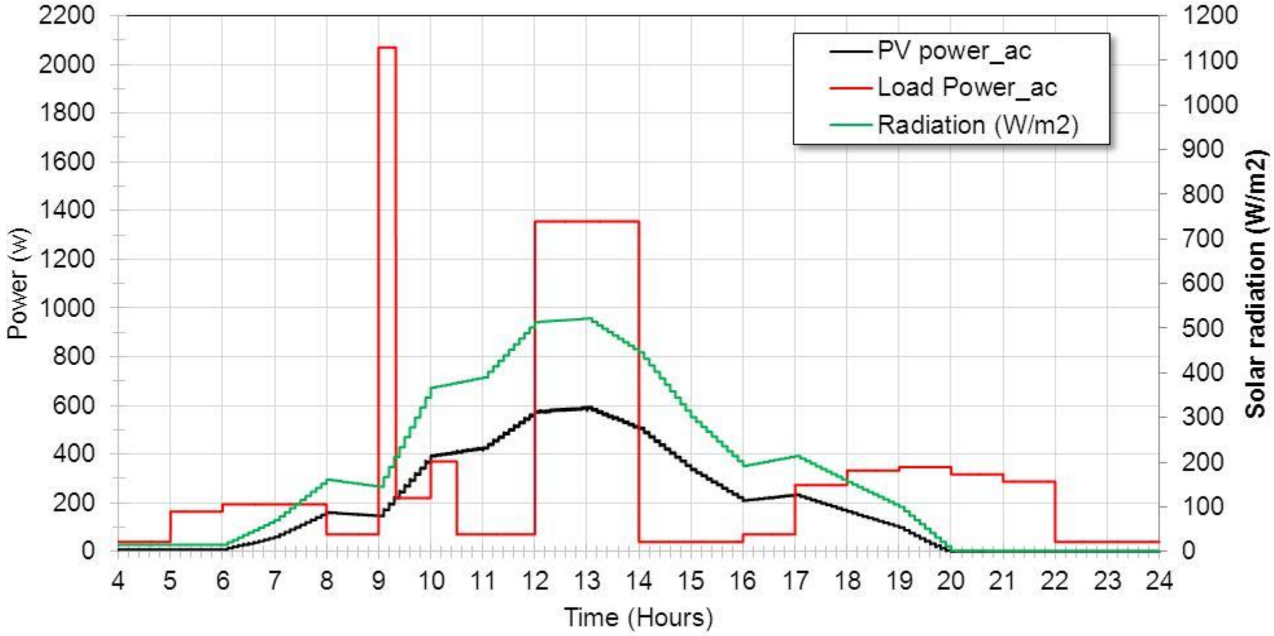


(a)



(b)

Fig. 5.11. Simulation results for a summer day (a) curves of PV power, Load power and solar radiation (b) curves of power sale and power purchase



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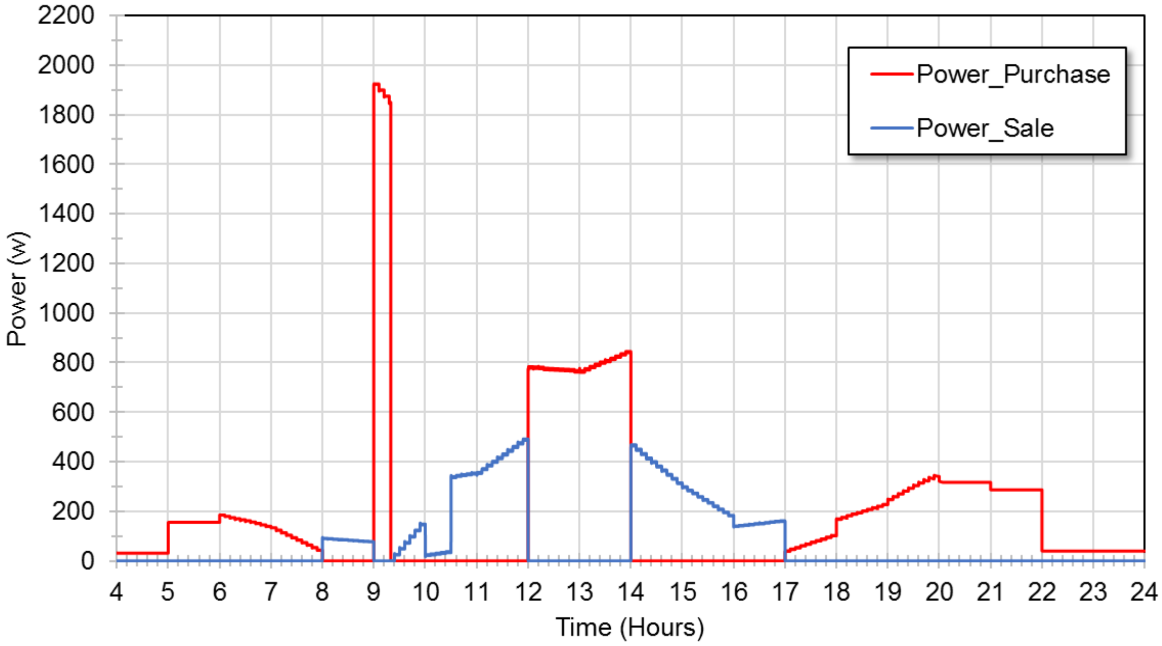

(b)

Fig. 5.12. Simulation results for a winter day (a) curves of PV power, Load power and solar radiation (b) curves of power sale and power purchase

The daily rate of energy production and energy consumption obtained for this case study are as follows:

- **Energy production:** In winter, the daily rate of energy produced by the PV array was 49% of the total electric power produced in the house and daily energy imported by the grid was 51%. But in summer, daily rate of electricity produced by the PV array building was 67.6% and daily energy imported by the grid was 33.4%.
- **Energy consumption:** In winter, the daily rate of electricity consumed by loads was 81% of the electric power consumption in the house and daily rate of electricity injected into a grid (sold to the grid) was 19%. But in summer, the daily rate of electricity consumed by loads 58% and daily rate of electricity injected into a grid was 42%.

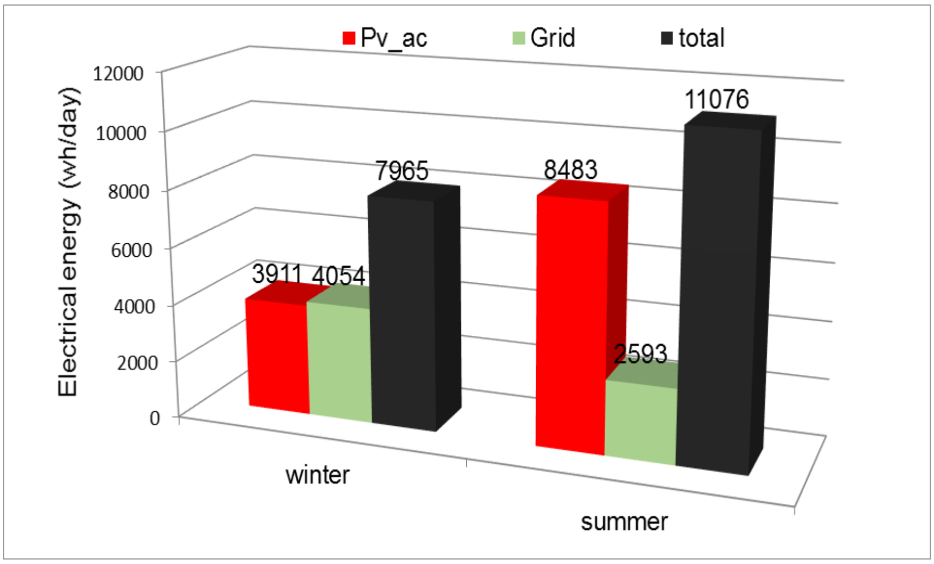

Fig 5.13. Daily electric power production

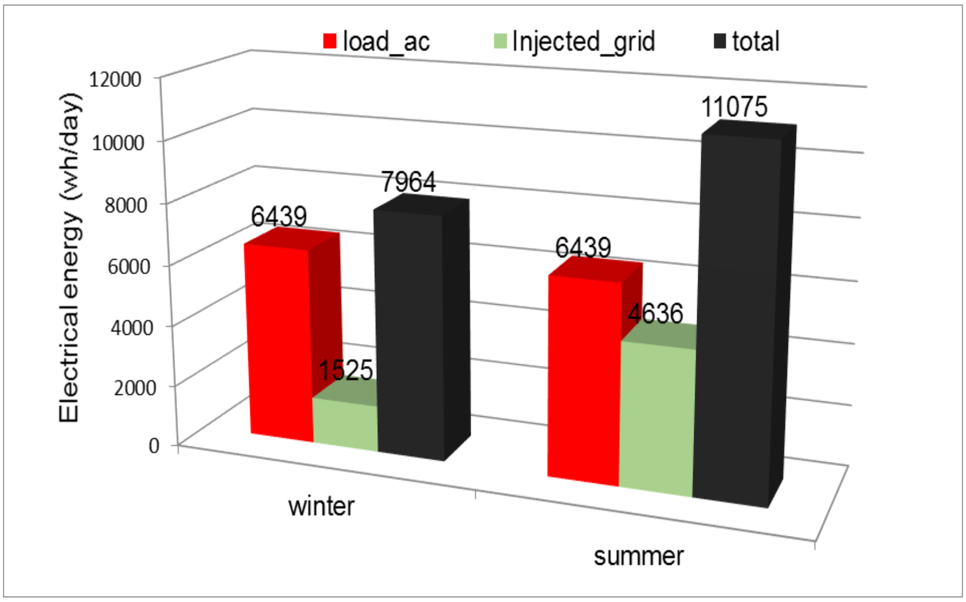

Fig 5.14. Daily electric power consumption

5.6.2 Monthly Energy

The monthly average electrical simulation result for grid-connected PV system is shown in Figure 5.15. The maximal production of the PV system is 8.2 kWh/day in August and the minimal production is 3.5 kWh/day in December. However, the monthly average energy purchased is very important in winter (4.1 kWh/day in December) and it is minimal in summer (2.5kWh/day in August). The power_purchases is the monthly energy imported from the grid and "power_sale" denotes the monthly energy exported from the grid. In addition, we have calculated the net energetic gain by subtraction of the electricity given to the grid from the electricity imported from the grid. The simulation results during the summer shows a positive net energetic gain per month, the reason for this benefit belong to that the monthly energy given to the grid is much higher than the energy purchased from the grid. In the other hand during the winter season, the monthly net energetic gain is negative. This means that the energy delivered to the grid is lower than the energy purchased from the grid.

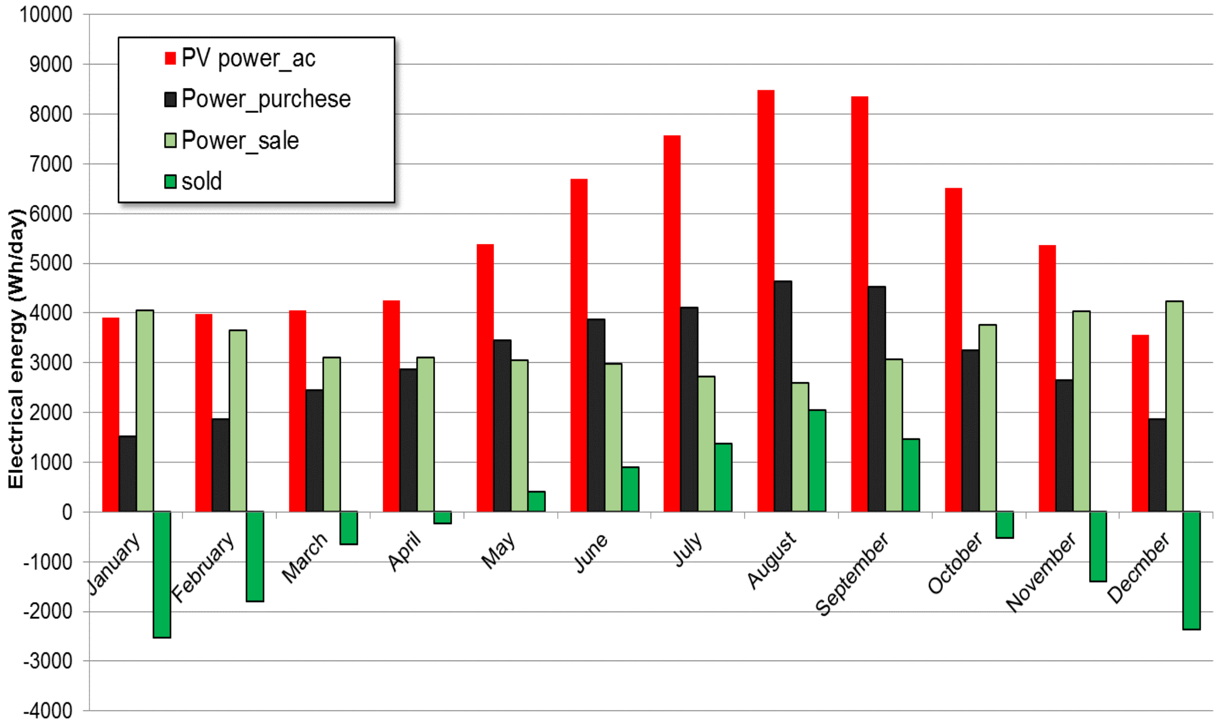

Fig. 5.15: Monthly average electrical simulation results for grid-connected PV system.

5.6.3 Annual Energy

The annual results of the electrical simulations are illustrated in Fig. 5.16. The annual consumption of electricity in the house from the grid and the photovoltaic generator is 2350 kWh. The annual production by the photovoltaic system is 2075 kWh. The annual electricity exported to the grid that occurs when the photovoltaic generator gives an excess of electricity in compared with the electricity demand of the house. So, the annual electricity sales are 1130 kWh. In other hand, the annual electricity imported from the grid is 1227 kWh.

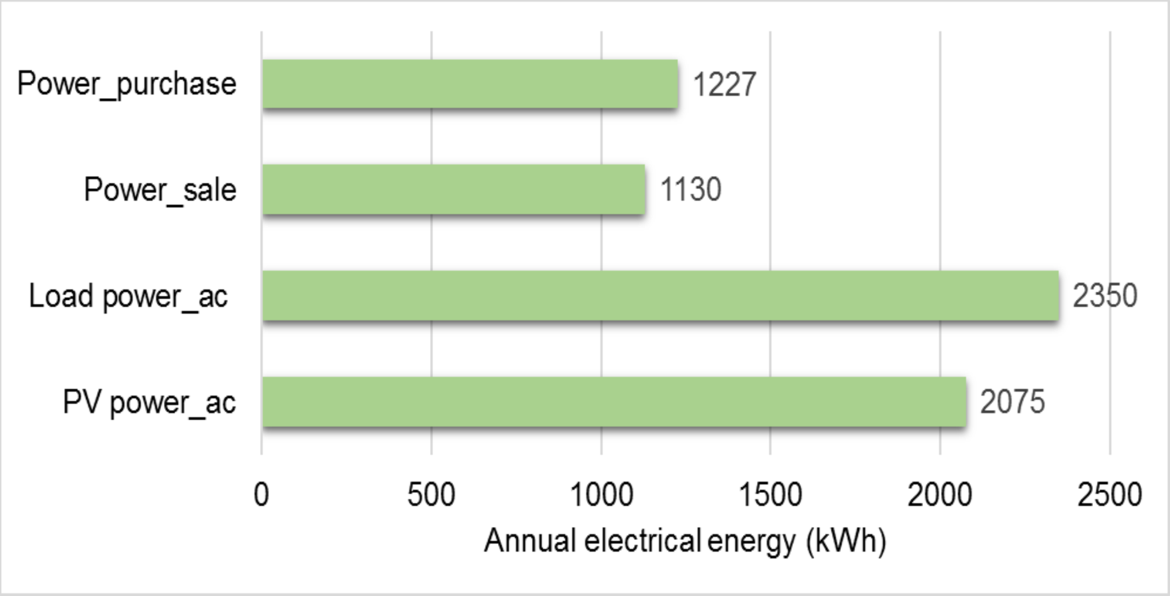

Fig. 5.16: The Annual electrical simulation results for grid-connected PV system

5.7 CONCLUSIONS

This study reveals that the grid-connected PV system can completely meet the energy needed for the considered house, where we can still utilize the grid as storage of electricity during night time when solar energy is off.

The results of simulation of electrical performances are very effective and efficient. The daily energy balance on a summer day shows that the photovoltaic system produced more than the energy required for the house. Regarding the excess energy, it was exported to the grid. However, it was found that for a winter day, photovoltaic production is not sufficient to meet all of the demand. Nevertheless, in order to compensate the needed energy, this later is purchased from the grid. In summer, the daily energy generated by the PV system is equal to 67.6% of the overall energy used in the house. The daily energy taken from the grid is around 33.4% of the global energy utilized in the house, and the energy injected into the grid is greater than the energy purchased from the grid. A positive balance of 2 kWh/day was observed. From the previous results, we outcome that the monthly average electrical results show a positive net energetic gain per month, the reason for this benefit belong to that the monthly energy given to the grid is much higher than the energy purchased from the grid. The photovoltaic system produced the equivalent to 88% of the annual electricity consumed in the building, and the total electricity purchased per year into the grid equivalent to 12% of the annual electricity consumption of the building.

General Conclusion

General Conclusion

The aim of this work was to study the contribution of on the integration of photovoltaic solar energy on the energy balance of high energy quality housing in Algeria. The energy situation in Algeria has been analyzed in the aspect of energy production and energy consumption. Furthermore, the potential of renewable energy and their application has been investigated. It has been concluded that in one hand, the energy consumption is still expansion particularly in the residential sector and in other hands, Algeria enjoys by a great solar energy potential, which is suitable for solar energy systems applications. In addition, an analysis of solar energy integration in residential housing has been provided in order to explain the optimal methods used in the building design and solar systems sizing.

This study focused on the development of a dynamic model was implemented in Matlab-Simulink, to optimize the dimensioning of PV systems connected to the grid with the strategy of energy load management for high-energy houses in suburban areas. The methodology adopted in this model is based on actual consumption profiles, actual weather conditions, and the peak power of the PV generator, the presence and absence of the power grid. This study reveals that the grid-connected PV system can completely meet the energy needed for the considered house, where we can still utilize the grid as storage of electricity during night time when solar energy is off.

The results of simulation of electrical performances are very effective and efficient. The daily energy balance on a summer day shows that the photovoltaic system produced more than the energy required for the house. Regarding the excess energy, it was exported to the grid. However, it was found that for a winter day, photovoltaic production is not sufficient to meet all of the demand. Nevertheless, in order to compensate the needed energy, this later is purchased from the grid. In summer, the daily energy generated by the PV system is equal to 67.6% of the overall energy used in the house. The daily energy taken from the grid is around 33.4% of the global energy utilized in the house, and the energy injected into the grid is greater than the energy purchased from the grid. A positive balance of 2 kWh/day was observed. From the previous results, we outcome that the monthly average electrical results show a positive net energetic gain per month, the reason for this benefit belong to that the monthly energy given to the grid is much higher than the energy purchased from the grid. The photovoltaic system produced the equivalent to 88% of the annual electricity consumed in the building, and the total electricity purchased per year into the grid equivalent to 12% of the annual electricity consumption of the building.

Finally, it can be concluded that the integration of renewable energy sources in buildings has a positive impact both on the environment and on excess energy demands. and also, the elaborate management approach has contributed significantly to the optimization of the electrical energy consumption in a home. This energy management strategy minimized the number of preventive maintenances over a PV system lifecycle and improved the performance of the PV system connected to the power grid. As a result, the cost of generating electricity can be significantly reduced. Our contribution offers a triple advantage, system without electrochemical storage and reduced cost and increased reliability of the PV system connected to the electricity grid.

The thesis further proposes some perspectives for future work. In the Grid Connected PV system, there is a great need of designing the control system that could control the designed inverter power for the smart grid. The control would ensure the integrating the inverter with other renewable energy sources available, the realization of management device is envisaged as well as its application in a real photovoltaic installation to validate the proposed model.

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160. I. Laib, A. Hamidat, M. Haddadi, A. Alanazi, and A.G. Olabi,” Energy performance of residential buildings: housing case Study in Southern Algeria”, 11th International Conference on Sustainable Energy & Environmental Protection, At University of the West of Scotland, Paisley Campus 8-11 May, (SEEP’2018), Vol. 1, pp. 107-112. 4)
161. I. Laib, A. Hamidat, M. Haddadi, K. Kaced, N. Ramzan, and A.G. Olabi,” Model and Simulation of a grid-connected residential PV system”, Annual Research Conference April 2017, At University of the West of Scotland, Paisley Campus 27th April.

Appendix A

Appendix A

Circuit PCB of the electronic device for load profile

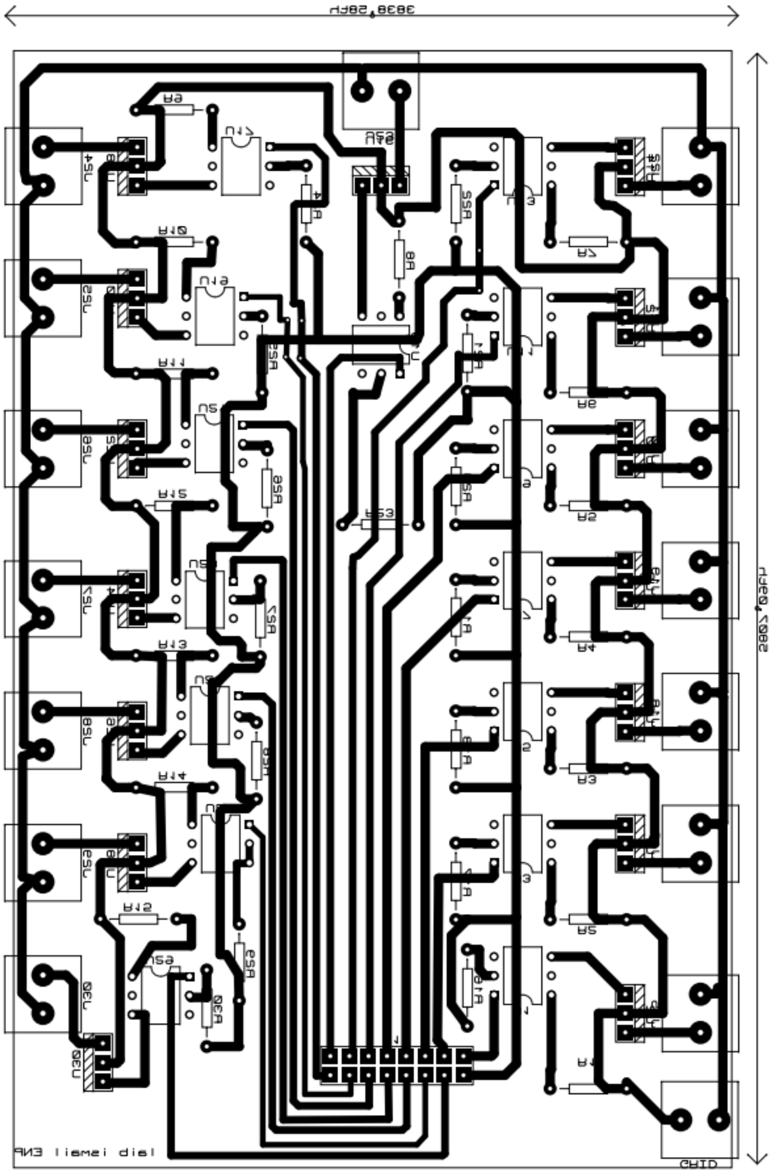


Fig A.1 PCB board of the electronic device for load profile

Appendix B

Appendix B

MATLAB/Simulink Models

See Figs. B.1, B.2, B.3 and B.4

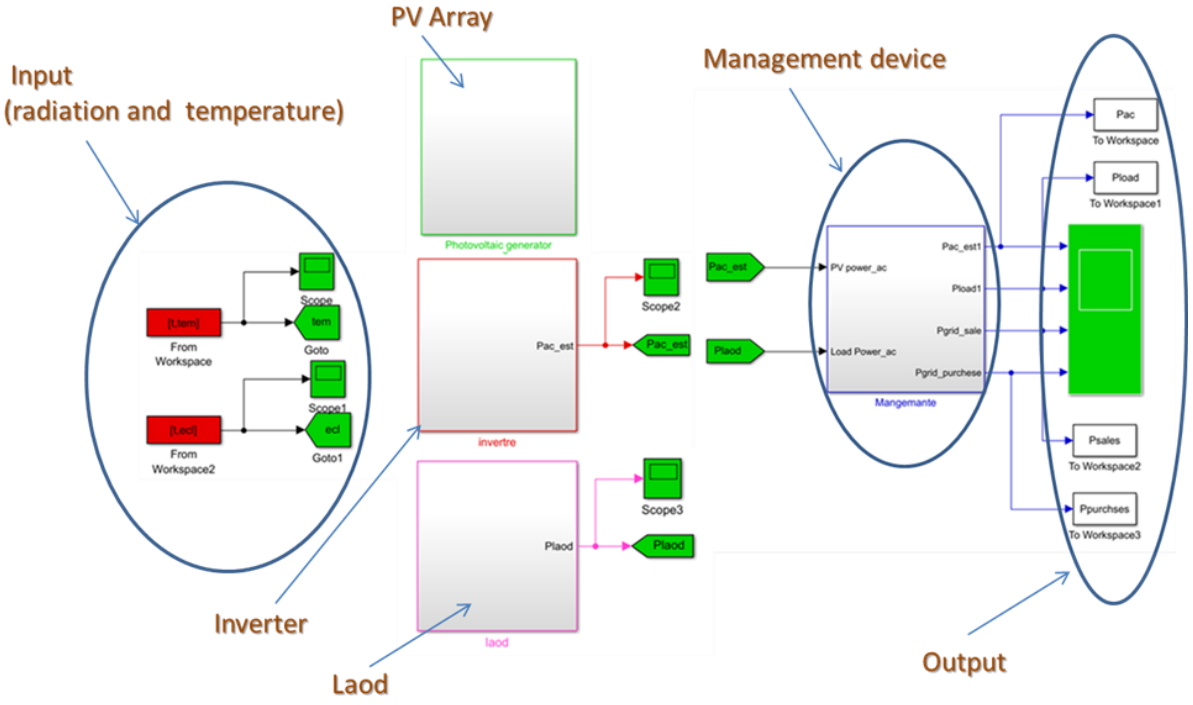


Fig. B.1 Schematic diagram of MATLAB/Simulink model for grid-connected PV system

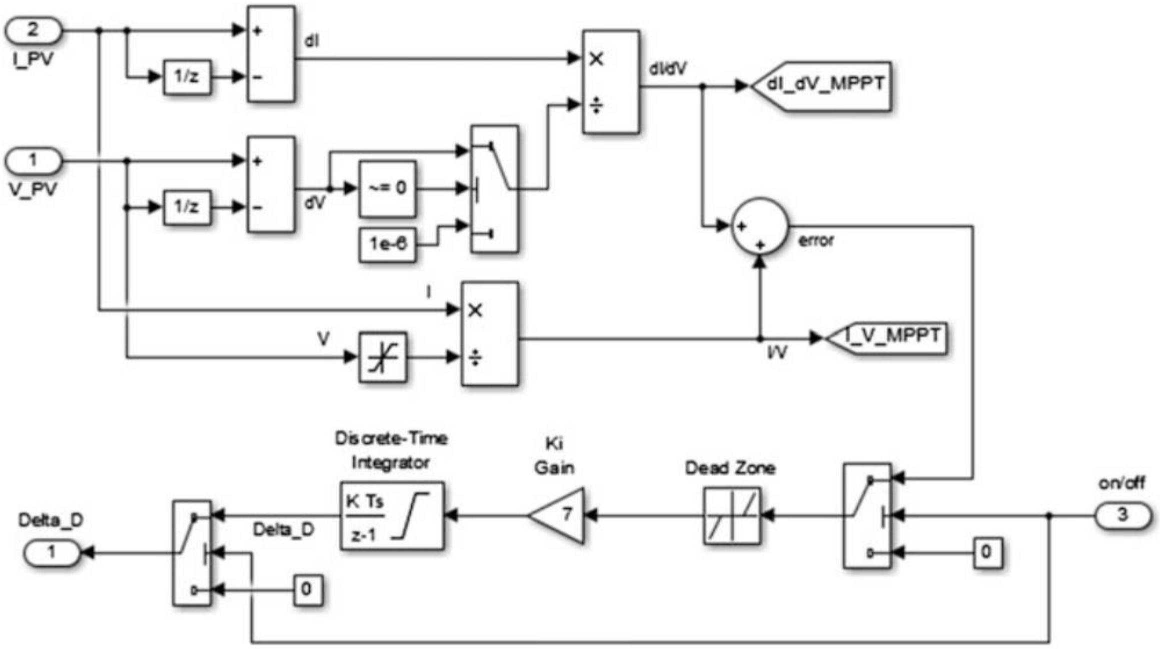


Fig. B.2 Incremental conductance MPPT controller

Appendix B

Model of the load profile used

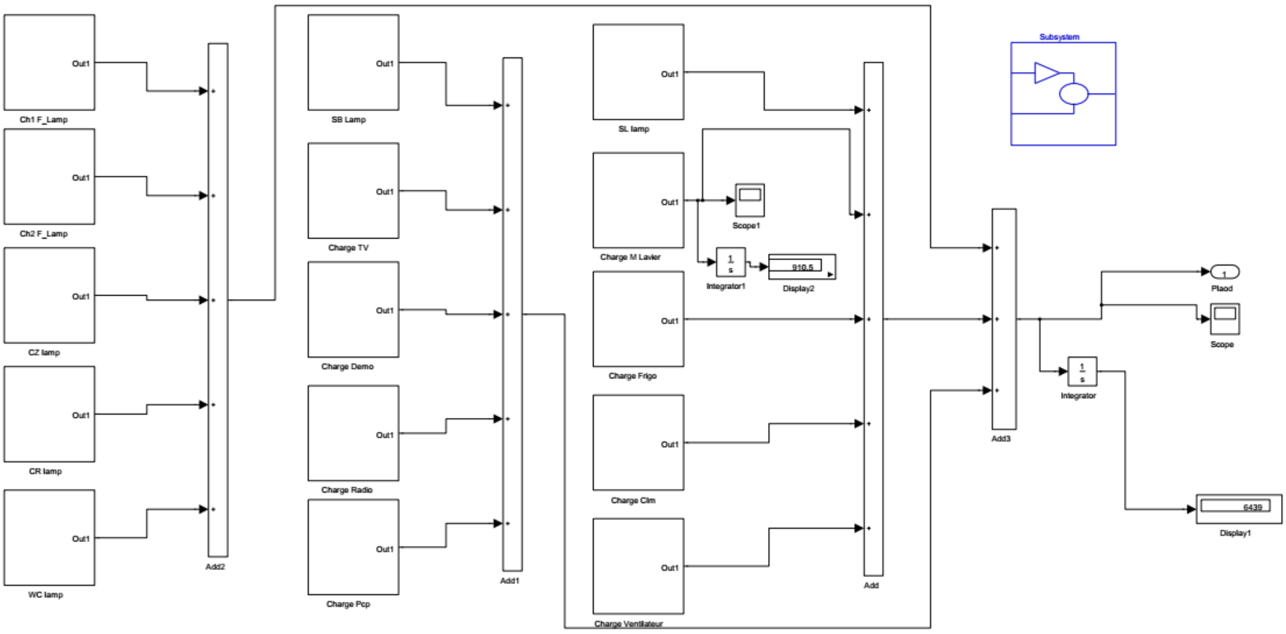


Figure B.2 shows the Simulink block for modelling the load of a home with various the consumption of each domestic appliance.

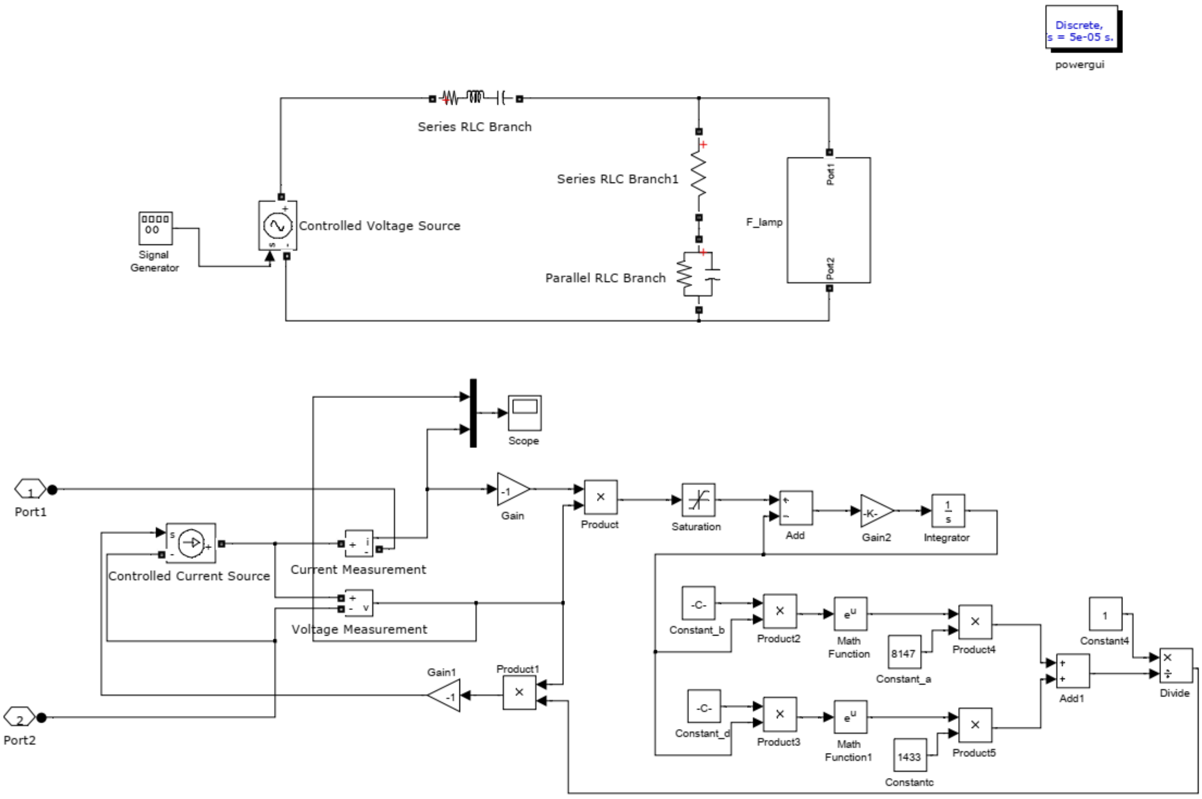
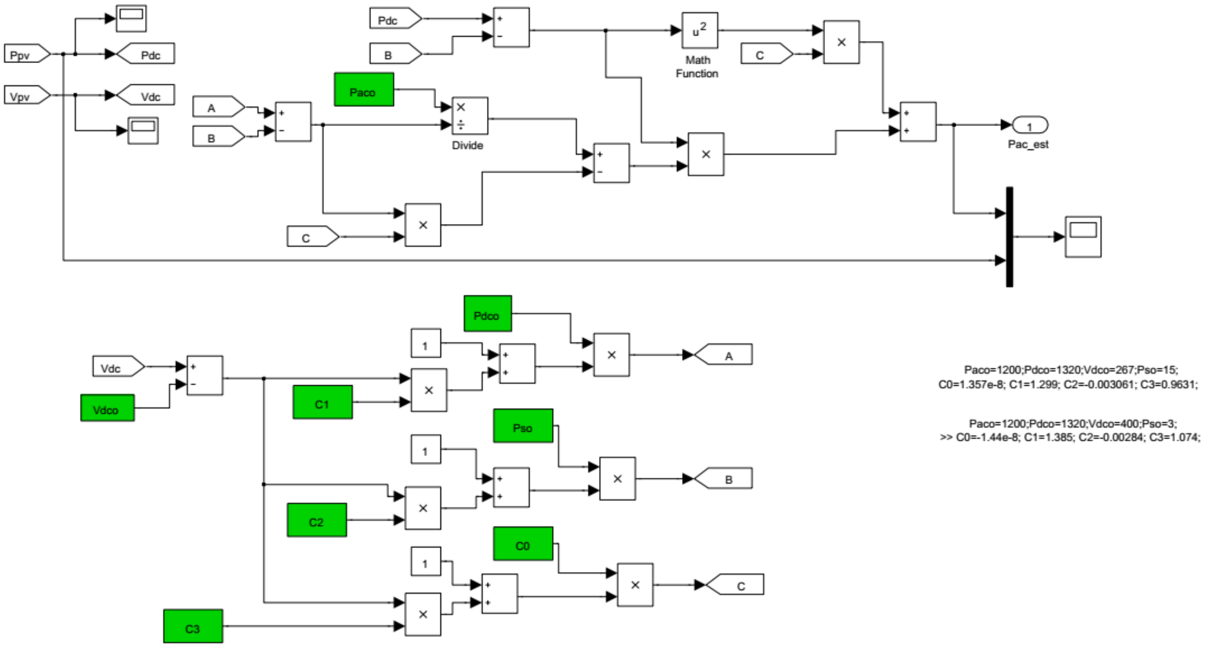


Figure B.3. fluorescent lamp model under Matlab-Simulink



```
Paco=1200;Pdco=1320;Vdco=267;Pso=15;
C0=1.357e-8; C1=1.299; C2=-0.003061; C3=0.9631;

Paco=1200;Pdco=1320;Vdco=400;Pso=3;
>> C0=-1.44e-8; C1=1.385; C2=-0.00284; C3=1.074;
```

Figure B.4. Parameters of the PV inverter model under Matlab-Simulink

Achievements of papers and conferences

Achievements of papers and conferences

1/ Journal papers

1) **I. Laib**, A. Hamidat, M. Haddadi, N. Ramzan, A.G. Olabi,” **Study and simulation of the energy performances of a grid-connected PV system supplying a residential house in north of Algeria**”, Energy, Vol. 152, 2018, pp. 445-454.
   Lien: https://www.sciencedirect.com/science/article/pii/S0360544218305668

2/ Conferences papers

1) **I. Laib**, A. Hamidat, M. Haddadi, A. Alanazi, and A.G. Olabi,” **Energy performance of residential buildings: housing case Study in Southern Algeria**”, 11th International Conference on Sustainable Energy & Environmental Protection, At University of the West of Scotland, Paisley Campus 8-11 May, (SEEP’2018), Vol. 1, pp. 107-112.
2) **I. Laib**, A. Hamidat, M. Haddadi, K. Kaced, and A.G. Olabi,” **Energy situation and renewables in Algeria**”, 11th International Conference on Sustainable Energy & Environmental Protection, At University of the West of Scotland, Paisley Campus 8-11 May, (SEEP’2018), Vol. 2, pp. 295-300.
3) **I. Laib**, A. Hamidat, M. Haddadi, N. Ramzan, and A.G. Olabi,” **Study and Simulation of the Energy Performances of a Grid-Connected PV System Supplying a Residential House in North of Algeria**”, 10th International Conference on Sustainable Energy & Environmental Protection, at University of Maribor Press, Bled-Slovenia 27-30 June, (SEEP’2017), Vol. Renewable Energy Sources, pp. 351-362.
   Lieu : http://press.um.si/index.php/ump/catalog/view/252/214/437-1

4) **I. Laib**, A. Hamidat, M. Haddadi, K. Kaced, N. Ramzan, and A.G. Olabi,” **Model and Simulation of a grid-connected residential PV system**”, Annual Research Conference April 2017, At University of the West of Scotland, Paisley Campus 27th April.

5) **I. Laib**, Y. Elgouni, S. Boukhnous, and A. Hamidat,” **Etude et réalisation d'un système de poursuite solaire pour générateur photovoltaïque**”, 3th Séminaire International sur les Energies Nouvelles et Renouvelables, at Unité de Recherche Appliquée en Energies Renouvelables, Ghardaia-Algeria 13-14 Octobre, (SIENR’2014).