الجمهورية الجزائرية الديمقراطية الشعبية
People's Democratic Republic OF Algeria
وزارة التعليم العالي و البحث العلمي
MINISTRY OF HIGHER EDUCATION AND SCIENTIFIC RESEARCH
جامعة الشهيد الشيخ العربي التبسي–تبسة
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كلية العلوم و التكنولوجيا

Department of Electrical Engineering

A Master's Thesis

Presented to obtain the diploma of Academic Master in Electrical Engineering
Discipline: Science and Technology
Specialty: Industrial Electrotechnics

Title

MODELING AND CONTROL OF SOLAR PHOTOVOLTAIC ENERGY CONVERSION SYSTEM

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2023/2024

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

Thanks

First, we would like to thank Allah Almighty, who gave us the strength, will, and patience to accomplish this work.

We thank our parents for their understanding and what they endured for us, as this gives us happiness and confidence, and all our family members and all our friends who have always supported us. Throughout our studies.

We would also like to express our sincere thanks to ***Dr. BOUGUERNE Abla****, for her availability at all times andHelp to finish this thesis.*

We thank the members of the jury Dr. DJEDDI Abdelghani*and Dr.*NEHAL Ouassila*who were kind enough to accept consideration of this memorandum, and in this regard we extend our utmost respect and appreciation to them.*

We also extend our special thanks to ***Professor Boukadoum Aziz****, who followed us during our work and for his valuable advice, and we also thank all the professors of the Electrical Engineering Department.*

In the end, we would also like to thank everyone who contributed directly or indirectly to the completion of this work.

Samah & Dhouha

Dedications

With joy, an open heart, and overwhelming happiness,

I dedicate this humble work

*To my dear mother: **Fatima**.*

*To my dear father: **Ahmed**.*

For their sacrifices, love, compassion, support and prayers throughout my studies.

*To my dear brothers and sisters: **Lazher, Karima, Mohammed Al-Tayeb, Taher, Malak, and Yahya**.*

*To my dear aunt: **Saliha**.*

*And all the family members, my grandmother **Meriem** and all my uncles and aunts.*

*To my fiance: **Nassim** and my second family.*

To my dear cousins.

*To my friends: **chaima, Khadija, Nadia,** and to everyone who loves me.*

*To my colleague: **Dhouha***

To all my friends and my entire class.

Samah

Dedications

With joy, an open heart, and overwhelming happiness

I dedicate this humble work

To my dear mother: **Fadjra**.

To my dear father: **Ahmed**.

For their sacrifices, love, compassion, support and prayers throughout my studies.

To my dear brothers and sister: **Badria, Alaa, Hamza**.

To my sister **Salma** and her husband **Saber**.

To my dear grandmother **Aaljia**, my uncle and my aunt.

To my cousin **DJalila** and her husband **Boudjemaa**.

To my fiance: **Abd el Raouf** and my second family.

To the **Abd el Razzak** family.

To my friends: **Najwa, Soumaia, Sabrin, Manal**, and to everyone who loves me.

To my colleague: **Samah**

To all my friends and my entire class.

Dhouha

ملخص

نظرا لتزايد عدد السكان، فان الطاقة من موارد الوقود الأحفوري (النفط والفحم والغاز الطبيعي)أصبحت ًغير كافية لتلبية احتياجات العالم المتنامية من الطاقة. لذلك كان من الضروري إيجاد حل قابل للتطبيق، مثل إنتاج الكهرباءمن مصادر الطاقة المتجددة، والتي تمثل حلا للمستقبل، تعد الخلايا الكهروضوئية واحدة من أفضل الطرق لإنتاج الكهرباءلأنها تمثل حلا اقتصاديا و مثاليا للمشاكل التي تواجهها المناطق المنعزلة في التغذيةالكهربائية، حيث تعتبر الكهرباء الشمسية من أهم الطاقات المتجددة في العصر الحديث من النـاحية الطاقوية، الاقتصادية والبيئية كما تتغير مع التطورات التكنولوجية الجديدة وباستخدام تكنولوجيات مبتكرة على أنظمة تحويل الطاقة الكهربائية. ومن خصائص الألواح الشمسية أنها لا تعطي استطاعتها العظمى إلا في نقطة معينة ومتغيرة بتغير الظروف المناخية المحيطة بها، كالتغير في شدة الضوء والحرارة، لذلك وجب استعمال نِظام تعقبُ للاستغلال الأمثل للطاقة المنتجة.

الهدف من هذا العمل هو دراسة ومحاكاة مكون من لوح شمسي ومقطع رافع للجهد الكهربائي بتقنية تعقب نقطة الاستطاعة العظمى الذي يسمح بالاستغلال الأمثل للطاقة الشمسية المولدة و ذلك باستخدام خوارزمية "التشويش والمراقبة" لاستخراج الطاقة القصوى في حالة تغيير الحمل والظروف الجوية بالإضافة الى محاكاة مولد كهربائي شمسي موصول بشبكة احادية الطور.

Abstract

Due to the growing population, energy from fossil fuel resources (oil, coal, natural gas) has become insufficient to meet the world's growing energy needs. Therefore, it was necessary to find a viable solution, such as producing electricity from renewable energy sources, which represents a solution for the future. Photovoltaic cells are one of the best ways to produce electricity because they represent an economical and ideal solution to the problems faced by isolated areas in electrical supply, as solar electricity is considered It is one of the most important renewable energies in the modern era from an energy, economic and environmental perspective, as it changes with new technological developments and the use of innovative technologies in electrical energy conversion systems.One of the characteristics of solar panels is that they only give out their maximum capacity at a specific point and it changes with changes in the climatic conditions surrounding them, such as changes in the intensity of light and heat. Therefore, a tracking system must be used for optimal exploitation of the energyproduced.

The aim of this work is to study and simulate a solar electric generator consisting of a solar panel and a voltage riser using the maximum power point tracking technology, which allows optimal exploitation of the generated solar energy by using the “distortion and monitoring” algorithm to extract maximum power in the event of a change in load and weather conditions and simulation of a photovoltaic system connected to single-grid.

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List of symbols

I_{pv}: Current delivered by the PV cell.

I_{ph}: Photo-current.

I_d : Diode current.

I: Current generated by the photovoltaic cell.

I_{sc}: short circuit current.

K_I: short circuit current of cell at 25°C and 1000 W/m^2

Irs: Reverse Saturation current

E_{g0}: band gap energy of the semiconductor

V_{pv} : Voltage delivered by the PV cell.

v_t: Thermal voltage.

v_d : Diode voltage.

T: Absolute temperature in ˚K.

T_c: Circuit temperature.

I_0 : Diode saturation current.

I_{sh} : Shunt current.

R_s: Series resistance (Ω).

R_p : Parallel shunt resistors (Ω).

R_{sh}: Shunt resistance (Ω).

N_p: Number of modules in the panel in parallel.

N_s: Number of modules in the panel in series.

q: Charge of the electron.

Pmax: Maximum power supplied by the cell (W)

Vmax: Maximum voltage supplied by the cell (V).

Imax: Maximum current supplied by the cell (A).

K: Boltzmann constant (1.38.10-23 J/K).

A: Ideality factor of the junction (1<A<2).

$\mathbf{V_{c0}}$: Open circuit voltage.

$\mathbf{I_{C0}}$: Open circuit current.

$\mathbf{I_{CC}}$: Short circuit current.

$\mathbf{V_{CC}}$: Short circuit voltage.

$\boldsymbol{f_f}$: Form factor.

η: Yield.

$\boldsymbol{K_2}$: Constant of proportionality.

$\boldsymbol{I_{opt}}$: Optimal current.

$\boldsymbol{V_{opt}}$: Optimal tension.

P: Power.

V: Tension.

I: Current.

G: Incremental conductance.

(W): Watt.

(V): Volt.

(A):Ampere.

(Ω): Ohm.

Abbreviations

PV: Photovoltaic.

GPV: Photovoltaic generator.

PPM:Maximum Power Point.

MPPT: Maximum Power Point Tracking.

P&O: Disturbance and Observation.

DC-DC:Direct Current (DC-DC converters).

IGBT:Insulated Gate Bipolar Transistor.

GTO: Gate Turn-Off Thyristors.

General introduction

General Introduction

As we know, most of the energy today is consumed by using fossil fuels such as oil, coal, natural gas or even nuclear energy. Recent studies and predictions alert us to thisthe extensive use of these resources will certainly lead to their complete exhaustion.In addition, everyone around the world is convinced of the seriousness of this processon the environment.

From this observation, it was necessary to search for other energy sources. renewable energies, such as photovoltaic, wind or hydraulic..., it represents an alternative solution par excellence and is increasingly more widely used nowadays. This type of energy is not only free and inexhaustible, but also very clean for the environment. Moreover, we often talk about “green” energy because it completely avoids pollution from source sourcestraditional.

Solar radiation constitutes the best combined energy source on earth and the most abundant portion of this radiation can be exploited to directly produce heat (solar thermal energy) or electricity (solar photovoltaic energy). The amount of energyit could be the sun that fired it.

However, due to their dependence on weather conditions, renewable energy sources pose new challenges to the electricity system.Photovoltaic electricity presents an interesting technical and economic optionin locations not connected to the central distribution network. When the needs to be covered are lowwhere there is no heavy maintenance. It is decentralized energy and can be used and at the same time produced and installed in all sunny and isolated areas. It makes it possible to cover the electricity needs of the home such as lighting and production of water.

Photovoltaic (PV) technology is an attractive solution to replace traditional sources of electricity supply. Accordingly, many scientific studies have focused on dynamic modeling. Simulate and control a photovoltaic system in order to describe its physical model and predict the evolution of its outputs such as current, voltage and power.

Algeria has great and strong potential in the field of developmentdue to its geographical location. The energy must take advantage of favorable conditions for the use of solar energy and the use of photovoltaic energy and the introduction of this new energy can easily be envisaged in many locations where it will be able to exploit solar energy on a large scale. Today we are witnessing that the energy transition is ultimately determining the energies of the future.

The aim of this work is to contribute to the study, modeling and monitoring of a system for converting photovoltaic energy into electrical energy. This choice justifies the interest shown by researchers and manufacturers in this type of photovoltaic structure.

For the practice of this etude, outside a general introductionand a general conclusion,the content of this memory is divided into several chapters:

- ✓ In the first chapter, we presented the various sources of renewable energy, including solar energy, which is considered one of the most important renewable energies and alternative resources that must be exploited as much as possible, as photovoltaic are considered one of the best ways to produce electricity, as we will study in the next chapter.
- ✓ The second chapter describes in general terms the different basic elements of a systemphotovoltaic while presenting the principle of the photovoltaic effect, the equivalent diagram of the photovoltaic cell and the mathematical model respectively describing, and The power photovoltaic generator variation with the irradiation and temperature function).
- ✓ The third chapter describes the different types of DC-DC converters used in PV conversion chains, giving their operating principle. After that, we are simulated of a photovoltaic system with boost converter and presented his results.
- ✓ Finally, the fourth chapter consist two parts, in the first part we will introduce the different MPPT controls, and optimize a photovoltaic system by applying Maximum Power Point Tracking (MPPT) structures in the simplest method (Perturb and Observe – P&O). In the second stage the system single-grid connected photovoltaic are modeling and simulated. All this section concludes by simulating using Matlab/Simulink.

CHAPTER I: RENEWABLE ENERGIES GENERALITY

I.1Introduction

In order to change the old vision of electricity production, researchers called for renewable energy resources that have the great advantage of being of natural origin and not polluting the environment. Today, more than 85% of the energy used in the world comes from fossil fuel deposits (coal, oil, gas) or uranium, which It was formed with the passage of time, technological development, the successive oil crisis of 1973, and the increased demand for energy in all countries of the world, which prompted industrialized countries to search for new sources of supply and develop them. However, the latter represents a common drawback due to its random nature, relying on weather and climatic conditions that change over time. In this chapter; we will present the different types of renewable energies and their statistics at the global and local levels [1].

I.2Definition of renewable energies

Renewable energies are energies derived from natural sources that are renewed at a rate higher than their consumption, and come from natural elements: sun, wind, waterfalls, tides, earth's heat, and plant growth. Exploiting renewable energies generates little or no waste and polluting emissions. These are the energies of the future [2].

Figure I.1 : Renewable energies

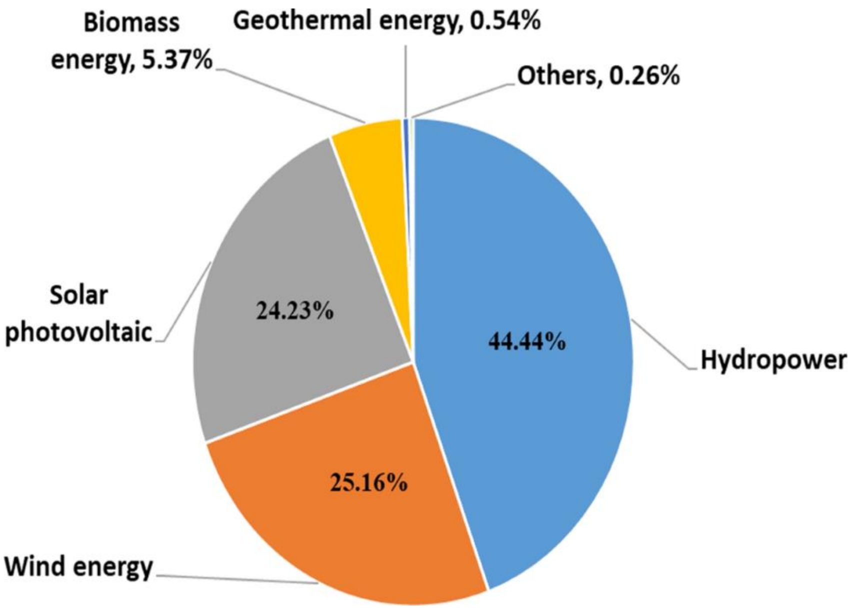


Figure I.2 : Structure of electricity production

I.3 Different Renewable energies

I.3.1 Hydraulic energy

It is the energy provided by the movement of water, in all its forms: falling, watercourses, sea currents, tides, waves. This movement can be used directly, for example with a water mill, or to be converted into electrical energy in a hydroelectric power plant. When the water is stored, simply open the valves to start the cycle electricity production. The water then rushes into a penstock or into a gallery dug into the rock following the installation, and heads towards the power station hydraulic located below.

Hydropower is currently the main source of renewable electricity. Hydropower installed worldwide in 2004 was estimated at 715 giga watts, or about 19% of total global electric power. Approximately 15% of the total installed electricity in Europe comes from hydraulics.

The production of hydraulic electricity exploits mechanical energy (kinetic and potential).water. The principle used to produce electricity with the power of water is the same principle used to produce electricity with the power of water mills in ancient times. Instead of energizing the wheel, the force of the water activates a turbine, which energizes the wheel
Operating the electric generator and producing electricity [3].

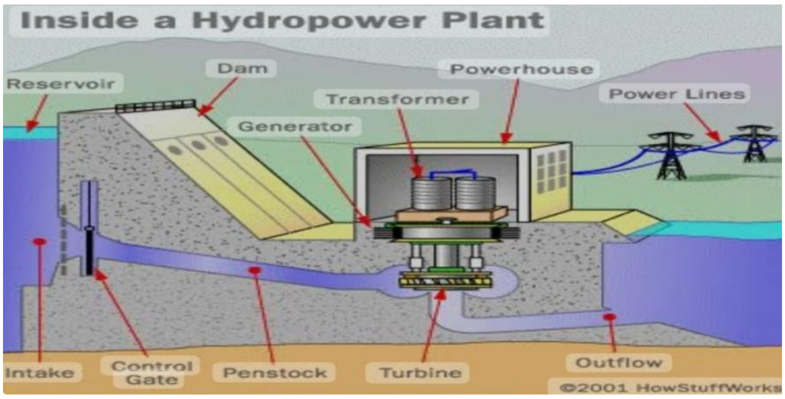


Figure I.3 : operating principle of a hydraulic power plant

I.3.2 Wind energy

By definition, wind energy is energy produced by the wind. This mechanical energy is exploited by wind turbines and propellers installed on top of towers that rotate under the influence of the wind. The rotation of the fans activates the electricity production system. It is a device that converts the kinetic energy of wind into mechanical energy. This energy is then converted into electricity by the motor. The cost of investment is high, especially "offshore", but the initial energy is free and the effects are high the environment is weak. However, there are still some problems with wind turbines in some areas, related to low-frequency noise, which is unpleasant for those who live near them [4].

There are two types of wind turbine installations:

— So-called “onshore” land wind turbines are installed on land.

— So-called “offshore” wind turbines are installed at sea.

Wind energy, considered a clean energy source, is booming,

But its share in total global electricity production remains limited to around 3%.

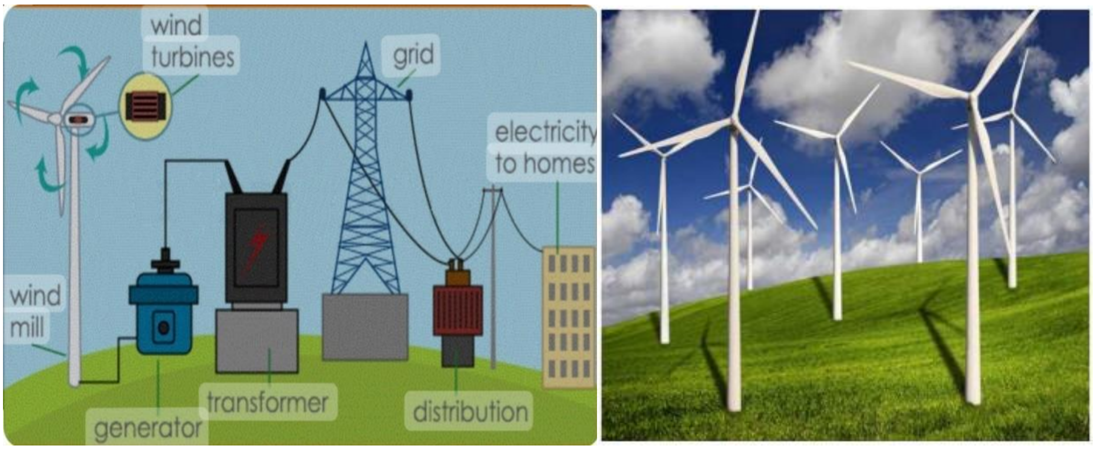


Figure I.4 : Main diagram of a wind power plant

I.3.3 Geothermal energy

Geothermal energy refers to geothermal energy derived from the energy of the Earth which is converted into heat. Classically, three types of geothermal energy are distinguished according to the temperature level available for operation:

- *High energy geothermal energy.*
- *Low energy geothermal energy.*
- *Very low energy geothermal energy.*

To use this underground energy, cold water is sent underground. This cold water warms up. It is then pumped and brought back to the surface where it is used either to produce electricity in a power plant, or directly as hot water in homes (water hot for the shower, radiators, etc.)[5].

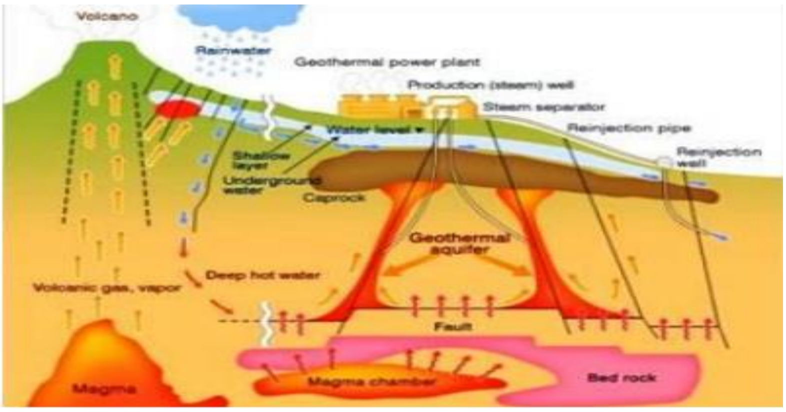


Figure I.5 : Geothermal

I.3.4 Biomass energy

Biomass is a real reserve of energy in the form of organic carbon, which is obtained from sunlight through photosynthesis and also organic matter that can be used as fertilizer for agriculture. It means any living matter of plant or animal origin on the surface of the Earth. In principle, by-products and waste are also sorted. There are different ways of looking at it. Like wood energy, biofuels and biogas, they are very abundant and most widely used resources in the world, and they are also stored in organic form thanks to solar PV [6].

This is clearly shown in (Figure I.6).

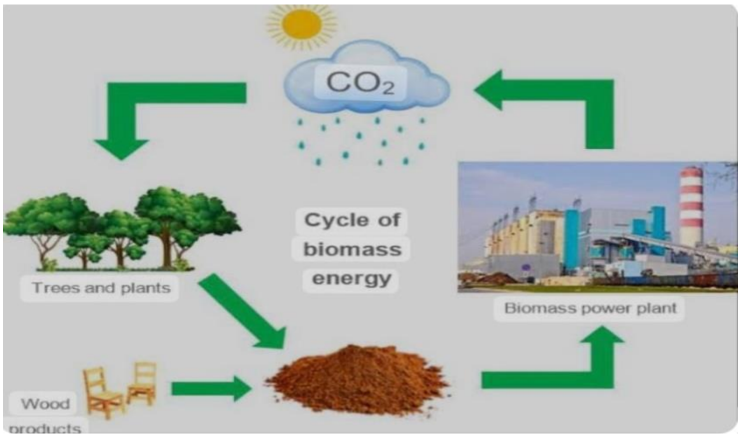


Figure I.6 : operating principle of the biomass

I.3.5 Solar energy

Solar energy comes, as its name suggests, from the sun. This energy can be usefully transformed into heat or electricity. We then distinguish three types of solar; thermal solar energy and photovoltaic solar energy, thermodynamic solar energy [7].

I.3.5.1 The different solar technologies:

I.3.5.1.1Energy Photovoltaic solar:

Photovoltaic solar energy converts light radiation directly into electricity. To do this, we use photovoltaic modules made up of solar cells which convert this energy.

Solar PV uses the sun as a light source by converting it into electricity. The energy of photons that reach the Earth's surface transfers its energy to the electrons in the semiconductor (which make up the photovoltaic cell). This transformation (photoelectric effect) takes place without mechanical action, noise-free, pollution-free and fuel-free. The photoelectric effect was discovered by the French physicist A. Becquerel in 1839. The word “photovoltaic cell” comes from the word “photo” (from the Greek word “phos”» which means “light”) and the word “volt” (the nickname of the physicist Alessandro Volta, who contributed very significantly to electricity research) [7].

Figure I.7 : Photovoltaic module

I.3.5.1.2 Solar thermal energy

The produces solar thermal energy heat from solar infrared radiation to heat water or air.In this case, we use thermal sensors which are a completely different technology. They are known as "solar water heaters" or "hot air collectors".

The principle of thermal energy is to convert solar radiation into thermal energy thanks to the fluid circulating in the panels exposed to the sun (Figure I.8). This form of energy conversion can be direct in the case of domestic water heating only.

While we wanted to generate electricity, we would have to use generators that convert the generated thermal energy into electricity (such as hot air engines).

Thermal energy uses heat from solar radiation to heat buildings or waste water. For the latter, it is interesting to know that in some countries domestic water heating accounts for about **20%** of household energy expenditure and that solar thermal energy can cover about **80%** of this energy expenditure [7].

Figure I.8 : Solar water heaters

I.3.5.1.3 Thermodynamic solar energy

Thermodynamic concentrated solar power is a technology that uses mirrors that focus solar energy towards a tube containing a heat transfer fluid that is heated to a temperature of up to 500 degrees Celsius. The resulting heat is transferred to the water circuit, and the resulting steam then activates a turbine coupled to an electric generator that produces electricity [8].

One of the great advantages of this technology comes from the fact that heat can be stored, allowing solar power plants to produce electricity during the night.

The mirrors that collect solar energy (placed 3 or 4 meters from the ground) form a zone shade on the ground, however there is enough light to eventually cultivate fruits or vegetables [7].

Part of the fresh water formed on site by condensation at the outlet of turbine, can be used for watering, see (Figure I.9).

Figure I.9 : Solar tower

I.4 Solar energy potential in Algeria

Due to its geographical location, Algeria has one of the largest solar deposits raised in the world. The duration of insolation over almost the entire national territory exceeds the 2000hours annually and can reach 3900 hours (highlands and Sahara).The energy received daily on a horizontal surface of 1m² is of the order of 5 kWh over most of the national territory, i.e. nearly 1700KWh/m/year in the North and 2263 kWh/m/year in the South of the country [8].

Algeria is considered one of the countries with the largest solar energy resources in the Mediterranean, as the radiation of the area near the sea is affected by the seasons. The Sahrawi’s receive a greater amount of energy but are characterized by a higher air temperature. Taking this diversity into account, the total energy received It is estimated at 169,400 TWh /year, or 5,000times the country's annual electricity consumption [7, 8].

Regions	Coastal region	Highlands	Sahara
Area (%)	4	10	86
Average duration of sunshine (Hours/year)	2650	3000	3500
Average energy received (KWh /m²/year)	1700	19000	2650

Table I.1 : Solar potential in Algeria

The following figure shows the distribution of energy received in Algeria, with a lower annual average. It displays the different energy levels that thus give the country a breakdown into equal energy zones.

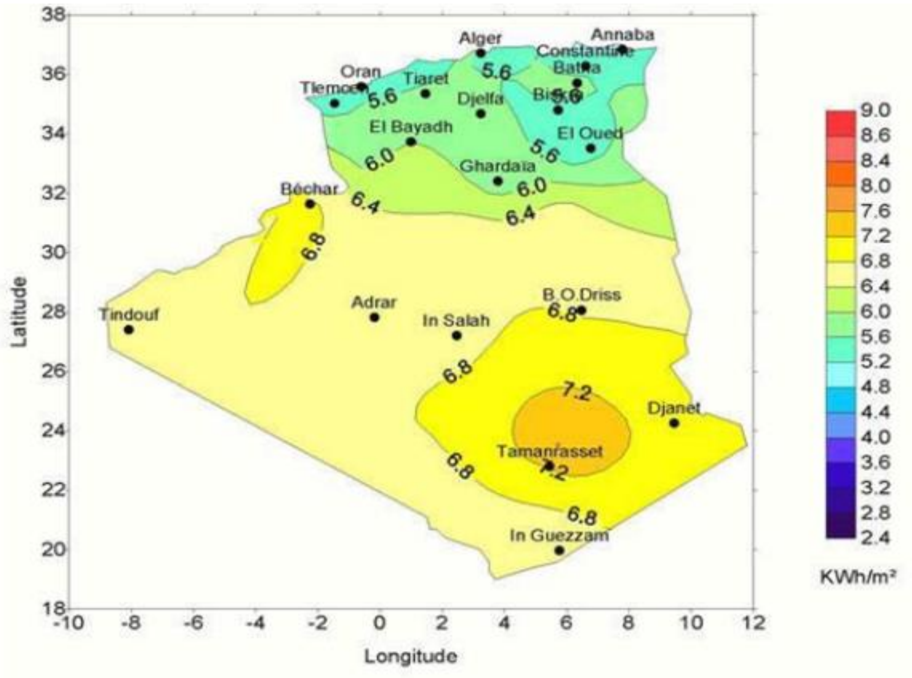


Figure I.10 : Annual average of energy received in Algeria

The National Program for the Development of Renewable Energies (ENR) was adopted.

In 2011 and then revised in 2015, aiming to achieve a total strength of 203022,000 megawatts are allocated for local consumption only. To this end, it is planned to implement a wide range of technological sectors where photovoltaic (PV) and wind power take the lion's share with 13,575 MW and 5,010 MW respectively, and the rest is distributed between solar thermal power (CSP), biomass, cogeneration, and solar energy. Geothermal.

The number of these sectors responds to the desire not to spare any means or effort for this to produce as much renewable electricity as possible in order to better compensate for the upcoming fossil energy deficit. Electricity is the only product each of them generates, so they could find themselves competing against each other instead.

Especially when two or more of them are running in succession two or more energy fields overlapping in the same area. In this case they cannot coexist naturally because economic selection would be necessary to choose more profitable.

This could happen with the two main sectors of the national training programme. Development of renewable energies, bearing in mind that the same logic can be extended to other sectors.

I.5 Renewable energies in Algeria

In recent years, Algeria has contributed to launching the green energy dynamism by launching a program to develop renewable energies. This vision is based on a strategy that focuses on developing and using resources to diversify energy sources and prepare the Algeria of tomorrow.

The program consists of installing renewable power of nearly 22,000 MW between 2011 and 2030 of which 12,000 MW will be dedicated to covering national demand in electricity and 10,000 MW for export. But exporting electricity Conditional on the presence of a long-term purchase guarantee, reliable partners and external financing.

The national potential in the field of renewable energies is strongly dominated by solar energy. This energy is considered an opportunity and a lever for development Economic and social growth in Algeria, especially through the establishment of wealth-generating industries, for example, the potential in wind energy, biomass, geothermal energy, and Hydropower is much less important. But this does not at all prevent numerous projects to build wind farms and implement pilot projects in biomass and geothermal energy.

Algeria is committed to designing through renewable energies in order to provide global and sustainable solutions to environmental challenges Problems of conservation of energy resources of fossil origin.

This strategic choice is motivated by the immense potential in solar energy. This energy constitutes the major axis of the program which devotes to solar thermal and solar photovoltaic an essential part. Solar energy is expected to reach more than **37%** of electricity by 2030. National electricity production.

Despite a fairly low potential, the program does not exclude wind power which constitutes the second axis of development and whose share should be around 3% of production electricity in 2030.

Algeria is also planning the installation of some experimental-sized units. In order to test the different technologies in terms of biomass, geothermal energy and desalination of brackish water using different renewable energy sectors [9].

I.6 InternationalStatistics renewable energy

According to a 2018 report by the International Energy Agency, renewable energies represent 16.4% of final energy consumption worldwide. This is about 1% more than in 1990 15.5%. Looking at these figures; we could say that the progress of renewable energies in the world is very weak: Less than 1% for 25 years. However, this figure hides a completely different reality since the 1990s, among the different types of renewable energy; some have decreased slightly while others have increased significantly.

Biomass (notably more important in energy consumption today than in 1990. This share has in fact fallen by 1.3%. But at the same time, other types of renewable energy have increased considerably: this is particularly the case for wind energy and solar energy, and even hydroelectric energy. Wind energy production, for example, increased from 3.4 TWh in 1990 to 790 TWh in 2016: it was therefore multiplied by 226 For solar, these are the same orders of magnitude: in 1990, we consumed 0.58 TWh of electricity from solar origin, for 279 TWh in 2016 (nearly 500 times more).This proves that for almost 30 years, renewable energies and in particular electricity from renewable sources has continued to increase[10].

I.7 some advantages and disadvantages of renewable energy

- ***Advantages***

- In general, renewable energies are cleaner than the fossil energies currently exploited throughout the world. They are more environmentally friendly and available in large quantities throughout the world, as they are free as soon as production facilities become available**.**
- Solar energy is widely popular in the energy sector and is developing rapidly, as it can be exploited on a large scale, for example in planned gardens, or on a small scale among individuals.
- Wind turbines demonstrate excellent production capabilities and are a viable alternative in remote areas where access to electricity is difficult.
- The contribution of biomass energy to local development is that it is inexpensive (tree logs and wood pellets are the cheapest types of fuel on the market).

- ***Disadvantages***

Since renewable energies have advantages, they must also have disadvantages, including:

- The relatively high cost of purchasing facilities whose profitability may take years to come.

- Its availability depends on the climate. For example, days when there is no wind or not much light can seriously hinder the production of wind and solar energy.
- The visual impact on the landscape and on biodiversity in general.

I.8 Conclusion

In this chapter we have presented different sources of renewable energy, and this type of energy has become a dire need for the world now as all our non-renewable resources are being depleted very quickly. Solar energy is considered one of the most important renewable energies and promising alternative resources that must be exploited as much as possible, as photovoltaic cells are one of the best ways to produce electricity.

CHAPTER II: CONSTITUENTS AND MODELING OF THE PV SYSTEM CONVERSION CHAIN

II.1 Introduction

Photovoltaic solar energy comes from the direct transformation of a part of the light into electricity. This conversion is carried out through a cell called a photovoltaic cell (PV) based on a physical phenomenon called the photovoltaic effect, which consists of producing an electromotive force when the cell is exposed to light. The generated voltage can vary depending on the material used for the fabrication of the cell.

There are several combination cells in series and parallel results in a photovoltaic generator (PV generator) with a non-linear current-voltage (I-V) characteristic presenting a maximum power point. Nowadays, and depending on the need, the electrical energy produced is available in the form of direct electricity (supplying a load) or stored in batteries [11].

In this chapter, we have recalled some basic concepts about the photovoltaic effect to better understand this phenomenon, the principle of the photovoltaic cell, their different models, and the load.

II.2 Photovoltaic energy

Photovoltaic solar energy is a renewable electrical energy produced from solar radiation. It originates from the nuclear fusion occurring at the center of the Sun. It spreads throughout the solar system and the universe in the form of electromagnetic radiation of photons**.**

The photovoltaic cell is the basic electronic component, utilizing the photoelectric effect. Several cells connected together form a photovoltaic solar module, and multiple modules grouped together constitute a solar installation that generates electricity, which can be used on-site or fed into a distribution network**.**

Overall, the Earth constantly receives a power of 170 million gigawatts, of which 122 are absorbed, while the rest is reflected. The total energy absorbed over a year is therefore 3,850 zettajoules (10^21 joules, ZJ). Solar energy can be used in several ways [12]:

- Directly (for light and heating)
- Indirectly (converted into electrical energy).

II.2.1 History of the Photovoltaic Cell

- The photovoltaic effect is the process of converting light into electricity, discovered by Edmond Becquerel in 1839. However, it would take nearly a century for scientists to delve deeper into and harness this phenomenon in physics.
- In 1875, Werner von Siemens presented an article before the Berlin Academy of Sciences on the photovoltaic effect in semiconductors.

- In 1913, William Coblenz filed the first patent for a solar cell that, unfortunately, would never be able to function**.**
- In 1916, Robert Millikan became the first person to generate electricity using a solar cell, but these photovoltaic cells had too low efficiency to effectively convert sunlight into energy.
- During the year 1954, three American researchers (Chapin, Pearson, and Prince) developed a high-efficiency photovoltaic cell (9%).
- The first solar panel is constructed by Bell Laboratories. However, it was too expensive to be produced on a large scale. It is the space race that truly advanced solar energy; the solar panel is the only non-nuclear means to power satellites.
- In 1958, the first launch of a satellite operating on photovoltaic energy took place. This marked the first significant use of photovoltaic solar technology.
- New types of solar panels have been developed, including very thin (4 mm thickness) and flexible solar panels, as well as solar paints. The goal was to significantly reduce the cost of solar energy [12].

II.2.2 Advantages and disadvantages of PV system

Photovoltaic energy has several advantages and disadvantages. Here is a general list of these aspects:

II.2.2.1 Advantages

- ✓ Renewable: Solar energy is a renewable source, as it is derived from the sun, an inexhaustible resource.
- ✓ Clean: Photovoltaic electricity production does not generate air pollution or greenhouse gas emissions.
- ✓ Long-term Cost Reduction: While the initial installation costs of solar panels can be high, solar energy can lead to long-term savings by reducing electricity bills.
- ✓ Energy Independence: Photovoltaic systems can contribute to energy independence by enabling individuals and businesses to generate their own electricity.
- ✓ Low Maintenance: Solar panels typically require minimal maintenance, reducing operating costs.

II.2.2.2 Disadvantages of Photovoltaic Energy:

- ✓ High Initial Cost: The initial installation of photovoltaic systems can be expensive, although costs have significantly decreased over the years.
- ✓ Intermittency: Electricity production depends on sunlight availability, resulting in intermittent production, especially at night and during cloudy weather.
- ✓ Space Requirement: Large photovoltaic installations often require considerable space to generate significant amounts of electricity.
- ✓ Energy Storage: Storing solar energy for use during periods without sunlight can be expensive and requires efficient solutions.
- ✓ Environmental Impact of Materials: The manufacturing of solar panels involves the use of certain materials and chemicals that may have an environmental impact. However, ongoing advancements aim to improve the sustainability of solar technologies.

II.3 Photovoltaic cell

The PV cell, or photovoltaic cell, is the smallest unit of a photovoltaic system. It is composed of semiconductor material and directly converts light energy into electrical energy.

The photovoltaic cellsare composed of:

- ✓ Thin semiconducting layer (material possessing a band gap, which acts as the energy barrier that electrons cannot cross without external excitation, and whose electronic properties can be varied), such as silicon, which is a material with relatively good electrical conductivity.
- ✓ Anti-reflective layer allowing maximum penetration of solar rays.
- ✓ Conductive grid on the top or cathode and a conductive metal on the bottom or anode.

The most recent ones even feature a new combination of multi-layered reflective coatings just below the semiconductor, allowing light to bounce around longer within it to improve efficiency [13].

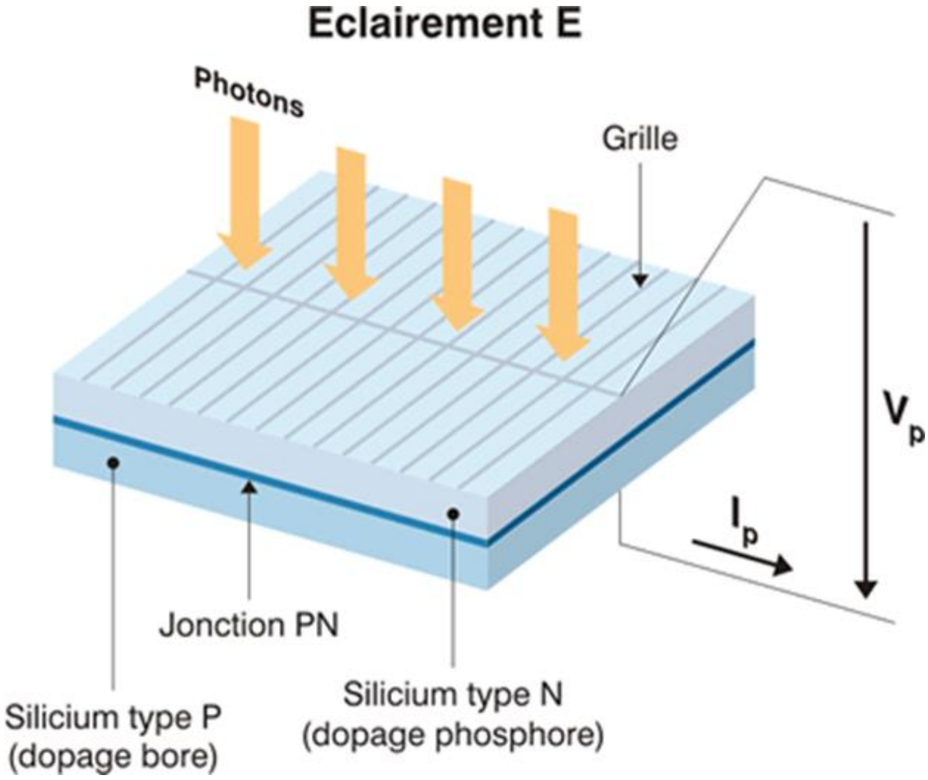


Figure II.1 : Elements of photovoltaic cell

II.3.1 Different solar cell technologies

II.3.1.1 Mono-crystalline cells

PV panels with mono-crystalline cells are first-generation photovoltaic cells. They are produced from a block of silicon crystallized into a single crystal. The manufacturing process is lengthy and energy-intensive; although more expensive, it is more efficient than polycrystalline silicon.

Raw silicon is melted to create an ingot. When silicon cools slowly and is controlled, a mono-crystal is obtained. A wafer is then cut from the silicon ingot. After various treatments (acid surface treatment, doping, creation of the P-N junction, deposition of an anti-reflective layer, placement of collectors), the wafer becomes a cell.

The cells are round or nearly square, and close-up, they have a uniform color. They have an efficiency of **12** to **18%**, but the production method is labor-intensive [14].

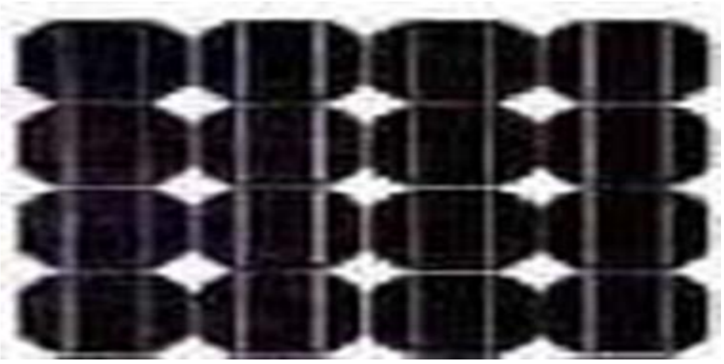


Figure II.2 : Mono-crystalline cells

II.3.1.2 Polycrystalline Cells

PV panels with polycrystalline cells are produced from a block of silicon crystallized into multiple crystals. When viewed up close, the different orientations of the crystals (different tones) can be observed.

They have an efficiency of 11 to 15%, but their production cost is lower than mono-crystalline cells. These cells, thanks to their productivity potential, have become widely used today. The advantage of these cells compared to mono-crystalline silicon is that they require 2 to 3 times less energy for their manufacturing.

The wafer is cut from a silicon ingot with a forced cooling process that creates a polycrystalline structure [14].

Figure II.3 : Polycrystalline Cells

II.3.1.3 Amorphous Cells

Photovoltaic modules with amorphous cells have a much lower production cost, but unfortunately, their efficiency is currently only 6 to 8%. This technology allows for the use of very thin layers of silicon applied glassing, flexible plastic, or metal through a vacuum deposition process.

The efficiency of these panels is lower than that of polycrystalline or mono-crystalline technologies. However, amorphous silicon enables the production of large area panels at a low cost with minimal raw materials.

Note: In chemistry, an amorphous compound is one in which atoms do not follow any order at medium and long distances, distinguishing it from crystalline compounds. Glasses are amorphous compounds [14].

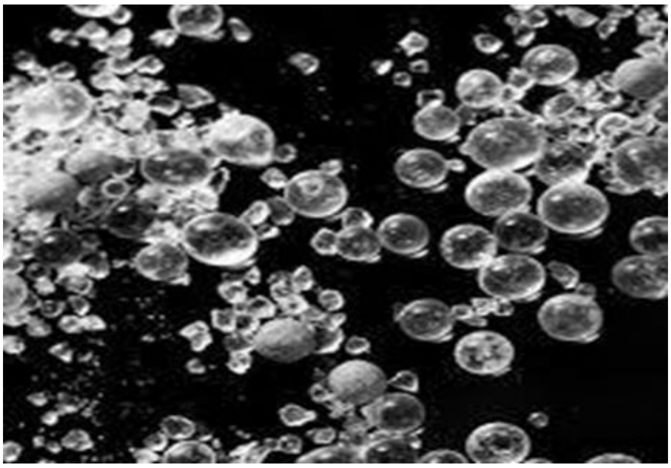


Figure II.4 : Amorphous cells

II.4 The photovoltaic field

The photoelectric field is the unit for generating direct current in the system; it is a group of interconnected photovoltaic modules designed to produce electricity, either independently or as part of a connection to a public grid [15].

Figure II.5 : Example of photovoltaic field

II.5 Different types of PV systems

II.5.1 Grid-Tied Solar PV Systems

Grid-Tied Solar PV Systems are connected to the utility grid and supply electricity to the grid or consume electricity from the grid depending on the demand and supply. A Schematic Diagram for a typical Grid-Tied Solar PV system is shown in (Figure II.6) [16].

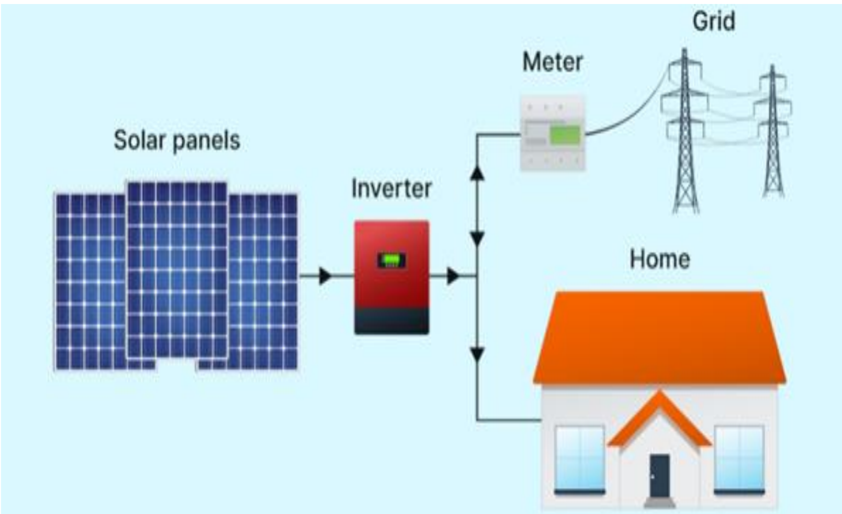


Figure II.6 : Typical Grid-tied solar PV system

II.5.2 Off-Grid Solar PV Systems

Off-grid or Stand Alone solar PV systems are independent of the utility grid and provide electricity to remote or isolated areas where grid power is not available or reliable.

A Schematic Diagram for atypical Off-Grid Solar PV system is shown in (Figure II.7) [16].

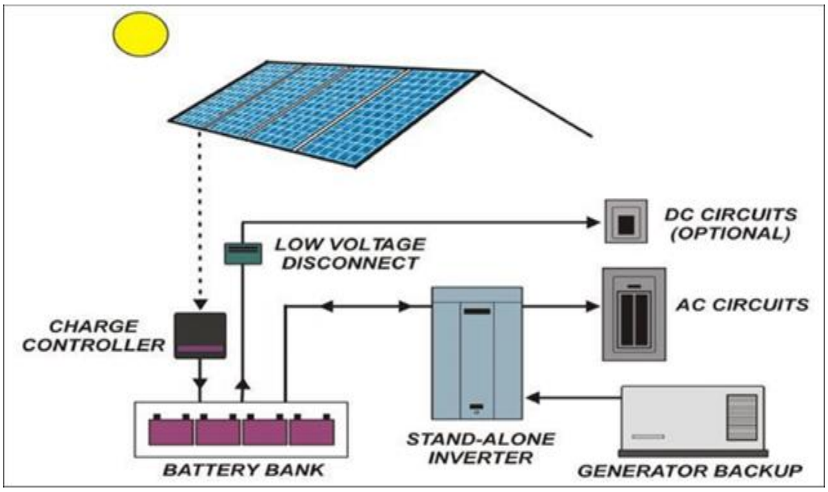


Figure II.7 : Typical Off-Grid Solar PV Systems

II.5.3 Hybrid Solar PV Systems

Hybrid solar PV systems are a combination of solar PV and other power sources, such as diesel generators or renewable sources like wind or hydro. A Schematic Diagram for a typical Off-Grid Solar PV system is shown in (Figure II.8) [16].

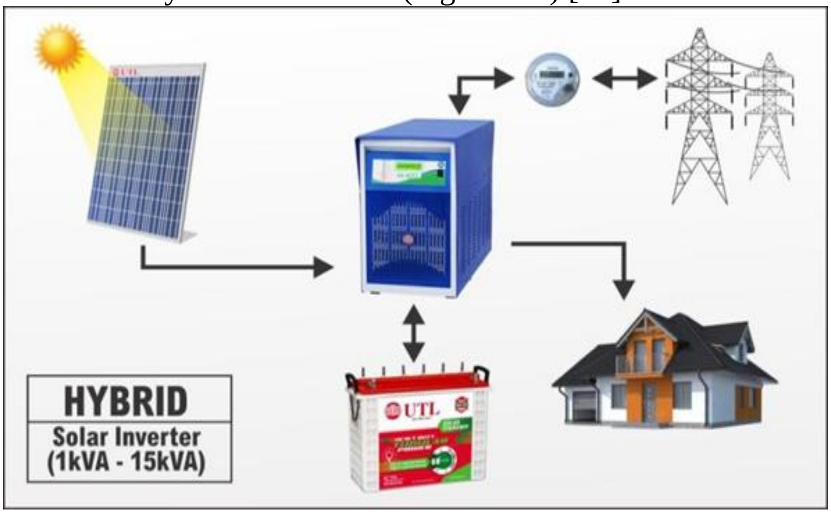


Figure II.8 : Typical Hybrid Solar PV Systems

II.6 Characterization of a PV system

The PV system (photovoltaic cell) model is characterized by a current-voltage curve (I_{pv} -V_{pv}) and a voltage-power curve (P_{pv}-V_{pv}) for different values of temperature and irradiance three physical quantities define these characteristics [17].

- ***Open circuit voltage (V_{co})***: This value represents the voltage generated by an illuminated but unconnected cell.
- ***Short-circuit current (Icc)***: This value represents the current generated by an illuminated cell connected to itself.
- ***The Maximum Power Point (MPP)***: Obtained for optimal voltage and current: Vopt, Iopt (sometimes also called Vppm, Ippm).

Figure (II.9) present the characteristics between current and voltage (I_{pv}-V_{pv}), for the actual characteristic of (P_{pv}-V_{pv}) is shown in the Figure II.10.

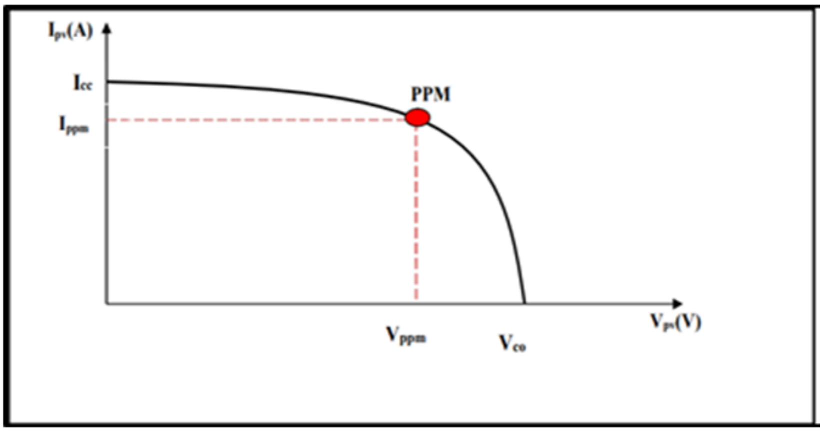


Figure II.9 : Characteristic of (Ipv-Vpv) [18]

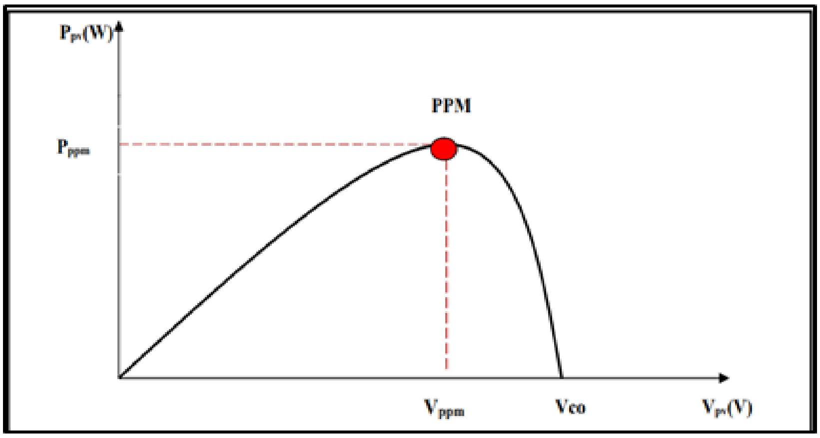


Figure II.10 : Characteristic of (Ppv-Vpv) [18]

II.7 Influence of Solar Illumination Intensity and Temperature on the Conversion Efficiency of Photovoltaic Cells

The conversion efficiency of photovoltaic (PV) cells is closely related to external environmental factors, with one important factor being the intensity of sunlight. While:

(Figure II.11) represents the relationship between the current and voltage of the PV cell under different light intensity conditions assuming a temperature of 25°C; it can be observed that the output current of the cell varies significantly with changes in light intensity, with higher light intensity resulting in increased current. However, the variation in output voltage of the PV cell is relatively small.

On the other hand, (Figure II.12) represents the relationship between the voltage and power output of the PV cell under different light intensity conditions. The power output delivered by the PV cell to the external circuit is determined by both the current and voltage, as evident in this figure, where an increase in light intensity leads to a significant increase in power output [19].

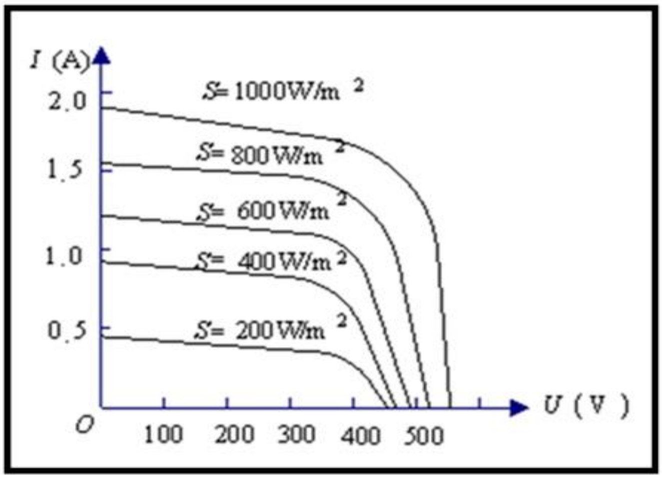


Figure II.11 : Current-voltage characteristics under different light intensity condition [19]

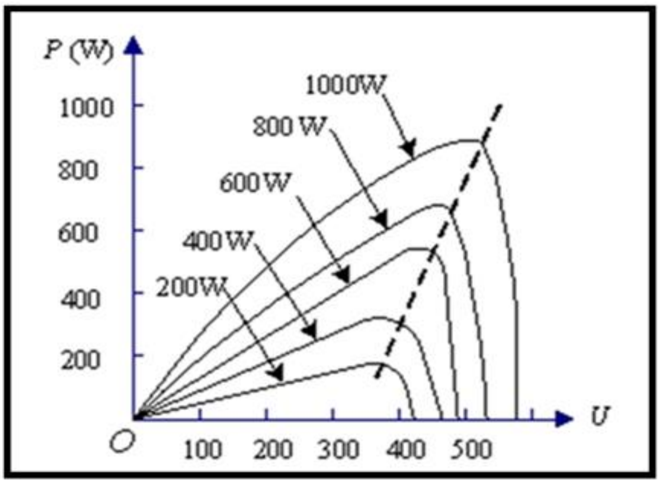


Figure II.12 : Voltage-power characteristics under different light intensity conditions [19]

Another factor that affects the power output delivered by the PV cell to the external circuit is temperature. Assuming an incident light intensity of 1000 watts per square meter, when:

(Figure II.13) represents the relationship between the current and voltage output of the PV cell under different temperature conditions; it can be observed that the current output of the solar cell remains relatively stable under different temperature conditions, while the voltage output varies significantly.

Similarly, (Figure II.14) represents the relationship between the voltage and power output of the PV cell under different temperature conditions. This (Figure II.14) illustrates that temperature has a noticeable effect on power output.

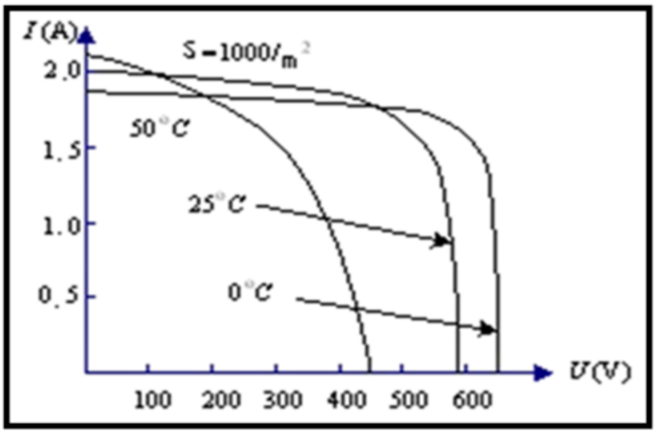


Figure II.13 : Current-voltage characteristics under different temperature conditions [19]

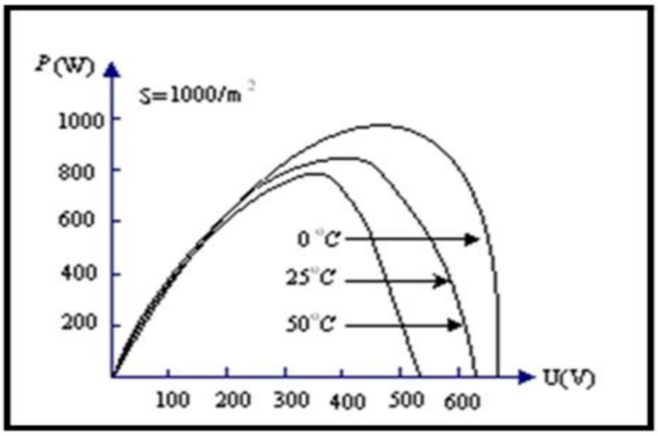


Figure II.14 : Voltage-power characteristics under different temperature conditions [19]

II.8 Mathematical model of a photovoltaic cell

II.8.1 Real photovoltaic cell

The equivalent circuit of a PV cell is shown in (Figure II.15). The current source Iph represents the cell photocurrent. Rsh and Rs are the intrinsic shunt and series resistances of the cell, respectively. Usually the value of Rsh is very large and that of Rs is very small, hence they may be neglected to simplify the analysis (Pandiarajan and Muthu 2011).

Practically, PV cells are grouped in larger units called PV modules and these modules are connected in series or parallel to create PV arrays which are used to generate electricity in PV generation systems. The equivalent circuit for PV array is shown in (Figure II.16).

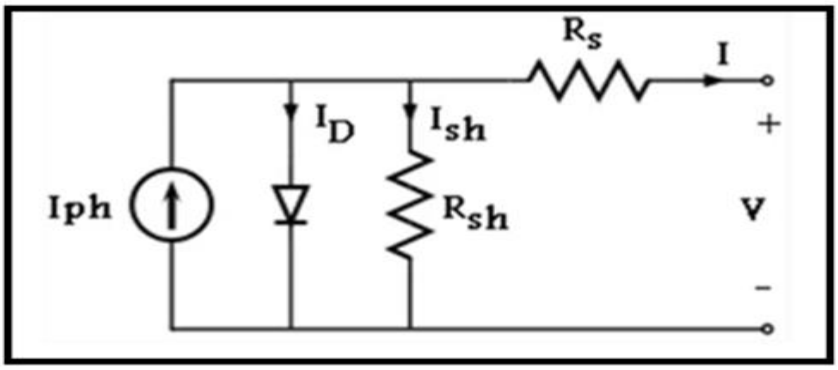


Figure II.15 : Equivalent circuit of a PV cell

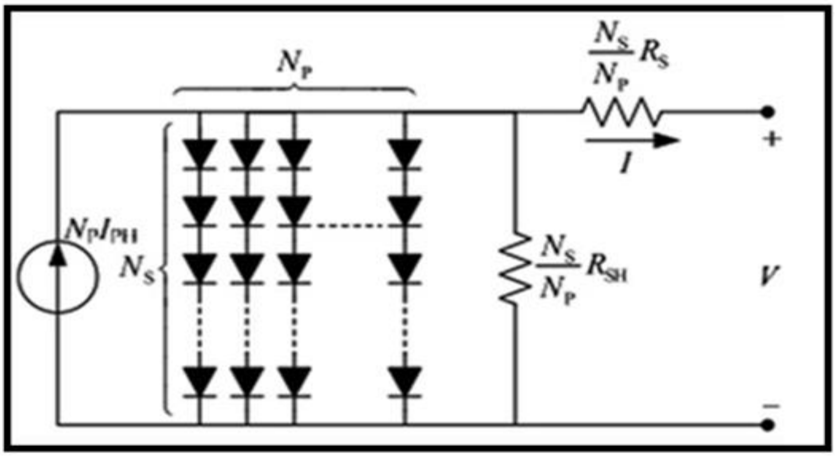


Figure II.16 : Equivalent circuit of solar array

The output current of a photovoltaic cell is expressed in the following mathematical form:

$I = I_{ph} - I_d - I_p$(II.1)

I: Current generated by the photovoltaic cell

I_{ph}: Photo current created by the cell (proportional to the incident radiation)

I_d: The current flowing through the diode

II.8.2 Determination of electrical parameters and their modeling

II.8.2.1Photon - current

$$I_{ph} = [I_{sc} + K_I(T + 298)] * \frac{G}{1000} \qquad \text{(II.2)}$$

With:

I_{ph}: Photo- current (A)

I_{sc}: short circuit current (A)

K_I: short circuit current of cell at 25°C and 1000 W/m^2

T: operating temperature (K)

T_n: nominal temperature (298) (K)

G: solar irradiation (W/m^2)

(Figure II.17) illustrate the bloc diagrammed of the photon – current equation model

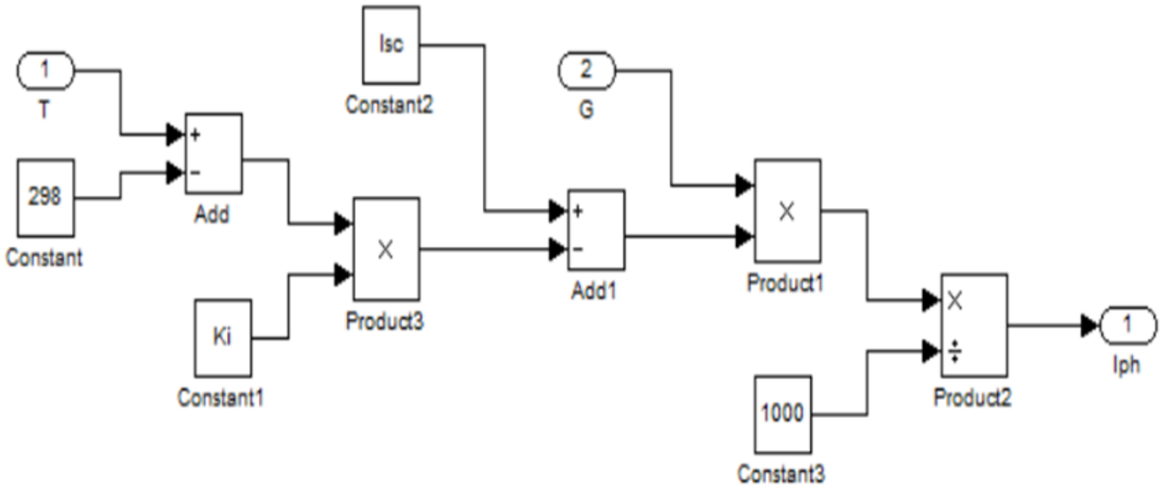


Figure II.17 : modeling the photon – current equation on MATLAB

II.8.2.2 Reverse Saturation current

$$I_{rs} = \frac{I_{sc}}{\left[exp\left(\frac{qV_{oc}}{N_S knT}\right)-1\right]} \qquad \text{(II.3)}$$

Irs: Reverse Saturation current

Q: electron charge (C)

V_{oc}: open circuit voltage (V)

N_s: number of cells connected in series

K: Boltzmann's constant (J/K)

n: the ideality factor of the diode

Figure II.18 illustrate the inverse saturation current equation bloc

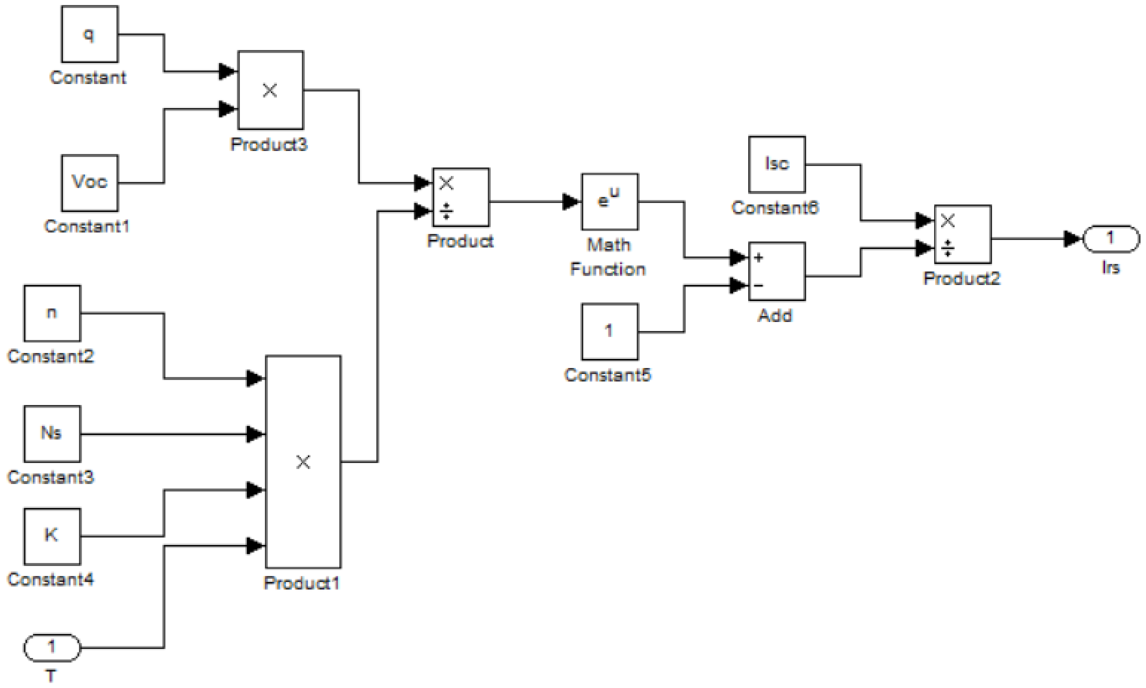


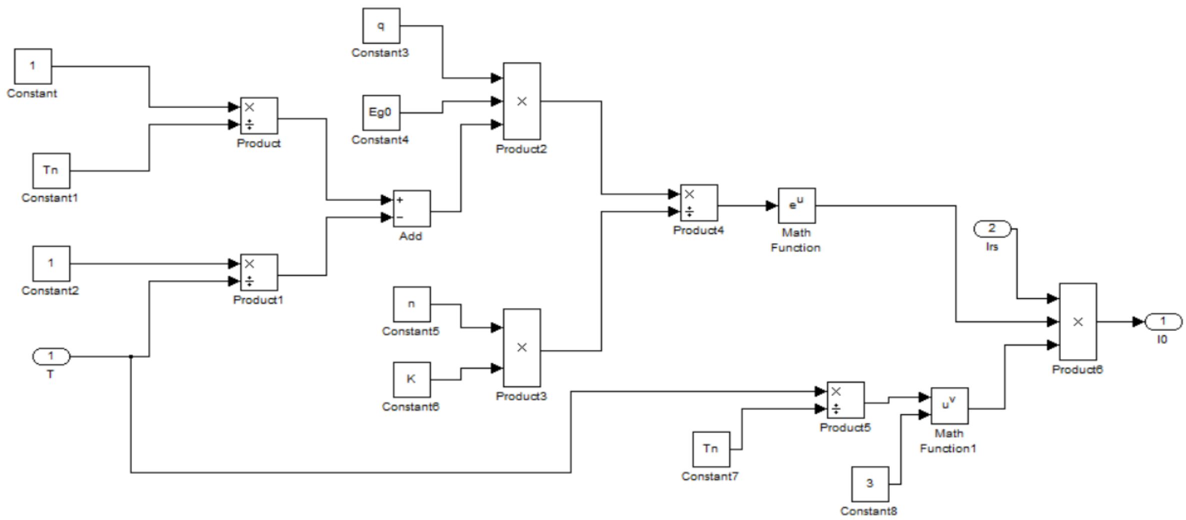
Figure II.18 : modeling the inverse saturation current equation of the diode on MATLAB

II.8.2.3 Saturation current

$$I_0 = I_{rs}\left(\frac{T}{T_n}\right)\hat{}3.\,exp\left[\frac{q.E_{g0}.\left(1/T_n - 1/T\right)}{n.K}\right] \quad (II.4)$$

I_0: Saturation current in (A)

E_{g0}: band gap energy of the semiconductor in (V)



II.8.2.4 Current through shunt resistor

$$I_{sh} = \left(\frac{V+I.R_s}{R_{sh}}\right) \quad \text{(II.5)}$$

I_{sh}: Current through shunt resistor (A)
V: diode thermal voltage (V)
R_s: series resistance
R_{sh}: shunt resistance

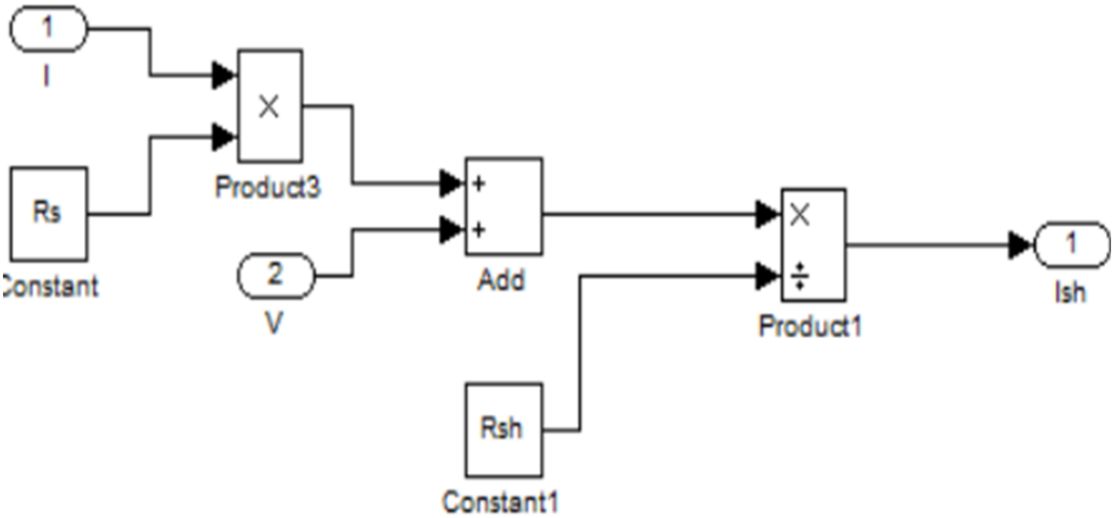


Figure II.19 : modeling the saturation current equation on MATLAB

$$I = N_p \times I_{ph} - N_p \times I_0 \times \left[\exp\left(\frac{V/N_s + I \times R_s/N_p}{n \times V_t}\right) - 1\right] - I_{sh} \quad \text{(II.6)}$$

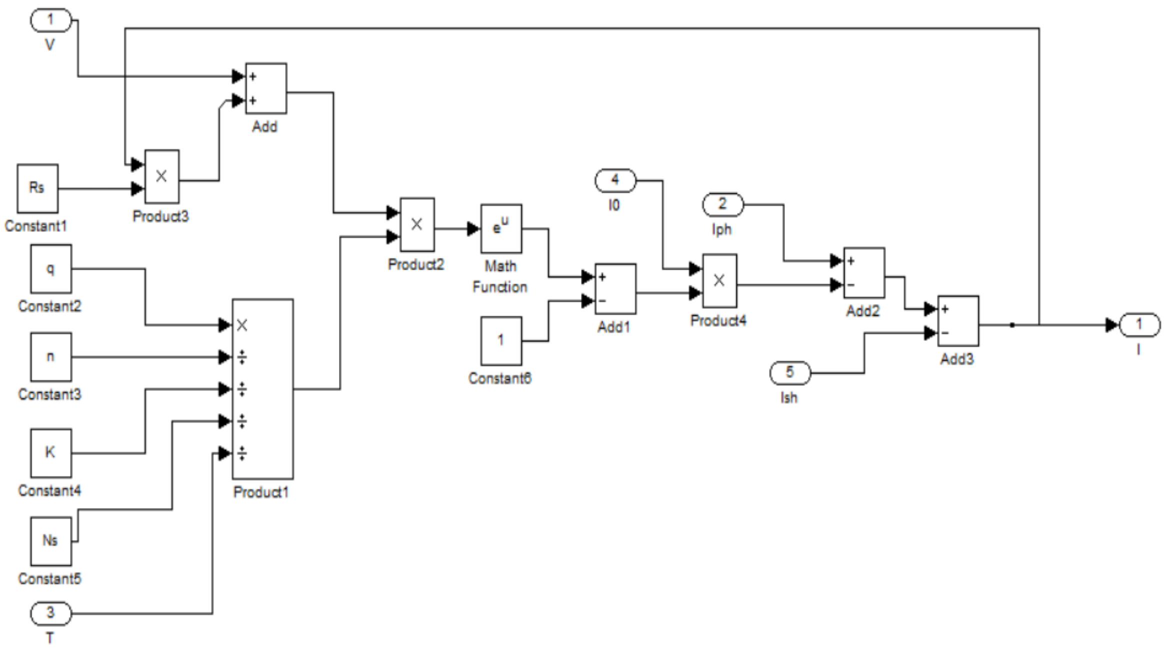


Figure II.20 : modeling the output current equation on MATLAB

II.8.2.5 The power of the PV cell

Under fixed operating ambient conditions (irradiance, temperature, ambient air flow rate, etc.), the electrical power P (W) available at the terminals of a PV cell is:

$$P=V*I \qquad (II.7)$$

P: The power supplied by the PV cell in (w).

V: The voltage measured at the terminals of the PV cell in (V).

I: The current output by the PV cell in (A).

II.8.2.6 The maximum power of a PV cell

For an ideal solar cell, the maximum power P_{max} would correspond to the open-circuit voltage

V_{oc} multiplied by the short-circuit current I_{sc}

$$P_{max}= V_{oc} *I_{sc} \qquad (II.8)$$

Pmax: The power supplied by the PV cell in (W).

$V_{oc:}$ The open-circuit voltage measured at the terminals of the PV cell.

I_{sc}: The short-circuit current output by the PV cell.

In practice, the characteristic curve of a PV cell is more "rounded" (Figure II.9), and the voltage at the maximum power point P_{max} is lower than the open-circuit voltage V_{oc} and the corresponding current I_{max} is lower than the short-circuit current I_{sc} The expression for the power at this point is given by:

$$P_{max} = V_{pmax} * I_{pmax} \qquad (II.9)$$

II.8.2.7 Energy efficiency

It is the ratio between the maximum electrical power supplied by the cell P_{max} (I_{opt},V_{opt}) and the incident solar power. It is given by:

$$n = \frac{P_{max}}{P_{inc}} = \frac{I_{max}*V_{max}}{P_{inc}} \qquad (II.10)$$

With: P_{inc} equal to the product of the irradiance and the total surface area of the photovoltaic cells.

This parameter reflects the quality of converting solar energy into electrical energy.

II.8.2.8 Form factor

The Form factor (FF), also known as the curve factor or fill factor, is defined as the ratio between the maximum power provided by the cell $P_{max}(I_{max},V_{max})$ and the product of the short-circuit current I_{sc} and the open-circuit voltage V_{oc} (i.e., the maximum power of an ideal cell) .

The fill factor indicates the quality of the cell; the closer it is to unity, the more efficient the cell is. It is typically around 0.7 for high-performance cells and decreases with temperature. It reflects the influence of losses due to both parasitic resistances R_s and R_{sh} It is defined by:

$$FF = \frac{P_{max}}{I_{sc}*V_{oc}} = \frac{I_{max}*V_{mqx}}{I_{sc}*V_{oc}} \qquad (II.11)$$

II.9 technology of solar panels

There are two possible technologies for connected solar panels:

II.9.1 solar panels in series

The series assembly of photovoltaic panels is undoubtedly the most used type of assembly. And this, especially when you want to produce electricity at 230 volts, whether to resell it on the network, or to consume it yourself at home.

To carry out this assembly, nothing could be simpler: simply connect the panels one after the other, that is to say the output of one to the input of the other (in other words: the cable "+" of one panel will be connected to the "–" cable of the next panel, and so on). They will therefore ultimately be connected "to the chain" (hence the name "String" in English). Here is a diagram to illustrate all this:

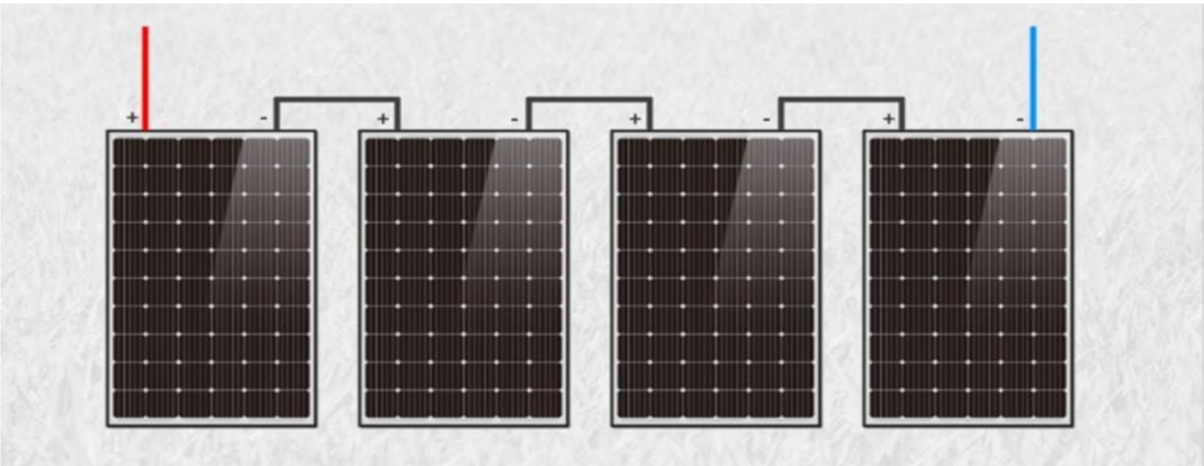


Figure II.21 : series mounting

The primary advantage of series assembly is in fact to be able to raise the voltage high enough (to be able, for example, to produce 230 V, whereas a single panel is less than 30 volts).

Moreover, in passing, you should know that an EDF voltage at 230 VAC (alternating) is in fact a voltage which permanently oscillates between -325 and +325 volts approximately, "peak to peak" (325 V being equal to 230 * √2). As you will have understood, you have to connect the solar panels together, in such a way that their voltages add up, to exceed these famous 325 volts, and thus, be able to inject current into the 230 volt electrical network.

And to achieve this, simply connect them in series. Thus, from a physical point of view, the model equivalent to a set of photovoltaic modules connected in series is:

- a voltage equal to the sum of the voltages of each panel
- a current, which is equal to that of a single panel

Let's take an example, to clarify all this: if you have 15 solar panels connected in series, and each panel delivers 30 volts at 5 amps, then:

- The resulting voltage is 15 x 30 volts, or 450 volts
- The resulting current is 5 amps (and this, regardless of the number of panels connected in series) [20].

II.9.2 solar panels in parallel

Another widely used type of mounting is parallel mounting. Here, we connect all the terminals of the solar panels together, and the same for all the terminals.

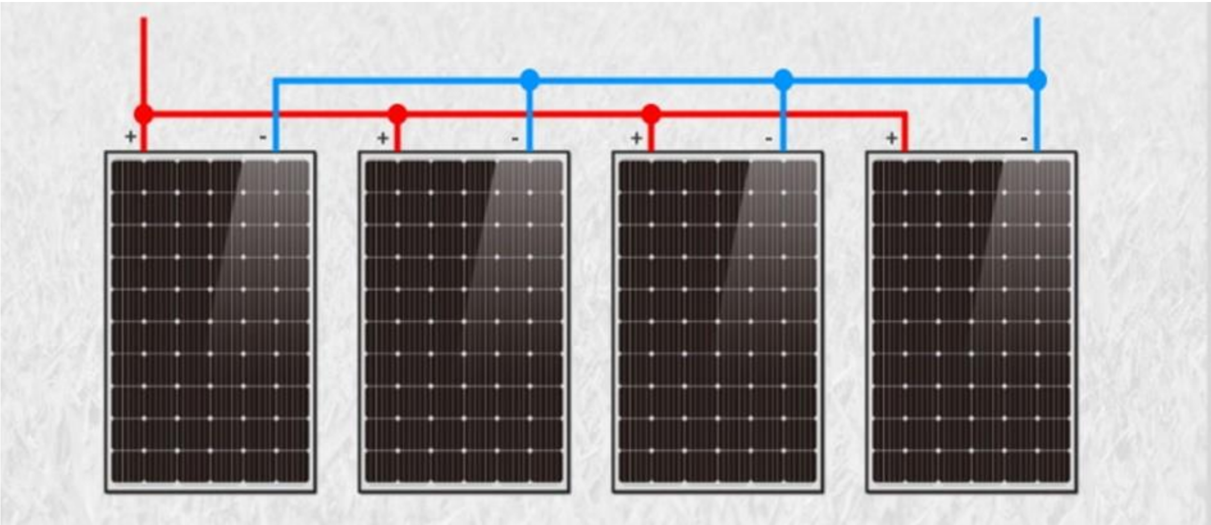


Figure II.22 : parallel mounting

The first advantage of this assembly is that it can remain at low voltage. Indeed, when all the photovoltaic modules are connected in parallel, the resulting voltage of this panel assembly is equal to the voltage of a single panel. On the other hand, the total current is equal to the sum of the currents supplied by each of the panels.

So, if for example you have connected 3 panels in parallel, each providing 28 volts at 4 amps, then:

- the resulting voltage will be equal to 28 volts (regardless of the number of panels connected in parallel)
- the current supplied will be 3×4, or 12 amps

We can therefore say that in parallel the currents are added, while the final voltage remains equal to the unit voltage of a panel.

We can supply a house with low voltage, in total autonomy. Thus, we could very well imagine supplying at least the entire house with low voltage, in particular the lighting, and a whole bunch of sockets, for low voltage devices (such as computers, laptops, smartphones, game consoles, etc.)[20].

II.10 Simulation results of PV cell

Based on the previously established equations, we conduct a simulation using MATLAB of a photovoltaic module under standard test conditions (Irradiance **1000W/m²**, cell temperature **25°C**). The table below shows the specifications of this photovoltaic module.

Rated power (Vmp)	200
Voltage at maximum power (Vmp)	26.4
Current at maximum power (Imp)	7.58
Open circuit voltage (Voc)	32.9
Short circuit current (Isc)	8.21
Total number of cells in Series (Ns)	54
Total number of cells in parallel (Np)	1

Table II.1 : System parameters

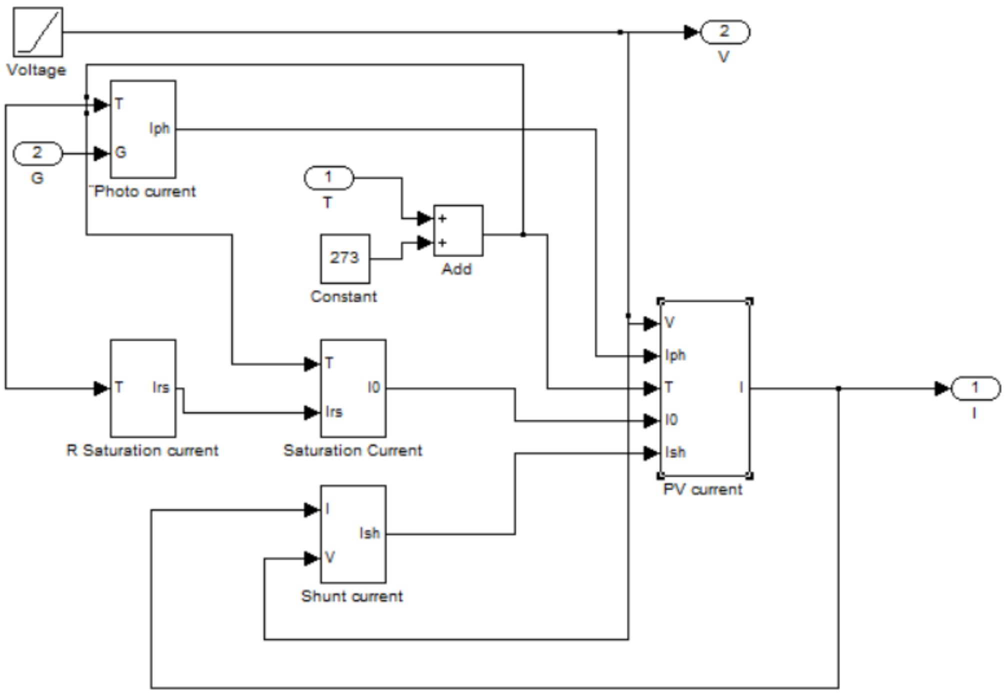


Figure II.23 : Model bloc of PV cell

If we simulate this photovoltaic panel model under standard conditions (T=25°C and G=1000W/m²), we obtain the following simulation results:

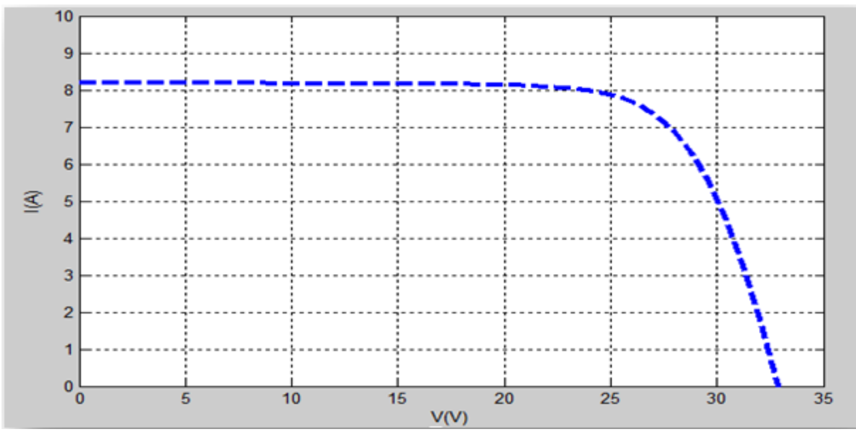


Figure II.24 : The I-V (current-voltage) characteristic of the panel

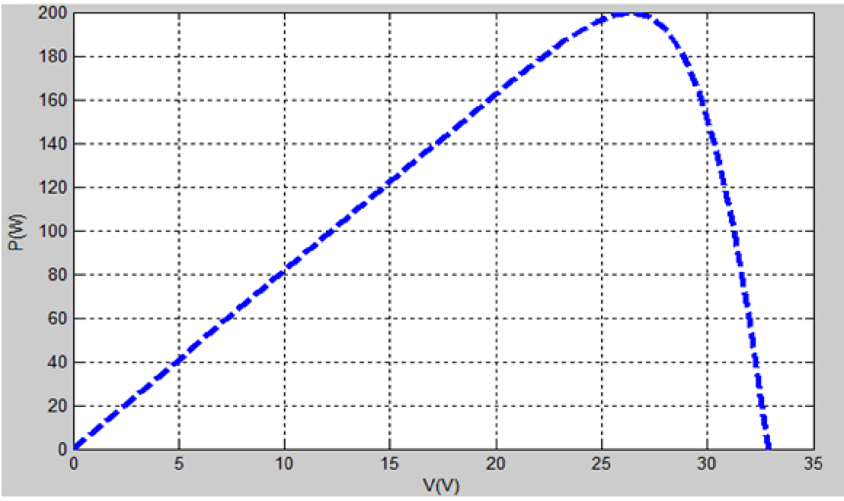


Figure II.25 : The P-V (power-voltage) characteristic of the panel

The I-V characteristic shows that the PV panel is considered as a constant current source for low voltage values with a current approximately equal to the short-circuit current (ISC). As the voltage increases, the current begins to decrease exponentially until it reaches zero at the voltage equal to the open-circuit voltage (VOC). Across the entire voltage range, there is only one point where the panel operates at the Maximum Power Point (MPP).

II.10.1Influence of different parameters

II.10.1.1 The influence of temperature

To observe the influence of temperature, we set the irradiance to 1000 [W/m²] and vary the temperature values to [25°C, 45°C, and 55°C].

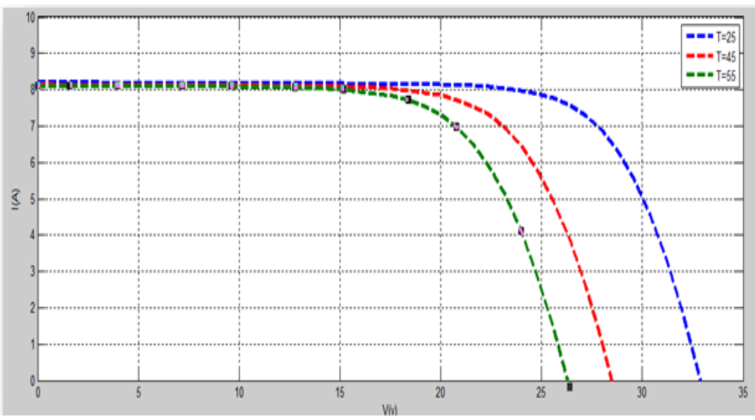


Figure II.26 : Influence of temperature on the I (V) panel

(Figure II.26) Influence of temperature on the panel P-V (power-voltage) characteristics

The increase in voltage as temperature decreases and the slight gain in current as temperature increases are noticeable. This can be explained by improved light absorption, as the energy band gap decreases with increasing temperature. The increase in current can be neglected at the maximum power point and even in the overall behavior of the cell.

II.10.1.2 Influence of irradiance

We set the temperature to 25°C while varying the irradiance (1000, 700, and 400 [W/m²]), then simulated the model and plotted the curve for each value.

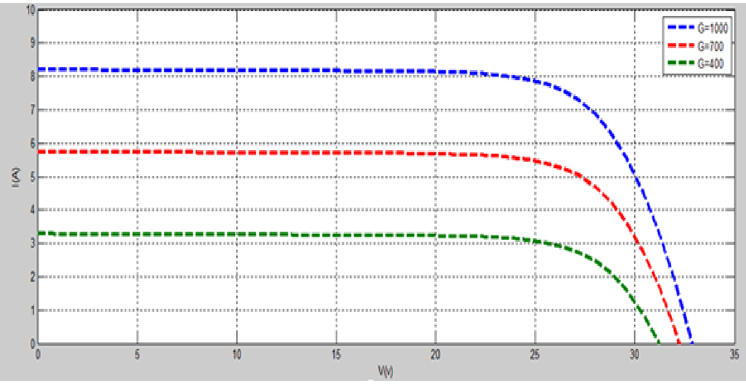


Figure II.27 : Influence of irradiance on the panel I-V (current-voltage) characteristics

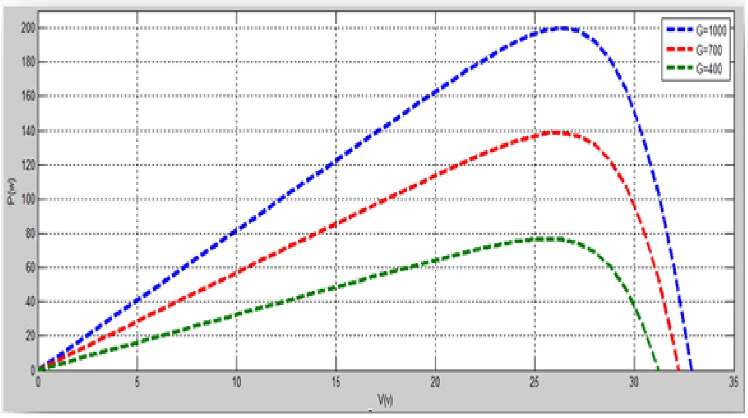


Figure II.28 : Influence of lighting on the P (V) panel

We observe that the current is directly proportional to the irradiance at these levels. However, the voltage is not significantly degraded when the irradiance decreases .The I-V curves shift towards higher values, allowing the module to produce higher electrical power.

II.11 Simulation of a PV panels

The (Figure II.30) illustrates a photovoltaic panel under standard light intensity of 1000 Watts per square meter and a temperature of 25degrees Celsius.

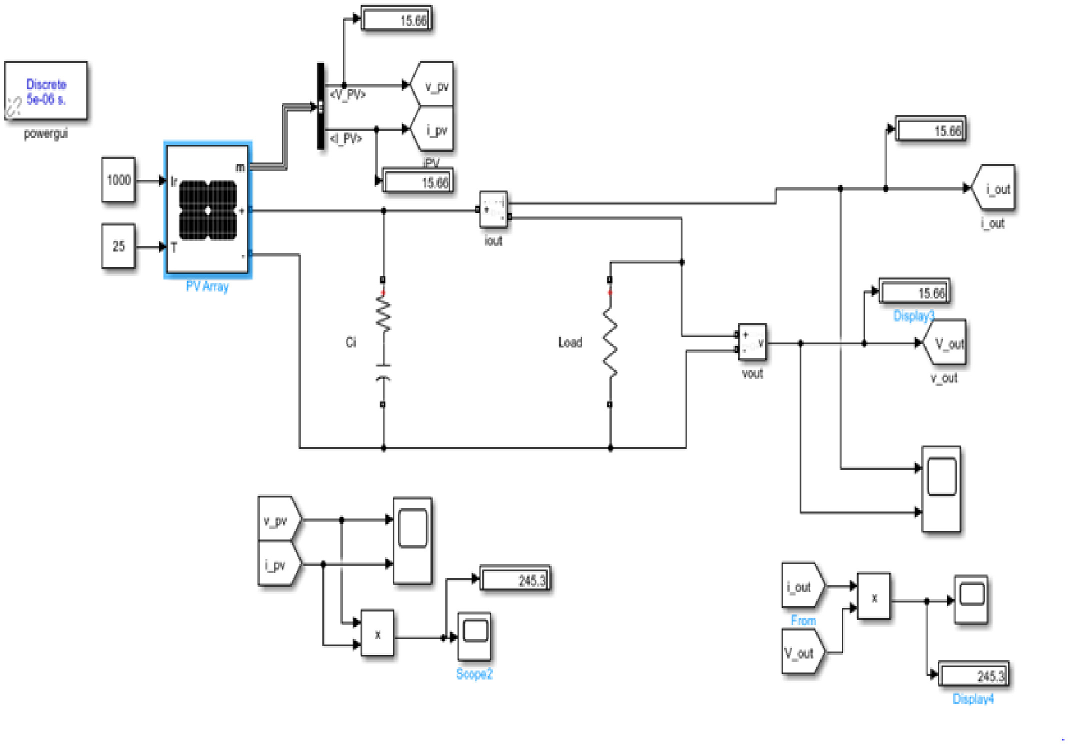


Figure II.29 : Simulation of a PV panels

II.11.1Result and discussion

In a photovoltaic (PV) system with an internal resistance of 1ohm, the input voltage in (Figure II.31)and current in (Figure II.32) are equal to the output current in (Figure II.34) and voltage in (Figure II.35). This is because the internal resistance of 1ohm ensures that there is no voltage drop across the internal resistance, making the input and output currents and voltages the same.

Instead, the power is the same at the input and output in (Figure II.33) and (Figure II.36).

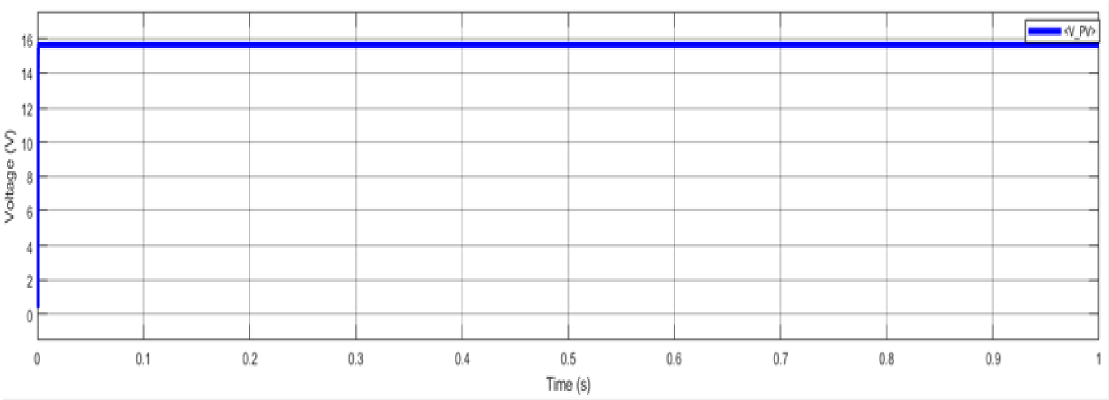


Figure II.30 : voltage of input in PV panel

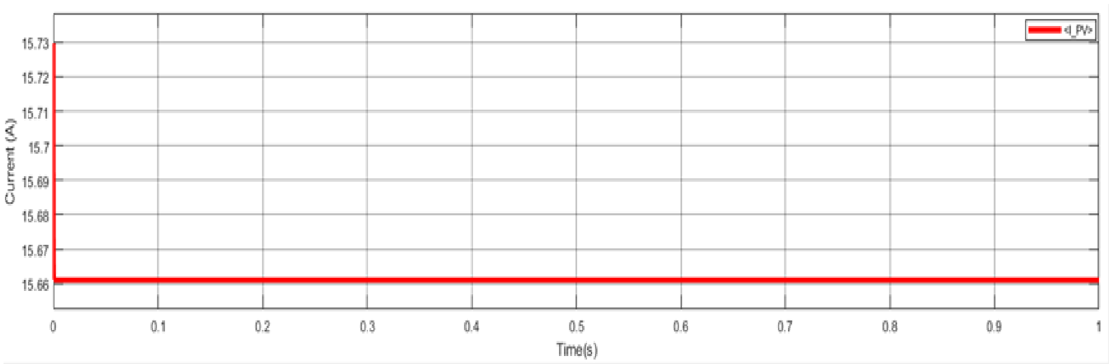


Figure II.31 : current of input in PV panel

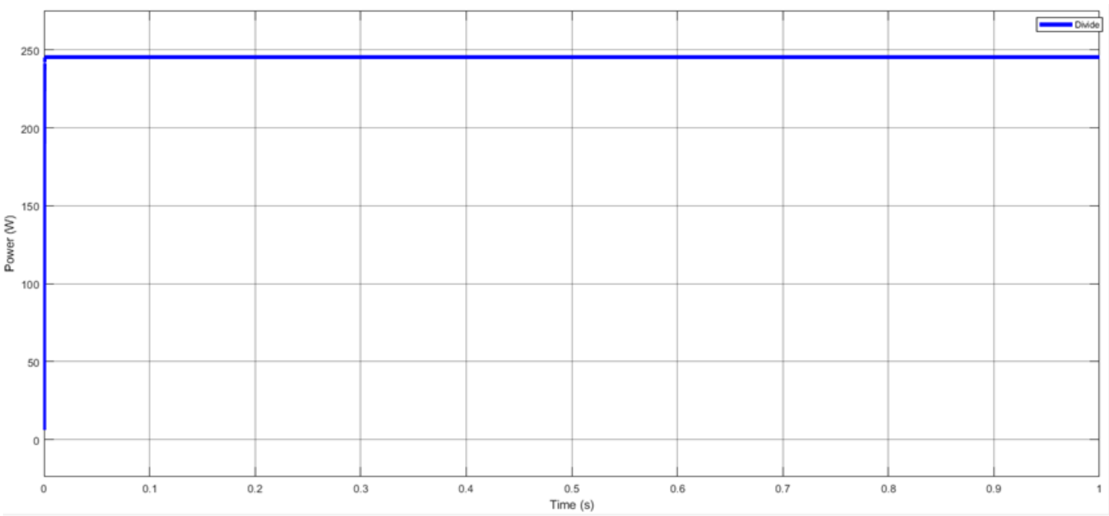


Figure II.32 : Power of a PV a panels input

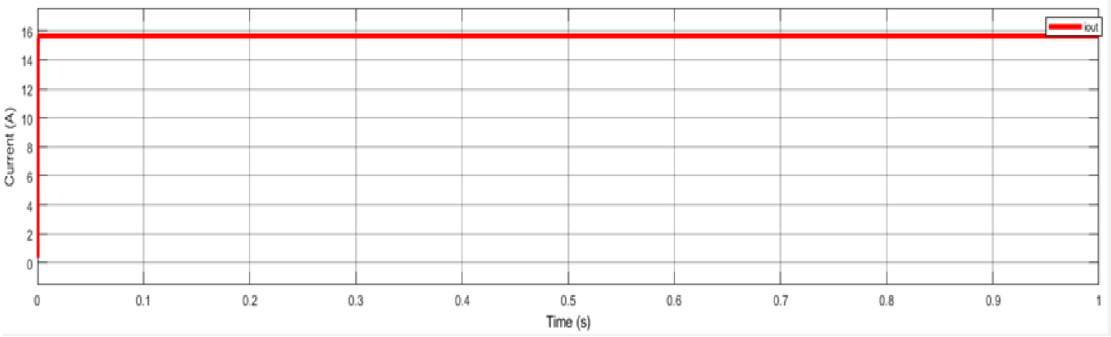


Figure II.33 : current of output in PV panel

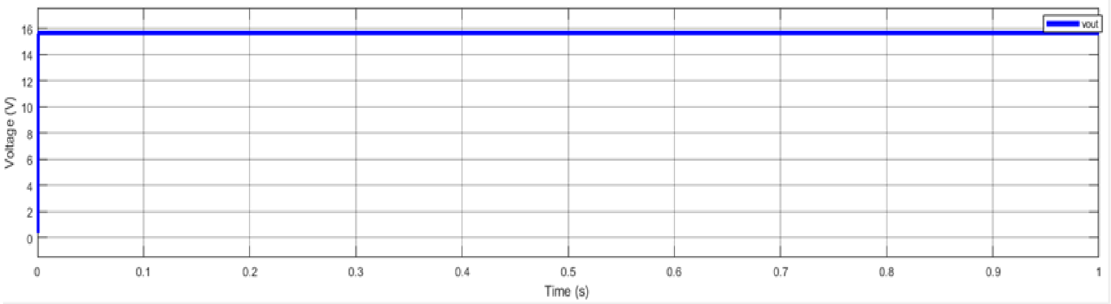


Figure II.34 : voltage of output in PV panel

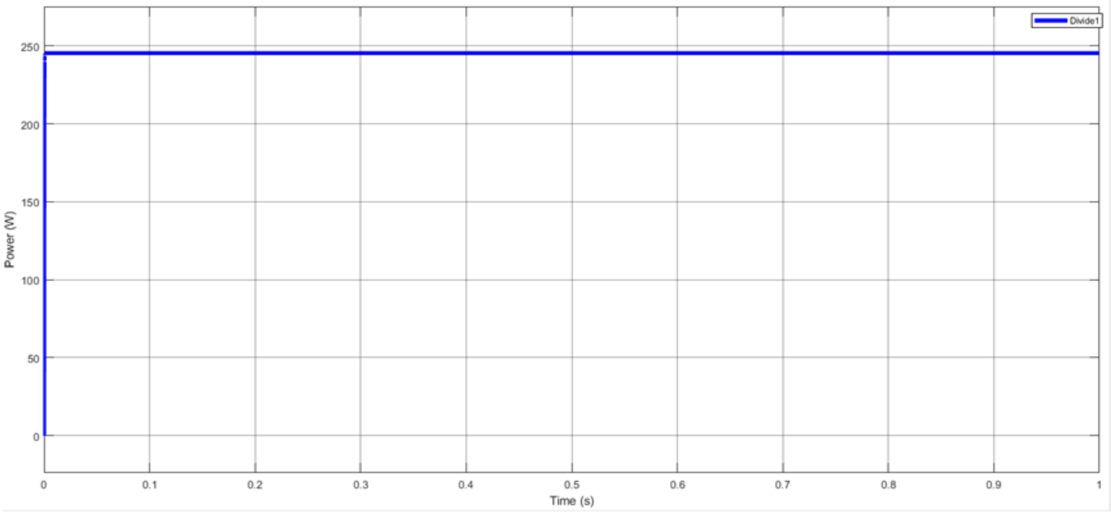


Figure II.35 : Power of a PV a panels output

II.12 Conclusion

In this chapter,we studies about the concept of the cell photovoltaic and the principle of its operation, how to assemble the cells photovoltaic, and presented the equivalent circuit of the cell with its peculiarities characteristics .We also studied the effect of temperature and luminance on the energy produced by the photovoltaic cell as well as the effect of the association of cells (series and parallel, series/parallel). After that we have presented the mathematical modeling of the photovoltaic cell, and then we used MATLAB –Simulink software to study the voltage and power cell and panels under standard conditions.

CHAPTER III: STUDY AND MODELING OF DC-DC CONVERTERS

III.1 Introduction

Solar energy is a source of energy whose availability varies considerably in day. Its optimal use requires consideration of load types (batteries, lamps, etc.). For this purpose, some authors use a converter boost to maximize production and use it optimally. The objective of this work is to present a better design of a boost converter able to search for maximum power regardless of variations in the sunshine.

In this chapter, we introduce some types of static DC-DC converters used in PV systems. In order to judge the efficiency of the proposed boost converter, we first modeled and simulated under Simulink a photovoltaic (PV) field directly connected to a load. Then modeling and simulation were performed with the PV field connected to a load through the boost interface.

III.2 Direct photovoltaic generator-load connection

For this type of connection, a diode is inserted between the GPV and the load (Figure III.1). This diode prevents the GPV from becoming a receiver when it is not lit and is not damaged if it reaches the limits of its operation as a receiver (thermal runaway, avalanche). This is the most widely used method today, which has the advantage of low cost as well as high reliability [21].

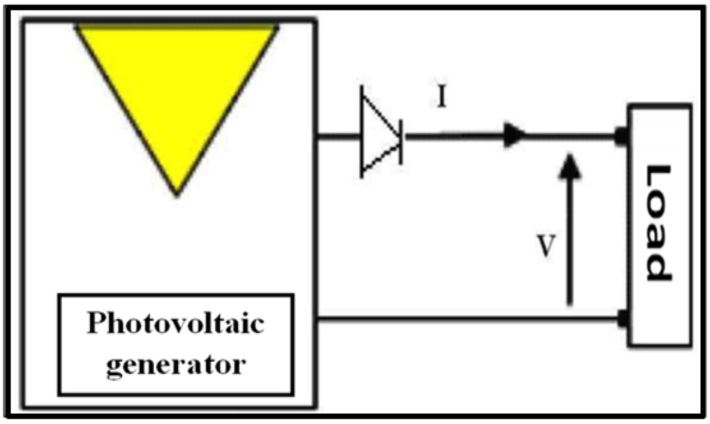


Figure III.1 : Direct connection of a GPV to its load [21]

III.2.1 Direct connection limit

However, this connection is not perfect. It is not possible adjust or limit the charging voltage or current. Moreover, in the case of pregnancy is a battery, it is the voltage of the latter that determines the operating point of the battery system, and therefore risks not being located on the PPM of the GPV and therefore not Use all available energy.

If the load accidentally ends up on the unit's PPM, this will only last a few moments, with the slightest variation of sunlight, cell temperature or battery charge level changing ppm.

Different types of fillings can be used. They can be resistive or resemble a direct current source or even constant voltage source. (Figure III.2) shows the operating points on the force curve (points A, B, and C) for each. These points can be if they are found away from the PPM, the GPV is poorly exploited and part of the power the maximum potential is not transferred to the load [21].

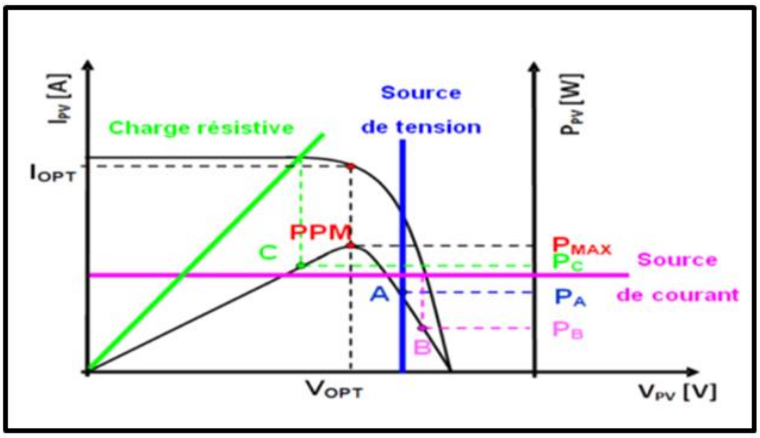


Figure III.2 : operating points for different loads [21]

III.2.2 Indirect GPV-load connection via one stage adaptation

To overcome the previously mentioned disadvantages, a fixed transformer is added between GPV and load in order to optimize voltage levels and/or Currents between the two elements FigureIII.3.Depending on the tension levels, the adapter structure will be different ("Buck" adapter, step-up "boost", "boost buck"[21].

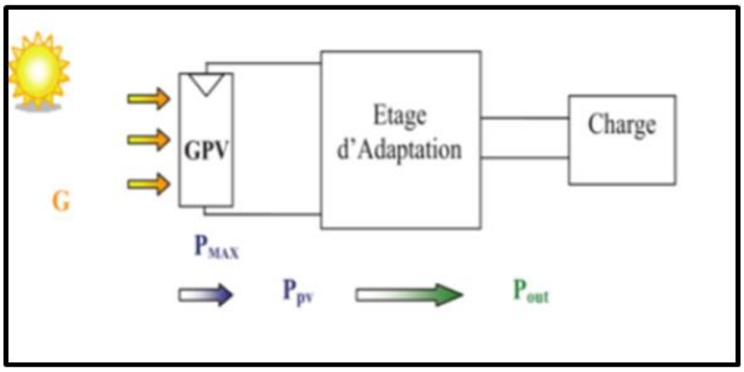


Figure III.3 : Adaptation stage between the GPV and the load [21]

This converter is associated with a control law allowing it to extract the maximum power of the GPV at any time. Named MPPT (Maximum Power Point Tracker), it constantly searches for the PPM (power point maximum) by modifying the input impedance of the converter.

III.3 Converter voltage gain

(TableIII.1) represents the voltage gains of the different DC/DC converters. Gain of converters.

	BOOST	BUCK	BUCK-BOOST
Voltage gain	$\frac{1}{1-a}$	a	$\frac{a}{1-a}$
Source current	continuous	Discontinuous	discontinuous

Table III.1 : Voltage gain of converters [22].

III.4 DC-DC converters

Choppers are fixed DC-DC converters which make it possible to do this Make a variable DC voltage source from a DC voltage source Pinned. These converters are intended to adapt at every moment to the apparent load impedance of the PV generator corresponding to the maximum power point. Choppers can be made using electronic switches that can be controlled on and off such as bipolar effect transistors, gate field thyristors, IGBTs, or insulated GTOs operating in switching mode (all or none) [23].

In this work, among the existing DC-DC converters we present the principle of the three types of switching converters such as step down, Enhanced and mixed. These converters are frequently used in photovoltaic systems Generating the required voltages and currents as well as for adapting photovoltaic panels with different fees.

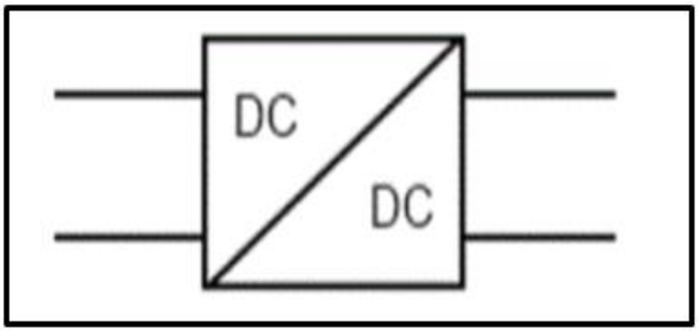


Figure III.4 : Symbol of a DC-DC converter

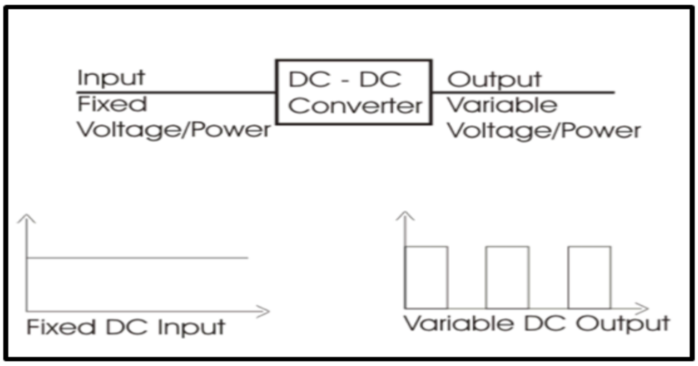


Figure III.5 : DC/DC converter symbol and signals

(Figure III.6) shows the representation of a DC/DC converter, which can be used as interface between source and load [24].

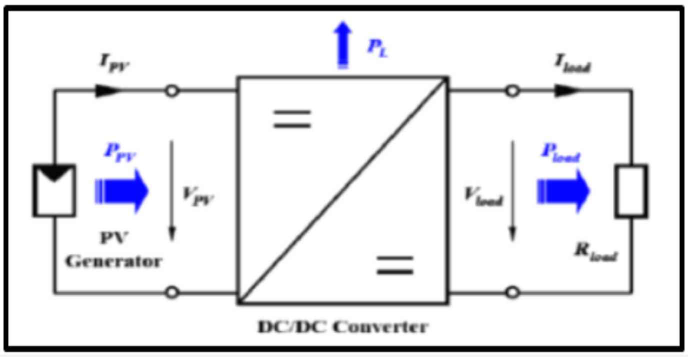


Figure III.6 : DC/DC converter

Converters used in PV systems to generate currents and desired tensions are:

- Buck type converters (step-down converters) in which Vs <Ve.
- Boost type converters (step-ups) in which Vs > Ve.
- Buck-Boost type converters which can operate in Buck or Boost in function of the duty cycle α.

III.4.1 Booster converter

The boost converter, also known as “survolter” or chopper parallel. It is used to convert its input voltage to a higher output voltage. Its principle diagram is presented in (Figure III.7) [25].

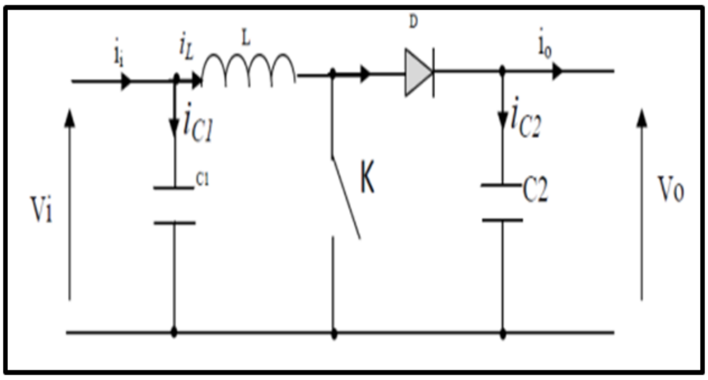


Figure III.7 : Schematic diagram of a booster

In order to collect the functions of the boost converter in the case Balance, it is necessary to provide equivalent diagrams of the circuit at each position for switch K. (FigureIII.8) represents the two equivalent diagrams of the transformer Enhanced for two practical sessions [25].

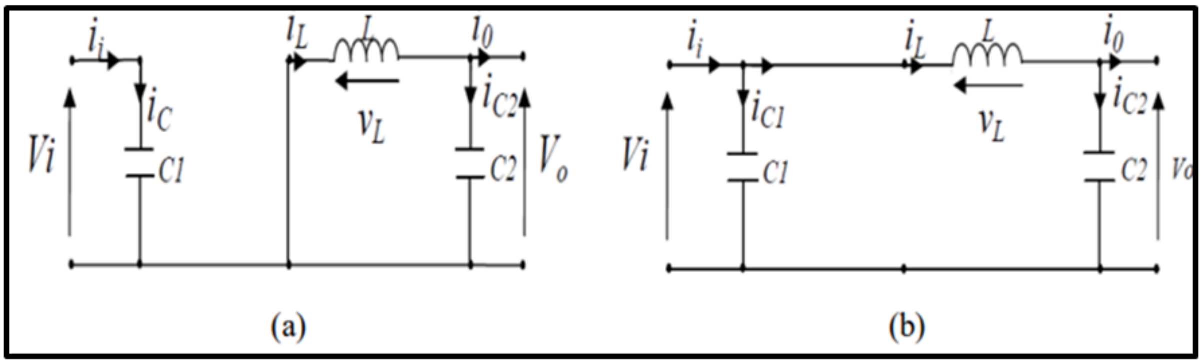


Figure III.8 : Equivalent diagrams of the booster chopper

(a): K closed; (b): open

When Kirchhoff's law is applied to the two equivalent circuits of the booster converter of the two operating phases, we will have both systems following equations:

For the first perioddT_s :

$$\begin{cases} i_{c1}(t) = c_1 \frac{d_{vi(t)}}{dt} = i_i(t) - i_l(t) \\ i_{c2}(t) = c_2 \frac{d_{v0(t)}}{dt} = -i_o(t) \\ v_l(t) = l \frac{d_{il}}{dt} = -v_i(t) \end{cases} \qquad \text{(III.1)}$$

For the second period$(1 - D\ )T_s$:

$$\begin{cases} i_{c1}(t) = c_1 \frac{d_{vi(t)}}{dt} = i_i(t) - i_l(t) \\ i_{c2}(t) = c_2 \frac{d_{v0(t)}}{dt} = i_l(t) - i_i(t) \\ v_l(t) = l \frac{d_{il}}{dt} = v_i(t) - v_o(t) \end{cases} \text{(III.2)}$$

To find a dynamic representation valid for the entire period Ts, we use generally the following expression [25], [26].

$$<\frac{d_x}{dt}>T_s = \frac{d_x}{dtDT_s} dT_s + \frac{d_x}{dt(1-D)T_s}(1-d)T_s \text{(III.3)}$$

Or $<\frac{d_x}{dt}>$is the average value of the derivative of x over a periodT_s.

This relationship is valid if $\frac{d_x}{dtDT_s}$ and $\frac{d_x}{dt(1-D)T_s}$are constant over periods withdT_s and $(1-D)T_s$Respectively.

By applying the relation (III.3) to the systems of equations (III.1) and (III.2) we find the approximate model of the boost converter.

$$\begin{cases} i_l(t) = i_i(t) - c_1 \frac{d_{vi(t)}}{dt} \\ i_o(t) = (1-d)i_l - c_2 \frac{d_{vi(t)}}{dt} \\ v_i(t) = l \frac{d_{il}}{dt} = (1-d)v_o \end{cases} \text{(III.4)}$$

For a study in continuous mode, by eliminating the derivatives of the dynamic variables, and replacing these signals with their average values. The system of equations becomes:

$$\begin{cases} i_0 = (1-d)i_l \\ i_i = i_l \\ v_i = (1-d)v_o \end{cases} \quad \text{(III.5)}$$

The conversion ratio is defined as the ratio between the output voltage and the input voltage as follows [25], [26]:

$$M = \frac{v_o}{v_i} = \frac{d}{1-d} \quad \text{(III.6)}$$

So the booster chopper is indeed a voltage booster.

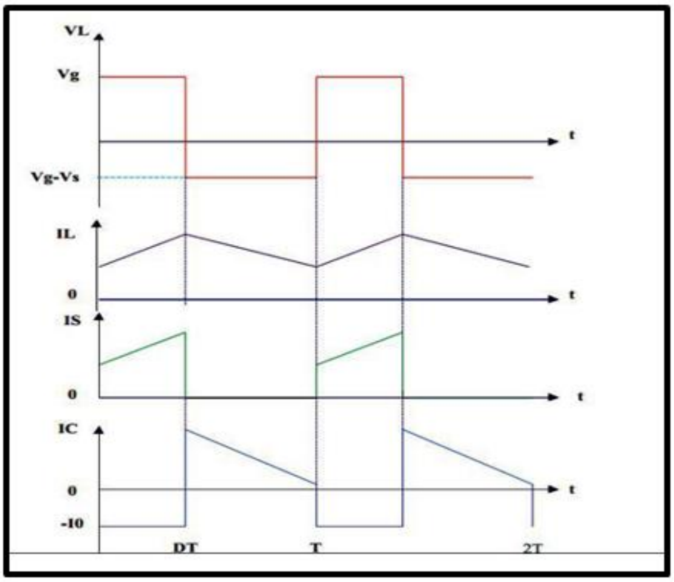


Figure III.9 : Voltage and current characteristic of the booster chopper

III.4.1.1 Simulation boost converter

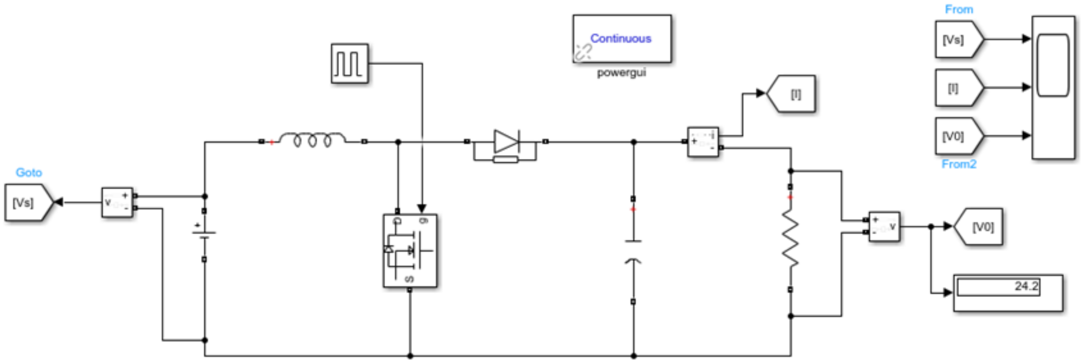


Figure III.10 : Simulink boost converter

III.4.1.1.1Result

Voltage input	Inductance	Capacitance	Duty cycle	Resistance
12V	19.53exp-6H	25exp-6F	0.5	10ohm

Table III.2 : the parameters of the converter boost

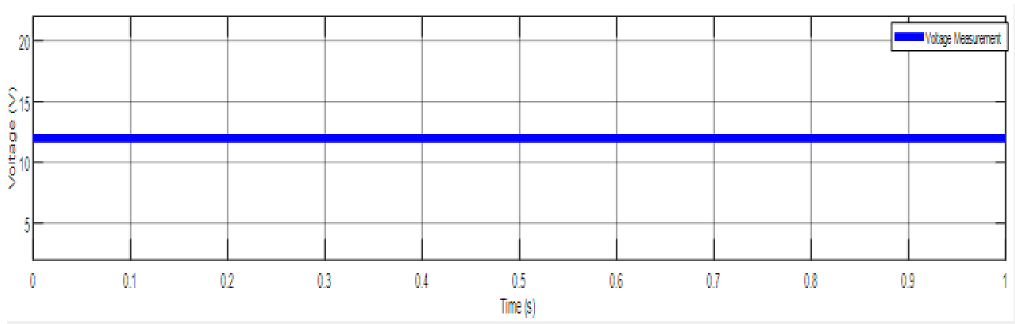


Figure III.11 : Input voltage of boost as function of time

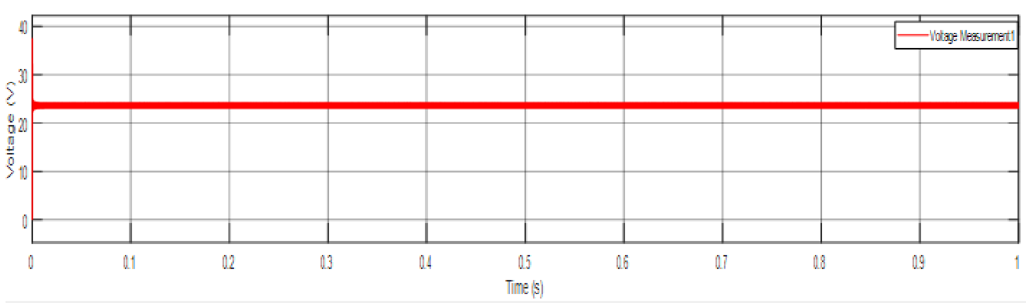


Figure III.12 : output voltage of boost as function of time

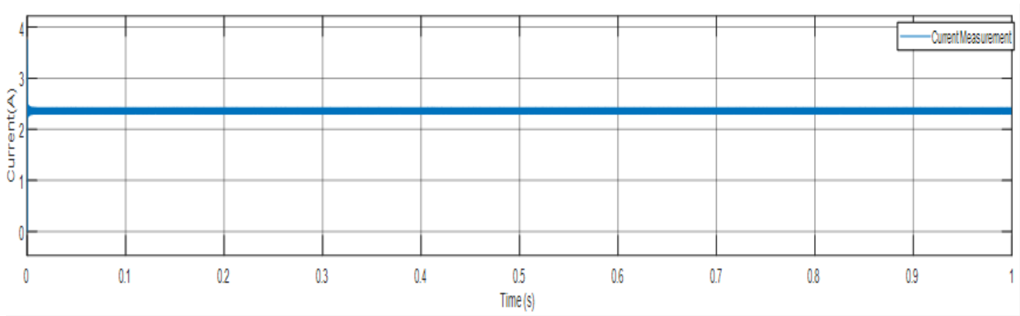


Figure III.13 : current waveform boost

III.4.2 Buck converter

The buck converter can often be found in the literature under the name of “dévolteur” chopper or series chopper. Its typical application is to convert its input voltage at a lower output voltage. (Figure III.14) represents the block diagram of the buck converter [25], [26].

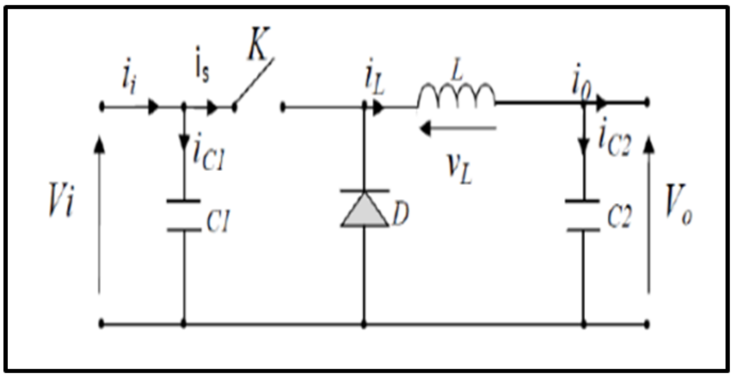


Figure III.14 : Diagram of the electrical circuit of a buck converter

In order to be able to synthesize the functions of the buck converter in the state balance, it is necessary to present the equivalent diagrams of the circuit at each position of the switch K. (Figure III.15) represents the two equivalent diagrams of the converter step-down for the two cycles two operations [25], [26].

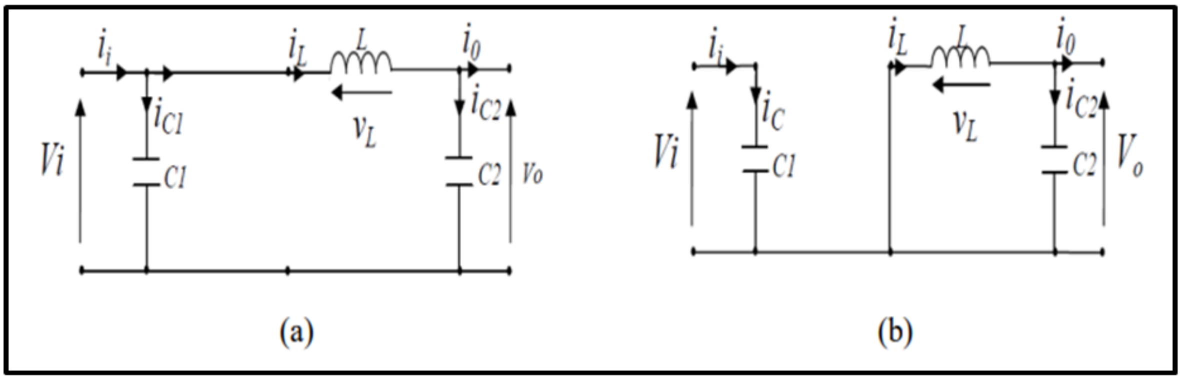


Figure III.15 : Equivalent diagrams of the step-down chopper,

(a): K closed, (b): open

As for the boost converter, by applying Kirchhoff's laws on the two circuits in (Figure III.15), we obtain the following systems of equations:

For the first perioddT_s:

$$\begin{cases} i_{c1}(t) = c_1 \frac{d_{vi(t)}}{dt} = i_i(t) - i_l(t) \\ i_{c2}(t) = c_2 \frac{d_{v0(t)}}{dt} = i_l(t) - i_o(t) \\ v_l(t) = l \frac{d_{li}}{dt} = v_i(t) - v_o(t) \end{cases} \quad \text{(III.7)}$$

For the second period$(1 - D\ )T_s$:

$$\begin{cases} i_{c1}(t) = c_1 \frac{d_{vi}(t)}{dt} = i_i(t) \\ i_{c2}(t) = L \frac{d_{iL}(t)}{dt} = i_L(t) - i_O(t) \text{(III.8)} \\ v_l(t) = l \frac{d_{li}}{dt} = -v_o(t) \end{cases}$$

By applying the relation (III.3) to the systems of equations (III.7) and (III.8), we find the approximate model of the buck converter.

$$\begin{cases} i_O(t) = i_L(t) - c_2 \frac{d_{vo}(t)}{dt} \\ i_L(t) = \frac{1}{d}\left(i_i(t) - c_1 \frac{d_{vi}(t)}{dt}\right) \quad \text{(III.9)} \\ v_i(t) = \frac{1}{d}\left(L \frac{d_{iL}(t)}{dt} + v_o(t)\right) \end{cases}$$

For a study in continuous mode, by eliminating the derivatives of the dynamic variables, and replacing these signals with their average values. The system of equations becomes:

$$\begin{cases} i_i = di_l \\ i_o = i_l \quad \text{(III.10)} \\ dv_i = v_o \end{cases}$$

The conversion ratio of the buck converter is given by [25], [26]:

M=$\frac{v_o}{v_i} = d$(III.11)

So the series chopper is indeed a voltage step-down.

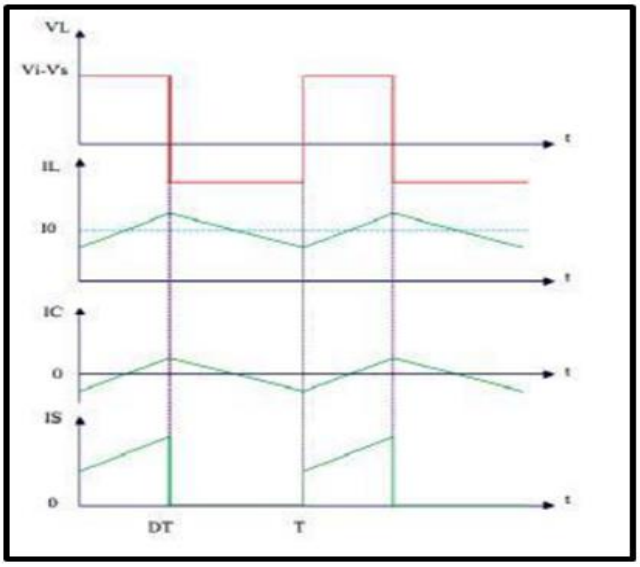


Figure III.16 : Characteristic of voltage and currents in the transistor and the inductance of a Buck converter.

III.4.2.1 Simulation Buck converter

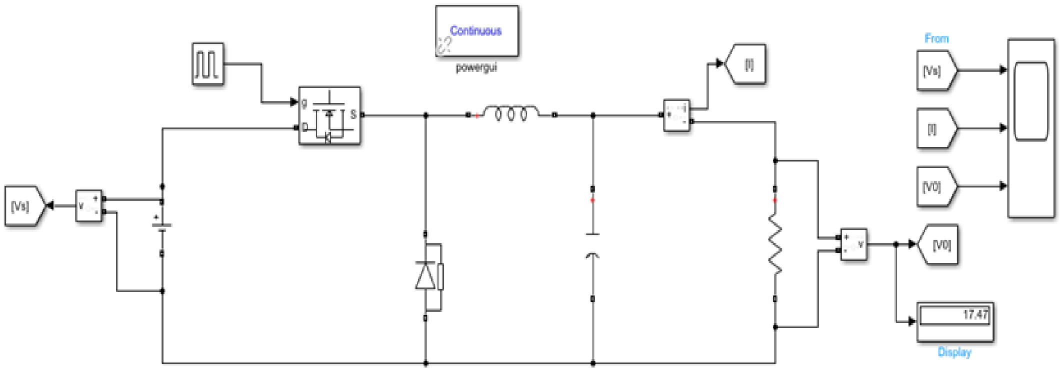


Figure III.17 : Simulink Buck converter

Voltage input	Inductance	Capacitance	Duty cycle	Resistance
48V	97.5exp-6H	100exp-6F	0.375	10ohm

Table III.3 : the parameters of the converter buck

III.4.2.1.1Result

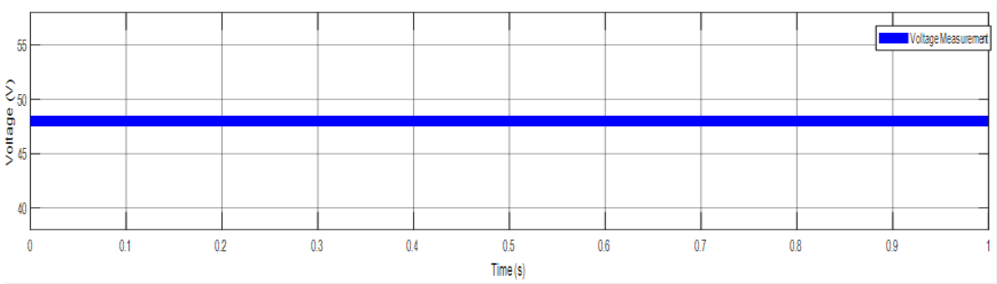


Figure III.18 : Input voltage of buck as function of time

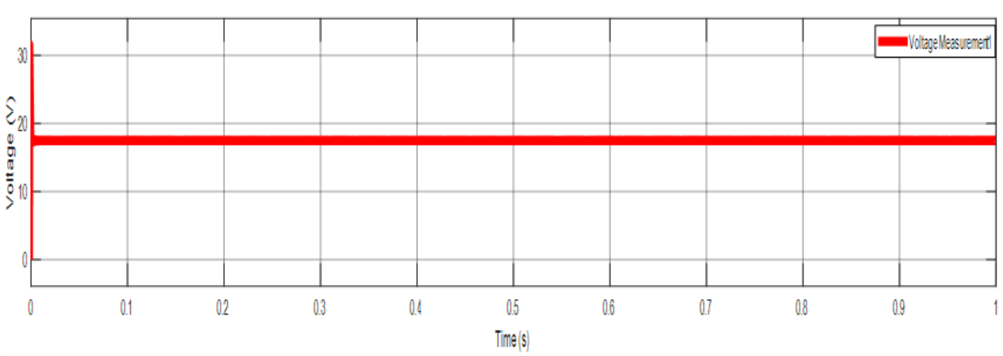


Figure III.19 : output voltage of buck as function of time

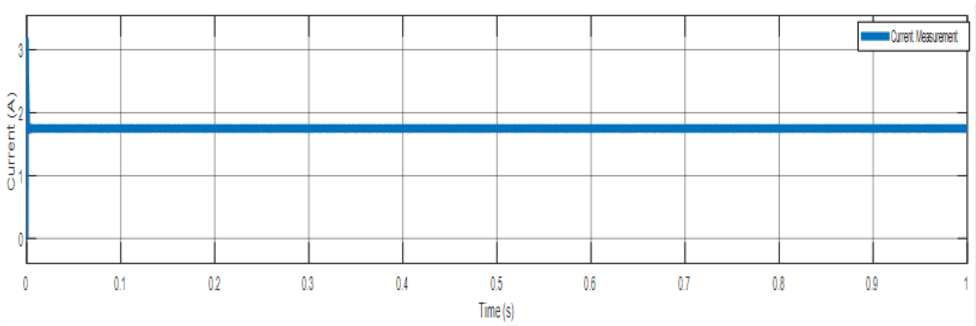


Figure III.20 : current waveform buck

III.4.3 Buck-boost converter

The buck-boost converter has acquired the characteristics and properties electrical of the two types mentioned above. It therefore presents an output of a hybrid transformer (step-down/step-up) for DC input/output voltage; her Basic diagram is illustrated by (Figure III.21) [25], [26], [27].

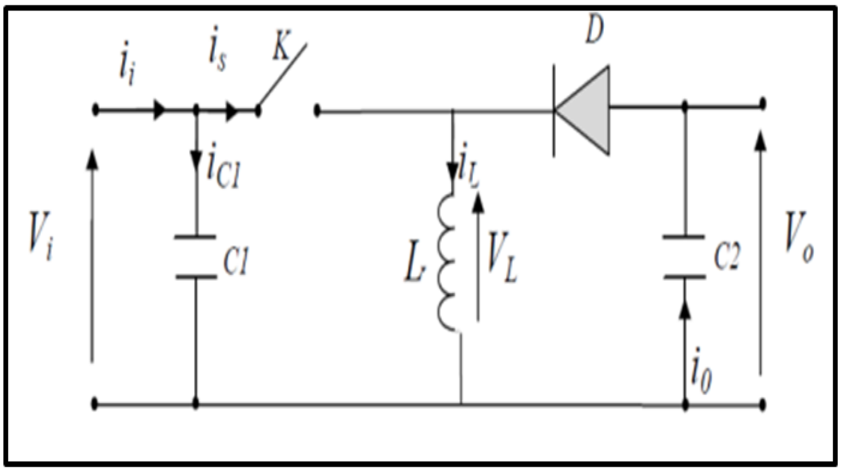


Figure III.21 : Basic diagram of a Buck / boost converter

(Figure III.22) shows the two equivalent diagrams of the buck-boost converter for the two cycles two operations [25], [26].

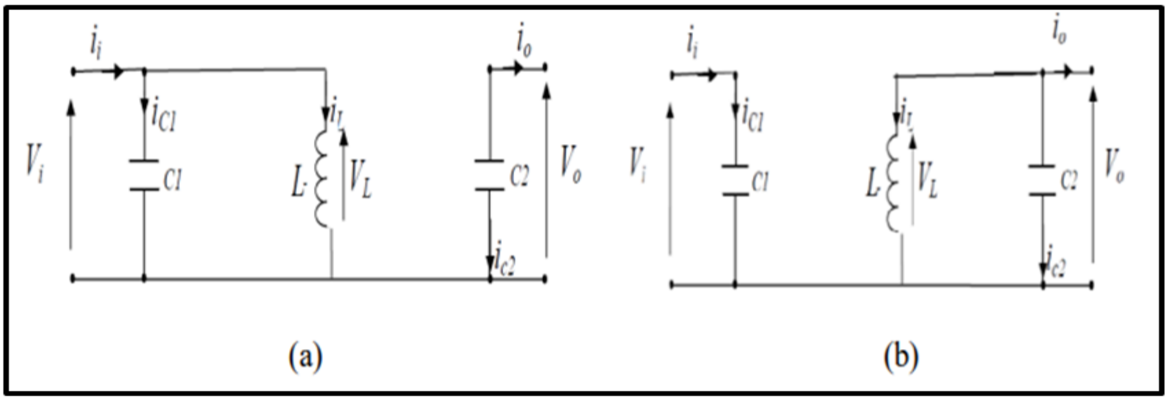


Figure III.22 : Equivalent diagrams of the buck-boost converter

(a): K closed, (b): K open

By applying Kirchhoff's law on the two equivalent circuits of the converter buck-boost of the two operating phases, we obtain:

For the first perioddT_s:

$$\begin{cases} i_{c1}(t) = c_1 \frac{d_{vi(t)}}{dt} = i_i(t) - i_L(t) \\ i_{c2}(t) = c_2 \frac{d_{v0}(t)}{dt} = -i_o(t) \\ v_l(t) = l \frac{d_{li}}{dt} = v_i(t) \end{cases} \quad (III.12)$$

For the second period$(1 - D\ )T_s$:

$$\begin{cases} i_{c1}(t) = c_1 \frac{d_{vi(t)}}{dt} = i_i(t) \\ i_{c2}(t) = c_2 \frac{d_{v0(t)}}{dt} = i_L(t) - i_O(t) \\ v_L(t) = l \frac{d_{iL}}{dt} = v_o(t) \end{cases} \quad (III.13)$$

By applying the relation (III.3) to the systems of equations (III.12) and (III.13), we find the approximate model of the buck-boost converter.

$$\begin{cases} i_l(t) = \frac{1}{d}(i_i - c_1 \frac{d_{vi(t)}}{dt}) \\ i_o(t) = -(1-d)i_L - c_2 \frac{d_{vo(t)}}{dt} \\ v_i(t) = \frac{1}{d}(-(1-d)v_o + L \frac{d_{il}}{dt}) \end{cases} \quad (III.14)$$

As before, by canceling the derivatives of the dynamic variables, by, replacing these signals by their average magnitudes. The system of equations becomes:

$$\begin{cases} I_i = dI_L \\ I_O = -(1-d)i_I \\ dV_i = -(1-d)V_O \end{cases} \quad \text{(III.15)}$$

From the system of equations (III.15), we can calculate the conversion ratio of buck-boost converter [25], [26], [27]:

$$M\,(d) = \frac{V_O}{V_i} = -\frac{d}{1-d} \quad \text{(III.16)}$$

So this chopper is indeed a hybrid (step-down/step-up) voltage transformer.

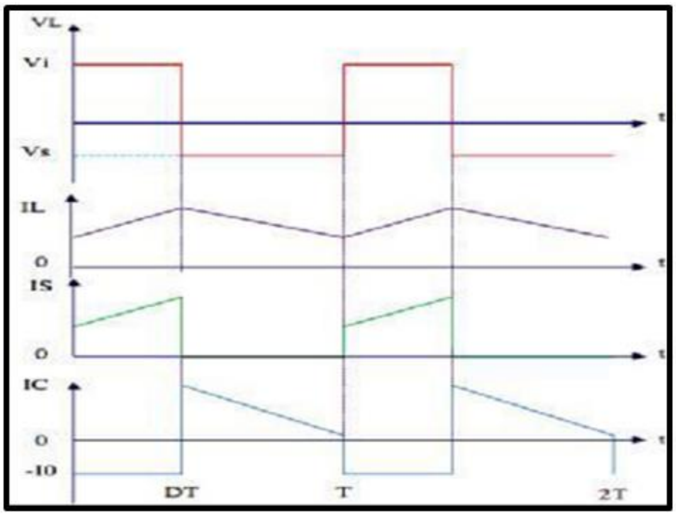


Figure III.23 : Characteristic of Buck-Boost voltage and currents

III.4.3.1 Simulation buck –boost converter

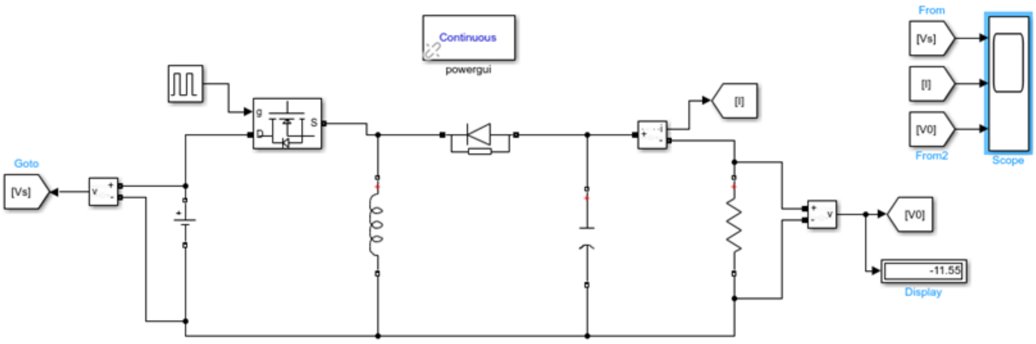


Figure III.24 : Simulink Buck –Boost converter

III.4.3.1.1Result

Voltage input	Inductance	Capacitance	Duty cycle	Resistance
18V	45exp-6H	100exp-6F	0.4	10Ohm

Table III.4 : the parameters of the converter buck –boost converter

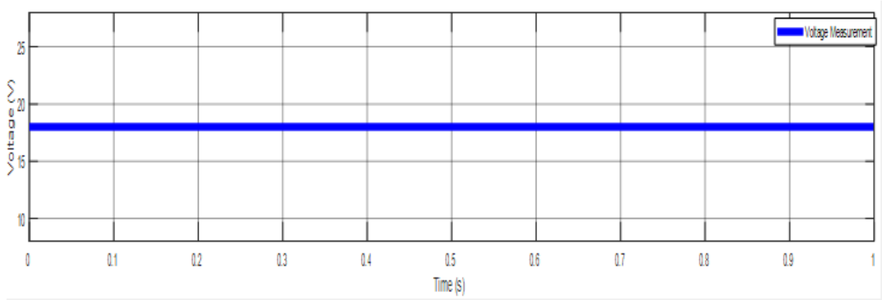


Figure III.25 : Input voltage of buck-boost as function of time

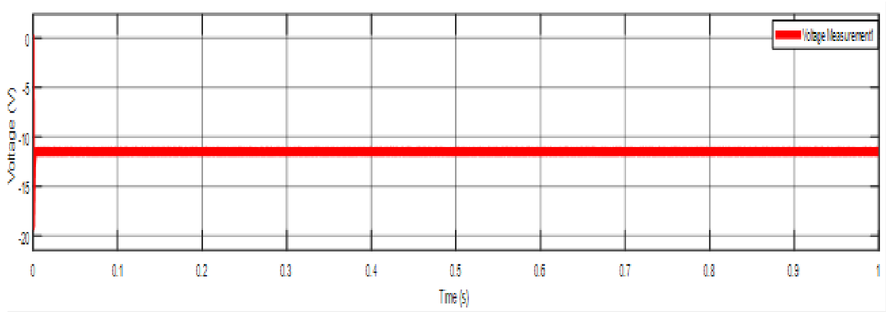


Figure III.26 : output voltage of buck-boost as function of time

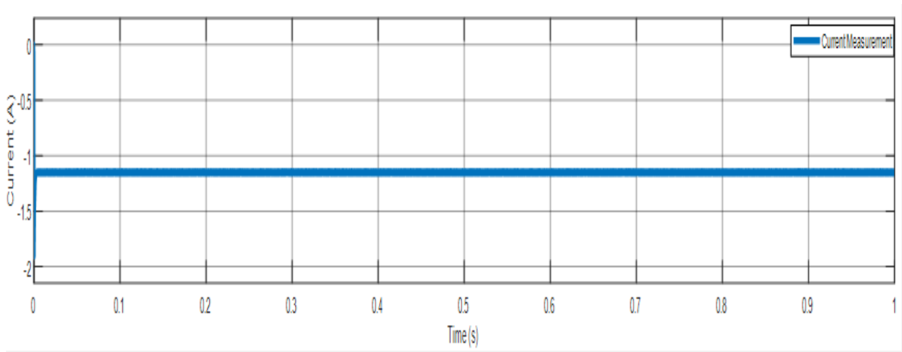


Figure III.27 : current waveform buck-boost

III.5 Analysis and choice of converter

Photovoltaic solar panels are a low voltage DC electricity generator. It is preferable to use a step-up device as transformer stage impedance between source and load. All of the above transformers except buck can play this role as a tension elevator. Moreover, the Buck-Boost structure and step-up duty cycle are greater than half. If we look at Complexity of structures, Boost is the simplest. Tension constraints and the current on switches and diodes is almost the same for different lift-off topologies.

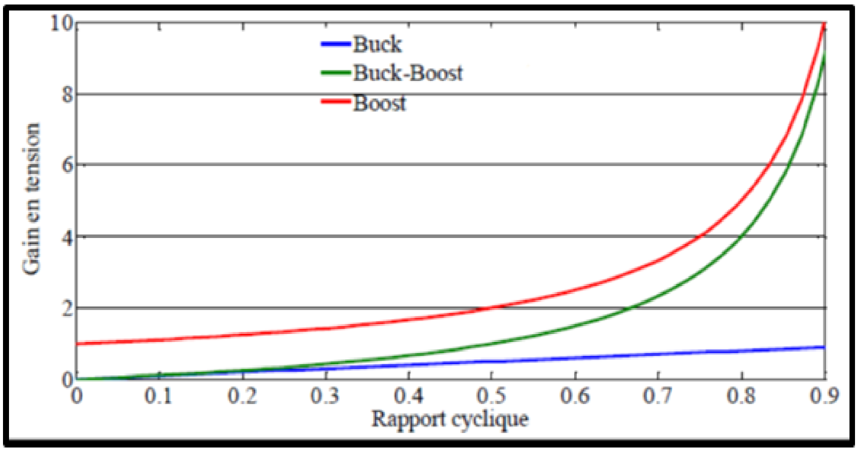


Figure III.28 : Evolution of the voltage gain as a function of the duty cycle

Of the converters [28]

If we compare it from the point of view of voltage gain, Boost also takes first place. Finally we can also note that the diode D in the Boost converter can play the role of GPV protection which makes it possible eliminate the need for an anti-return diode and save money compared to others. To better differentiate between transformers [28].

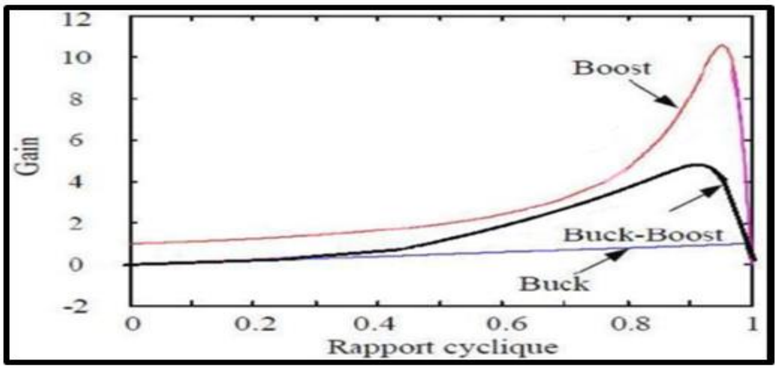


Figure III.29 : Evolution of the voltage gain taking into account

the parasitic elements of the converters [28]

III.6 Advantage of boost converter

Despite the high efficiency of the Buck converter in systems with conventional power sources, Boost converter may be more suitable to photovoltaic systems with the maximum power point tracker (MPPT) since the converter operates in direct current mode extracting as much power as possible from solar cells. Therefore the yield Energy of the boost converter can be larger than the Buck converter. The Boost converter is generally employed to obtain higher voltage output, while the Buck converter is used to lower the voltage of output [29].

III.7 Simulation PV with boost converter

After simulating the converter powered by a DC source, the latter will be replaced by the PV panel studied previously .for a first step, the characteristics of our system will be plotted for standard meteorological conditions (insolation =1000 W/m^2, T=25°C).The architecture in SIMULINK is represented by (Figure III.30).

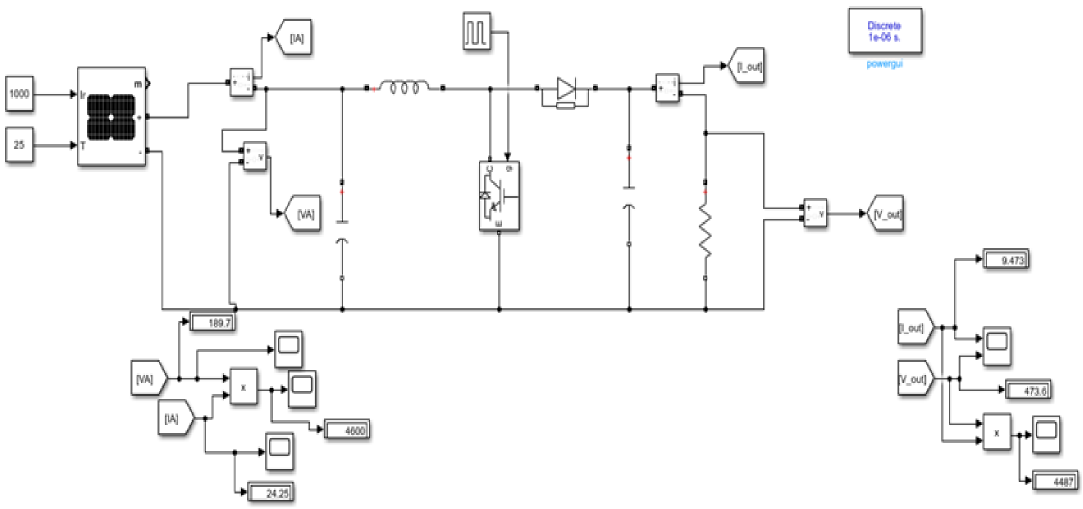


Figure III.30 : PV block diagram with boost converter

III.7.1Results and discussion

The curves at the input and output of the converter obtained under this condition aresimilar to those in the previousstudy, we notice an increase in output voltage (Figure III.35) compared to the PV voltage value (Figure III.31), and a decrease in the output current (Figure III.34) compared to the PV current value (Figure III.32).

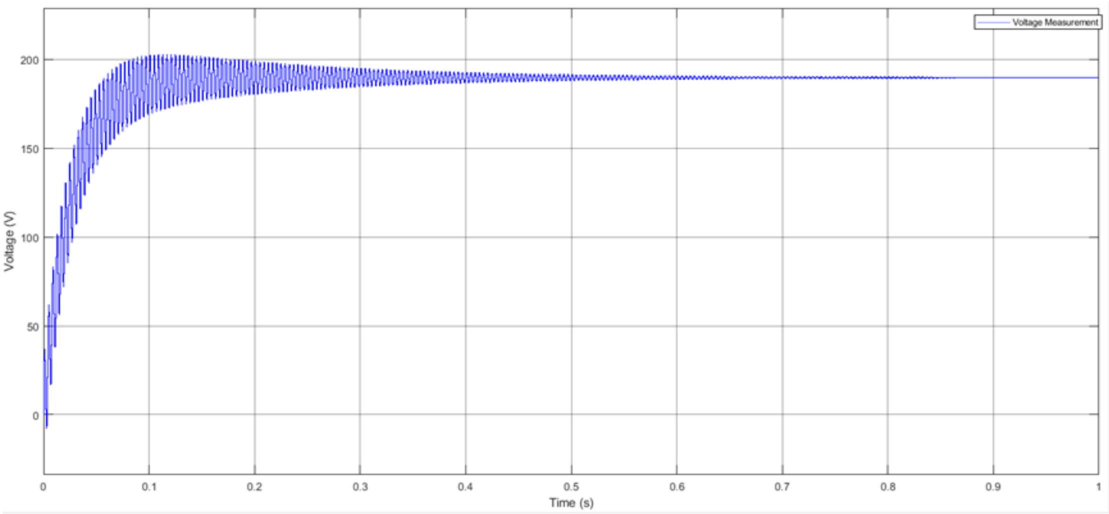


Figure III.31 : voltage of PV

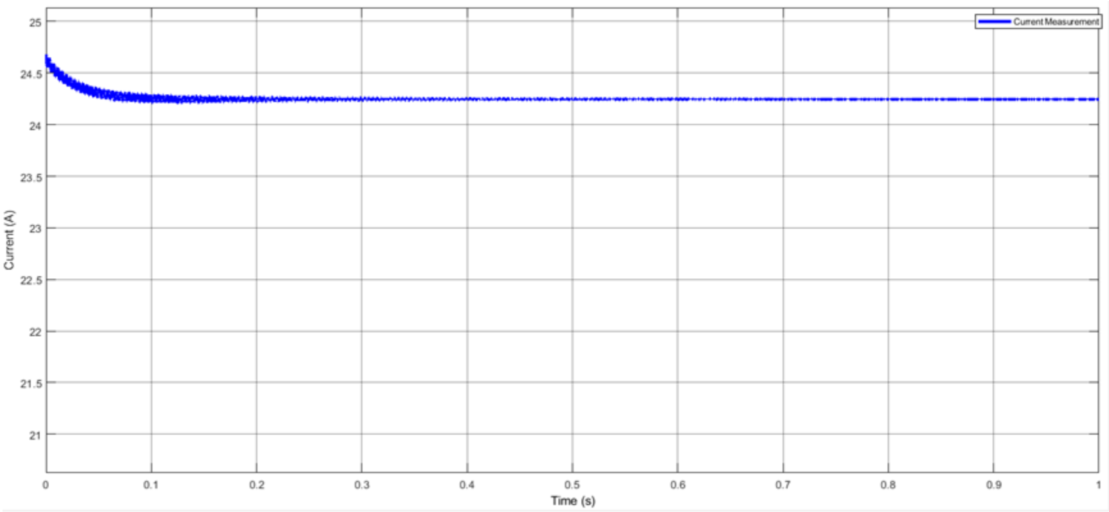


Figure III.32 : the current of PV

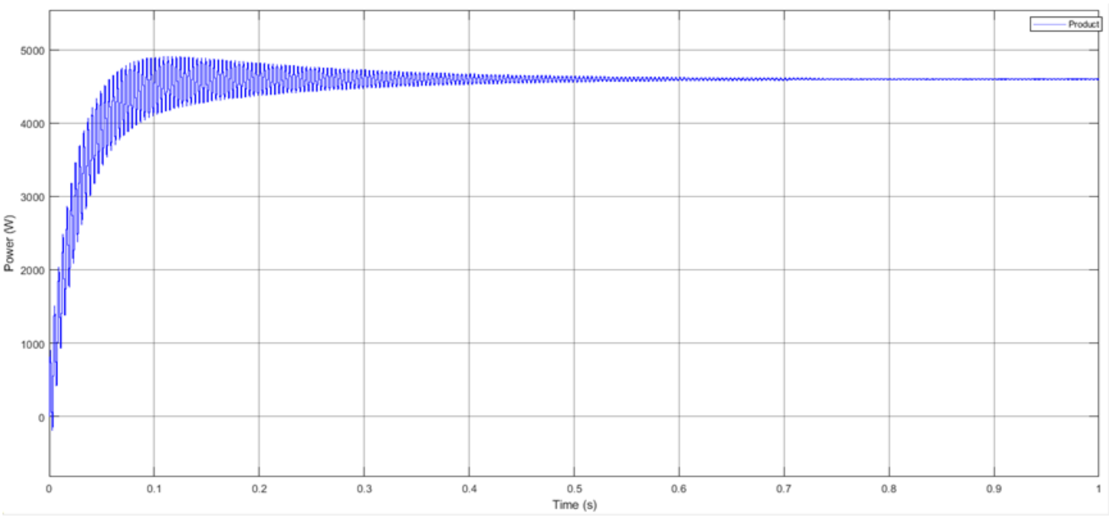


Figure III.33 : the power of PV

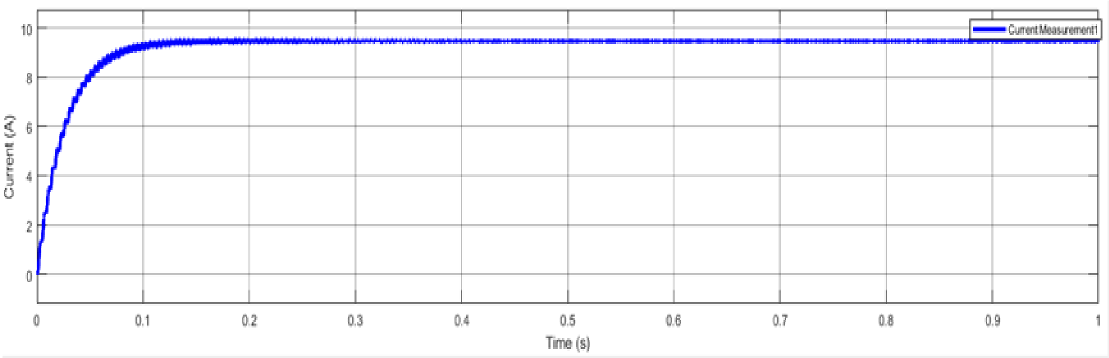


Figure III.34 : Output current in PV

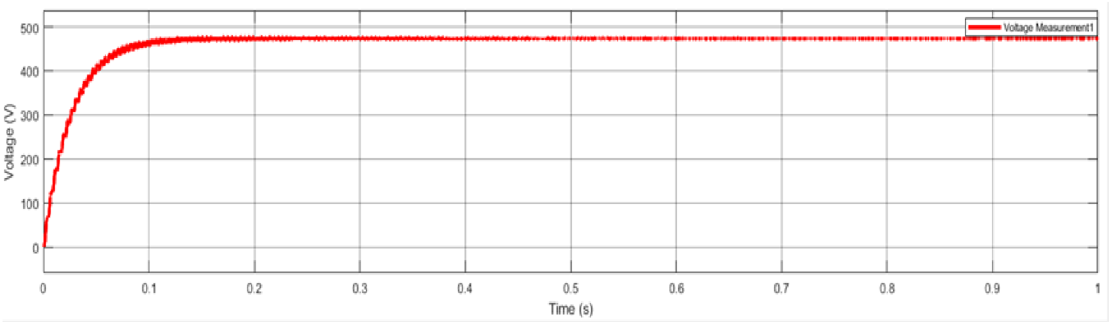


Figure III.35 : Output voltage in PV

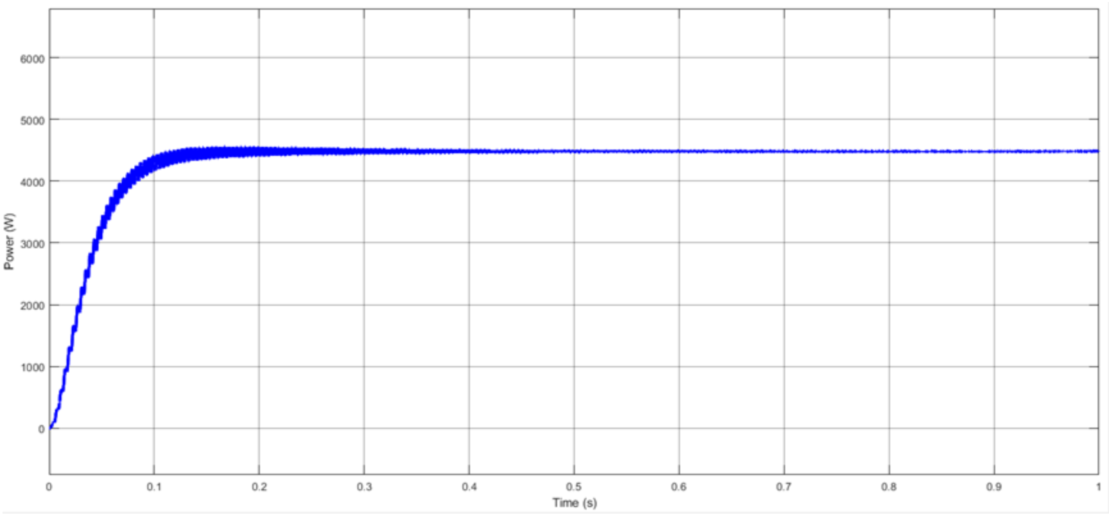


Figure III.36 : Output power of PV

III.8 Conclusion

In this chapter, we studies about the types of DC-DC converters. It performs decoupage conversion by chopper types such us buck, boost and buck-boost, and uses frequencies in photovoltaic systems to generate voltages and currents as well as to adapt solar panels to different charges. This type of transformer consists of transistor and reactive elements (self, condensator) which in the ideal case do not consume any energy. For this reason, it is highly efficient.

Each topology studied has advantages and disadvantages, and the importance of choosing the converter depends on the application or system it is studying. Boost is the best choice due to the increased gain and efficiency as well as the simplicity of the circuit.

CHAPTER IV: MPPT CONTROL OF PV SYSTEMS UNDER UNIFORM IRRADIATION

IV.1 Introduction

In this chapter, we will focus on optimizing a photovoltaic system by applying Maximum Power Point Tracking (MPPT) structures. The principle of these structures is based on automatically varying the duty cycle (α) to bring it to the optimal value in order to maximize the power delivered by the photovoltaic panel. We will start by defining and modeling the adaptation stage (boost converter). Then, we will present various MPPT controls. We will conclude this section by simulating the photovoltaic system using Matlab/Simulink with the simplest method Perturb and Observe (P&O)[30].

IV.2 MPPT Commands

Photovoltaic cells are used to provide energy in various electrical applications. To obtain the maximum power from the solar panel, a Maximum Power Point Tracking (MPPT) controller is used to control the converter[31].

The Maximum Power Point Tracking (MPPT) technique has been developed since 1968. This control is essential for the optimal operation of the photovoltaic system[32].

The principle of this control is based on automatically varying the duty cycle to bring it to the optimal value in order to maximize the power delivered by the photovoltaic panel

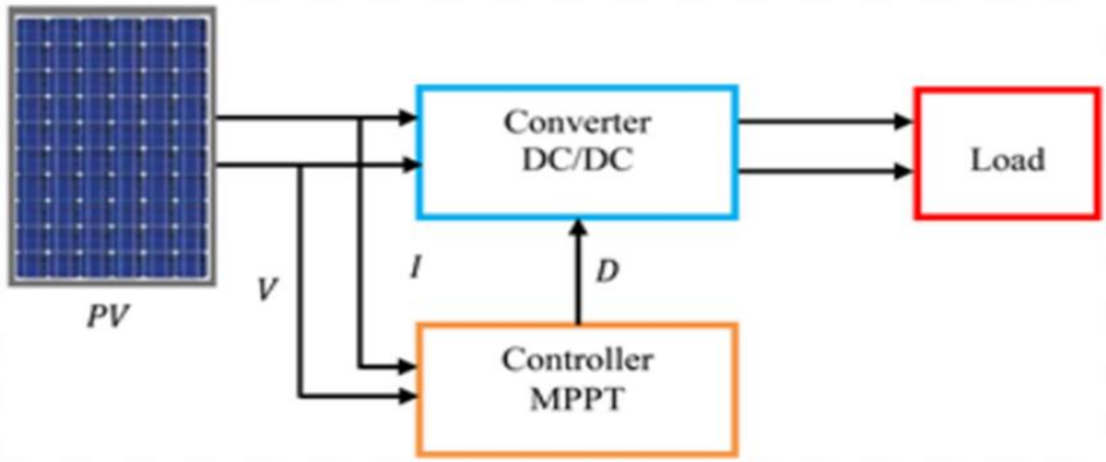


Figure IV.1 : Schematic diagram of the MPPT converter

IV.3 MPPT Control Techniques

Over the past few decades, numerous methods for finding the MPPT have been developed. These techniques differ in many aspects such as the required sensors, complexity, cost, efficiency scope, convergence speed, correct tracking during irradiation or temperature changes, hardware required for implementation, among others [33].

The classification of MPPT algorithms can be based on the function of the techniques or control strategies used. Thus, two categories can be presented: direct methods and indirect methods.

IV.3.1 Indirect methods

This type of MPPT control utilizes the existing relationship between measured variables (such as Isc or Voc), which can be easily determined, and the approximate position of the MPP. It also includes controls based on an estimation of the operating point of the PV panel made from a predefined parametric model. Additionally, there are controls that establish tracking of the optimal voltage by considering only variations in cell temperature provided by a sensor.

These controls have the advantage of being simple to implement. They are more suitable for inexpensive and less precise systems that can operate in geographic areas with minimal climatic changes. Among these methods, we find the open-circuit voltage method, the short-circuit method, etc. [34].

IV.3.2 Direct methods

This type of MPPT control determines the optimal operating point MPP based on the measured currents, voltages, or powers in the system. It can therefore react to unpredictable changes in the operation of the PV panel .Generally; these procedures are based on a search algorithm with which the maximum of the power curve is determined without interrupting the operation. For this, the operating point voltage is incremented at regular intervals. If the output power is greater, then the search direction is maintained for the next step; otherwise, it will be reversed. The actual operating point then oscillates around the MPP. This basic principle can be preserved by other algorithms against interpretation errors. These errors can

occur, for example, due to a wrong search direction resulting from high power due to a rapid increase in radiation level.

The determination of the PV generator's power value, essential for finding the MPP, requires measuring the voltage and current of the generator, as well as multiplying these two variables.

Among these methods, we find the differentiation method, the Perturb & Observe (P&O) method, the incremental conductance method, etc...[34].

IV.4 Synthesis of various MPPT techniques encountered in the literature

There are specific control laws whose role is to bring devices to operate at maximum points of their characteristics without necessarily knowing these points in advance. In the case of energy sources, this translates to maximum power points. This type of control is often referred to in the literature as "Maximum Power Point Tracking" (MPPT). The principle of these controls is to perform a search for the maximum power point (MPP) while ensuring a perfect adaptation between the generator and its load in order to transfer the maximum power.

Regarding the design of MPPT controls, various adaptation approaches are available: analog implementation, analog-to-digital, and digital. Thus, the classification of MPPT has been performed based on different criteria such as the accuracy of the search or its speed to make a comparative evaluation.

In this chapter, we have chosen the digital MPPT control for the adaptation approach due to its simplicity of implementation despite its higher cost compared to other methods [35].

IV.5 Principle of Maximum Power Point Tracking (MPPT)

This principle, which ensures that the system will always be brought to its power optimum, is schematically depicted in (Figure IV.2) and (Figure IV.3).

(Figures IV.2) and (Figures IV.3) illustrate three cases of disturbance. Depending on the type of disturbance, the operating point shifts from the maximum power point (PPM1) to a new operating point P, this may be more or less distant from the optimum.

In the first case (a), for a variation in sunlight, it is sufficient to readjust the duty cycle value to converge towards the new maximum power point (PPM2).

In case (b), for a load variation, we can also observe a modification of the operating point, which can regain a new optimal position through the action of a control system [33].

Finally, in the last case (c), the variation in the operating point can occur due to the variation in the operating temperature of the PV panel, although action at the control level is also necessary.

In the reality, this variation is due to all three previous cases occurring simultaneously.

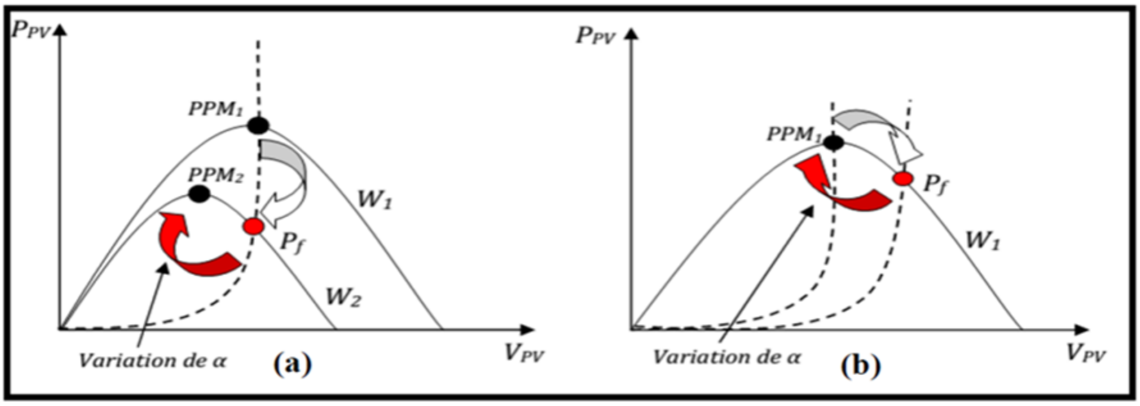


Figure IV.2 : Fluctuation of the maximum power point (PPM) with irradiance intensity (a) and load resistance (b) [37]

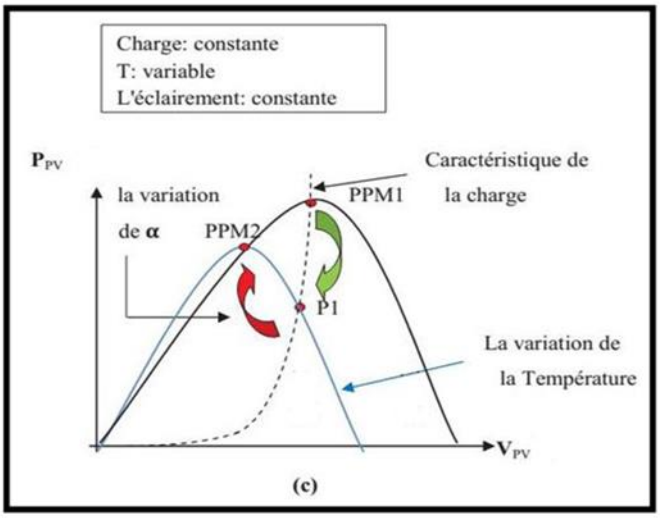


Figure IV.3 : Fluctuation of the maximum power point (PPM) with temperature intensity (c) [33]

The comparison of.Pa and P_b measured respectively at instants (t-1) and (t) allows for the search of the maximum power point (PPM), as shown in (Figure IV.3), by incrementing or Decrementing the duty cycle α If the derivative is positive (P_a<Pb) it means that we are approaching the PPM by incrementing α, and if the power derivative is negative ($P_a > P_b$), it means that we have exceeded the PPM and we need to decrement α Once α is modified, its value is taken, and a new measurement of I_{pv} and V_{pv} is performed to calculate the new power.

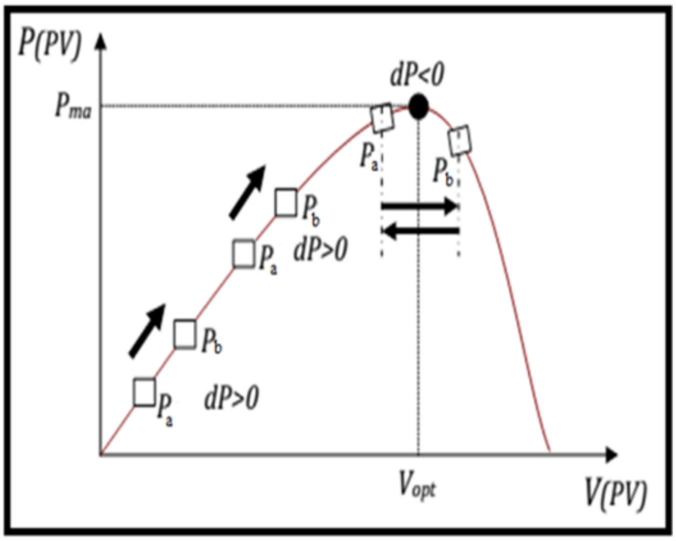


Figure IV.4 :presentation of the flowchart leading the system to operate at its Maximum Power Point (MPP) [33]

IV.6 Different Types of MPPT Controls

To continue tracking the actual MPP, it would be necessary to obtain information about the real power extracted from the PV module. This can be achieved by measuring the voltage V_{pv} at the output of the panel and the current Ipv it can provide.

From the electrical power equation $P= V_{pv}*I_{pv}$, different MPPT control algorithms can be used to track the MPP of the PV module. Three implementations of MPPT control are possible [36].

IV.6.1 MPPT with analog implementation

It is characterized by simplicity in design and great dynamic response compared to its digital counterpart and also various disturbances. It can be completely implemented with analog and logic components without the need for any calculations. Another advantage of this control is its ability to operate at high switching frequencies. It can easily exceed 1MHz. This

allows for a significant reduction in the size of passive components (capacitors and inductors) comprising the power converter.

IV.6.2 Mixed logic and analog implementation MPPT

Which is based on the addition of a filter called LFR (loss-free resistor). This concept was developed by S. Singer in the general case of highly nonlinear power sources[36].

IV.6.3 Digital implementation MPPT

The main component of these controls is a micro - controller. They are often integrated with various functions, including protections. The implemented algorithm varies in complexity depending on the accuracy of the system, the robustness, and the speed of the control loop. Thus, among the recently published new MPPT techniques, we can mention the digital MPPT control proposed by Mr. Matsui.

This control is based on measuring the output and input voltages of a boost converter[37]. Indeed, knowing the relationship between the input and output quantities of a static converter based on its duty cycle, once the measurements are made, the duty cycle value can be calculated.

These types of controls are effective at low frequencies and high powers. Their drawback becomes apparent when the conversion system frequency increases, as they may introduce errors in determining the optimal duty cycle. Consequently, they can result in significant efficiency losses. These digital controls are based on adaptive control algorithms, allowing the system to be maintained at its MPP.

IV.7 most commonly used MPPT control algorithms

The three most commonly encountered methods for MPPT are commonly referred to as follows: Hill Climbing, Perturb & Observe (P&O), and Incremental Conductance (IncCond). For a better understanding of the performance of these controls, we briefly recall their different principles in the following paragraphs.

IV.7.1 Perturb and Observe (P&O) Method

The principle of P&O MPPT controls involves perturbing the voltage V_{pv} with a small amplitude around its initial value and analyzing the behavior of the resulting power variation P_{pv} Thus, as illustrated in (Figure IV.5), it can be deduced that if a positive increment of the voltage V leads to an increase in power P this means that the operating point is to the left of the MPP. If, on the contrary, the power decreases, it implies that the system has exceeded the MPP. A similar reasoning can be applied when the voltage decreases. In summary, if, following a voltage perturbation, the PV power increases, the perturbation direction is maintained. Otherwise, it is reversed to resume convergence towards the new MPP [38].

The advantage of this method is that it has the particularity of having a simple regulation structure and few measurement parameters. It can deduce the maximum power point even during variations in illumination and temperature. For all these reasons, the P&O method has become a widely adopted approach in the search for MPPT.

The major drawback of this technique lies in the case of rapid changes in atmospheric conditions (such as a cloudy day with sunny periods). This method may shift the operating point in the wrong direction, and power losses may become even more significant. This incorrect adjustment will continue until.

Until the illumination change slows down or stabilizes, and before new disturbances occur, it is necessary for the static converter to operate in a steady state. That's why this method is considered too slow to regain the new operating point[39].

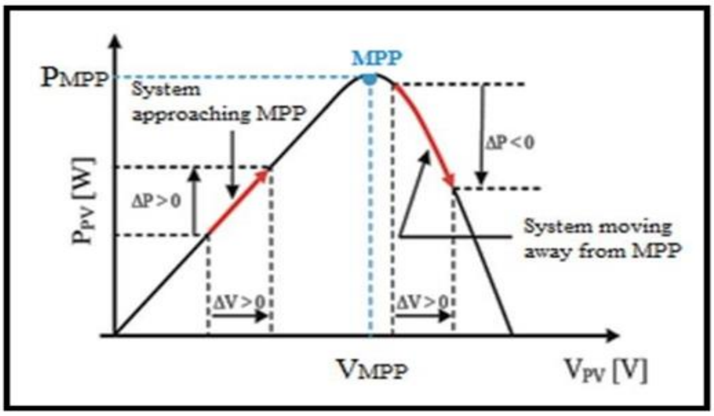


Figure IV.5 : The Power-Voltage characteristic (PPV or VPV) of a solar [35]

The following table summarizes the approach of this method.

Perturbation	Change in power	The next perturbation
Positive	Positive	Positive
Positive	Negative	Negative
Negative	Positive	Negative
Negative	Negative	Positive

Table IV.1 : Summary of the P&O algorithm [40]

(Figure IV.6) illustrates the classical algorithm associated with a P&O type MPPT control, where the evolution of power is analyzed after each voltage perturbation. For this type of control, two sensors (current and voltage of the PV generator) are required to determine the power of the PV at each moment.

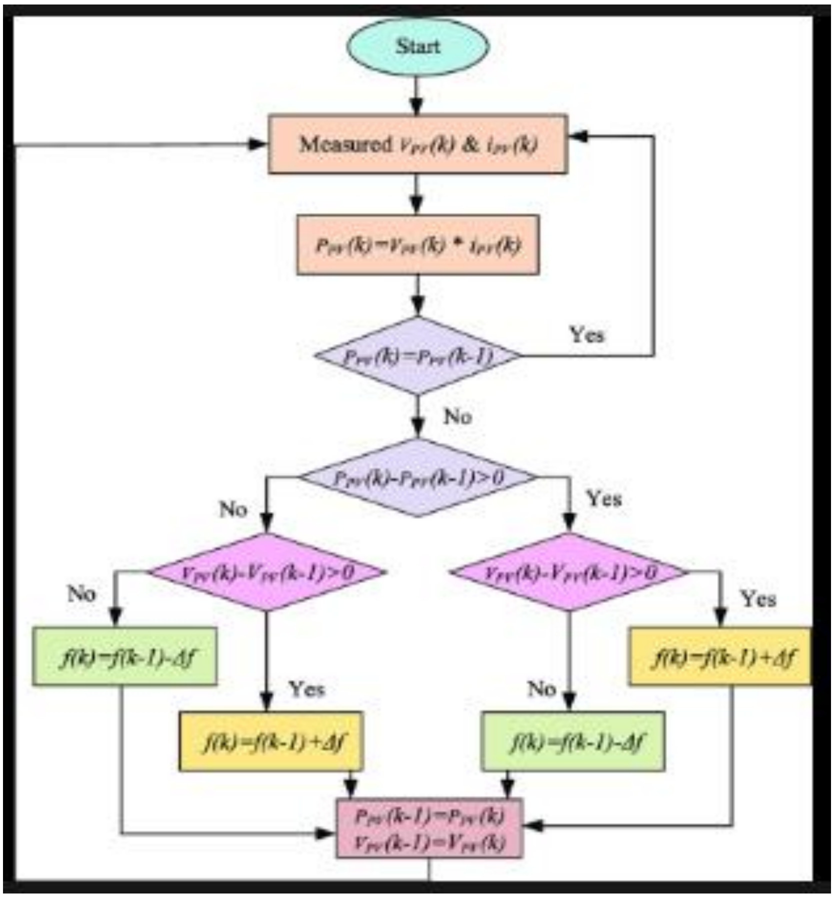


Figure IV.6 :the typical algorithm of the Perturb and Observe (P&O)

Indeed, upon detailed analysis, this search mode exhibits interpretation errors regarding the direction to follow to reach the Maximum Power Point (MPP) when abrupt variations in climatic conditions and/or load occur, as described in (Figure IV.7)

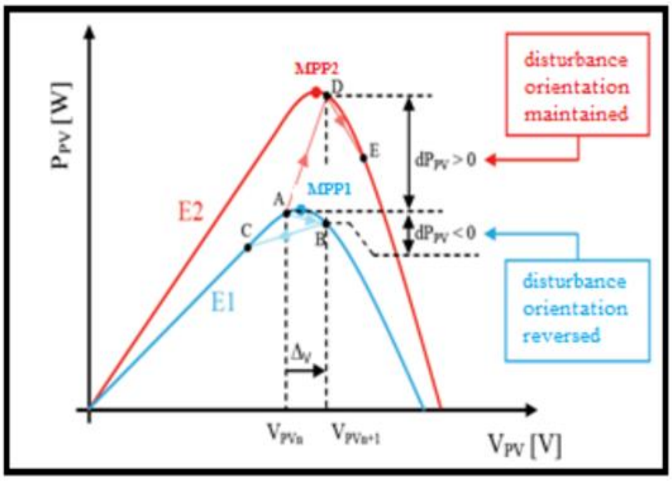


Figure IV.7 : Divergence of the P&O control during irradiance [35]

❖ **Advantages and disadvantages of P&O**

a) Advantage

- Simple control structure
- Reduced number of measured parameters

b) Disadvantages

- Exceeding the optimal maximum point in case of rapid changes in atmospheric conditions [47].

IV.7.2 The principle of "Hill Climbing" control

The control technique called Hill Climbing involves "ascending" the operating point along the generator's characteristic that exhibits a maximum. For this, two slopes are possible. The search theoretically stops when the maximum power point (MPP) is reached. This method is based on the relationship between the panel's power and the duty cycle value applied to the switching element. Mathematically, the MPP is reached when dP_{pv}/dD is forced to zero by the controller, as shown in the following (Figure IV.8) [41]. [42].

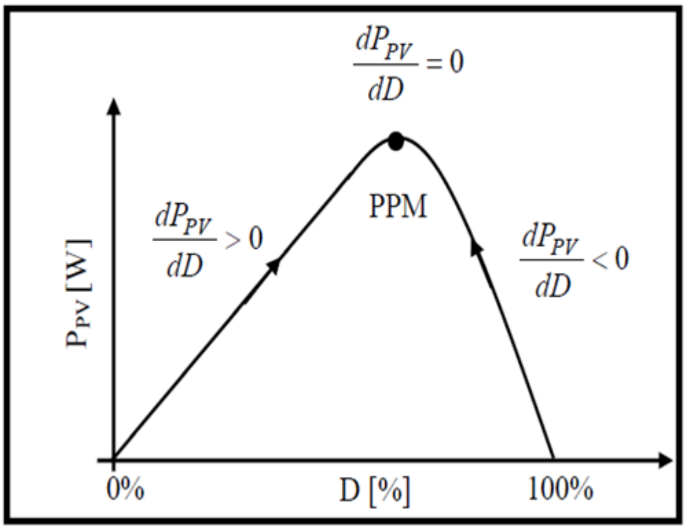


Figure IV.8 :the relationship between the solar panel power (PPV) and the duty cycle (D) of the static converter [34]

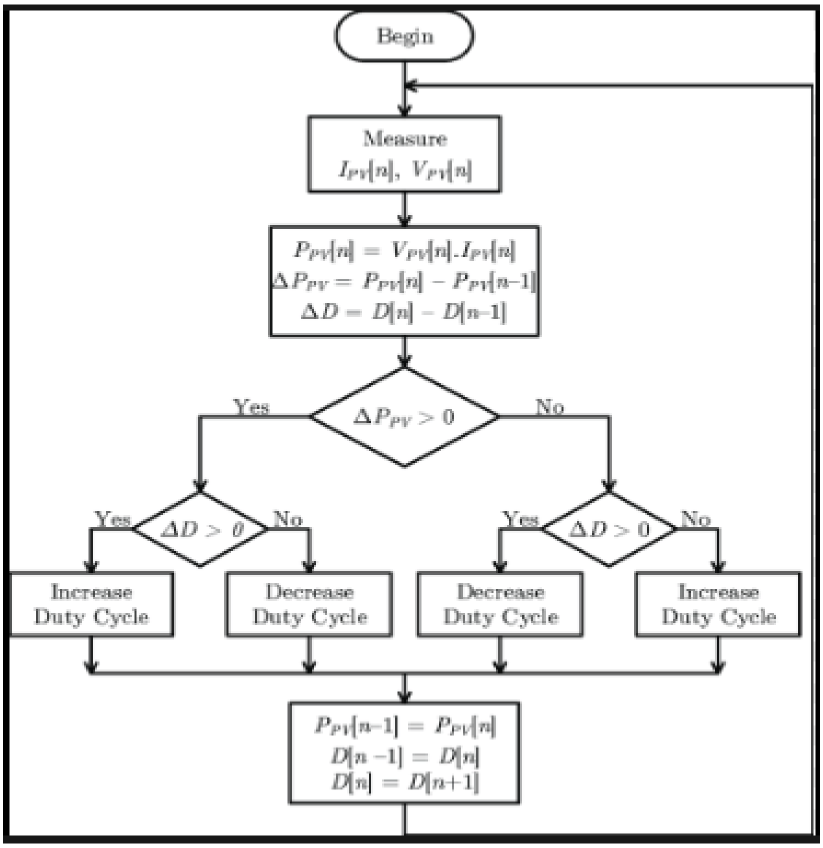


Figure IV.9 :the typical algorithm for the "Hill Climbing" control

The operation of this control is illustrated in Figure IV10 by using the basic PV conversion chain.

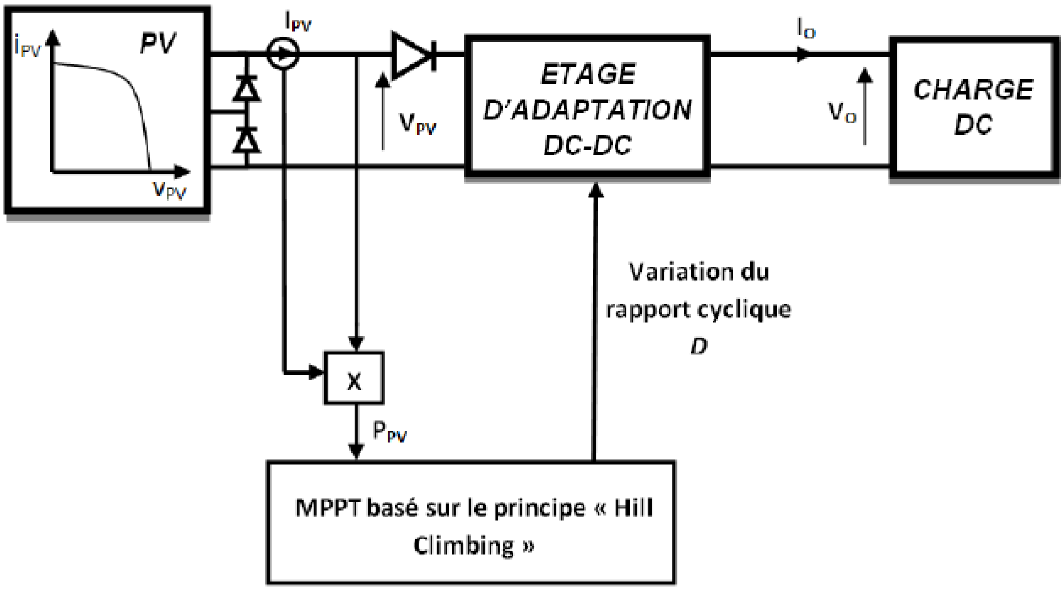


Figure IV.10 :schematic diagram outlining the principle of the "Hill Climbing" control

IV.7.3 The principle of "Incremental Conductance" (IncCond) control

To search for the maximum power point (MPP), this other technique relies on understanding the variation in the conductance of the PV generator (GPV) and its consequences on the operating point position relative to an MPP, as depicted in (Figure IV.11) Thus, the conductance of the photovoltaic module is defined by the ratio between the current and voltage of the PV generator [43]. [44].

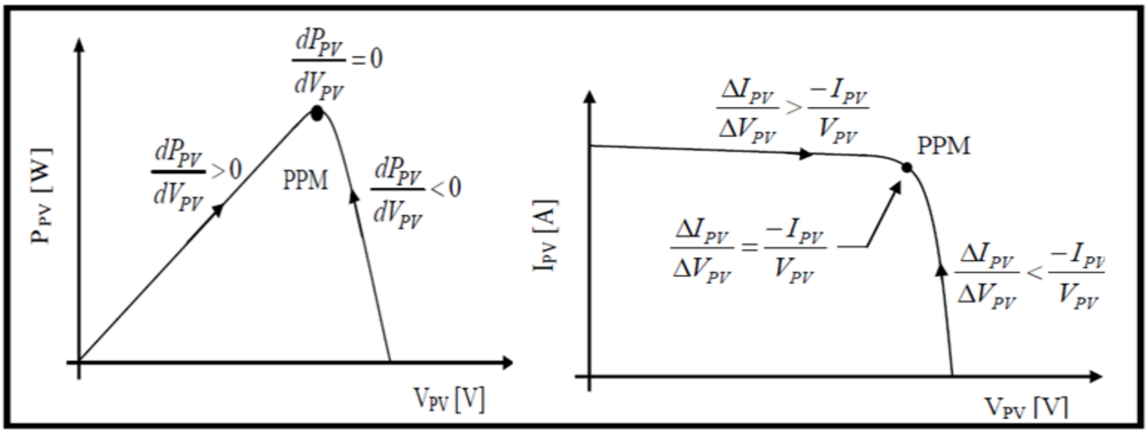


Figure IV.11 :positioning of the operating point according to the sign [34]

dPPV/dVPV Positioning of the operating point on the power characteristic curve (a)

ΔIPV/ΔVPV positioning of the operating point on the current characteristic curve (b)

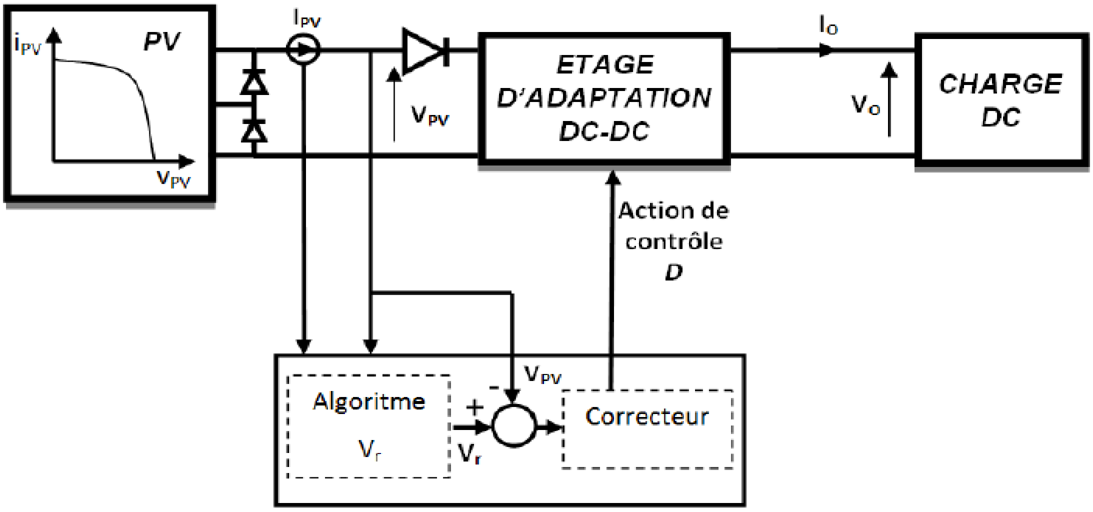


Figure IV.12 :the operation of an Incremental Conductance (IncCond) MPPT control is illustrated on a basic photovoltaic conversion

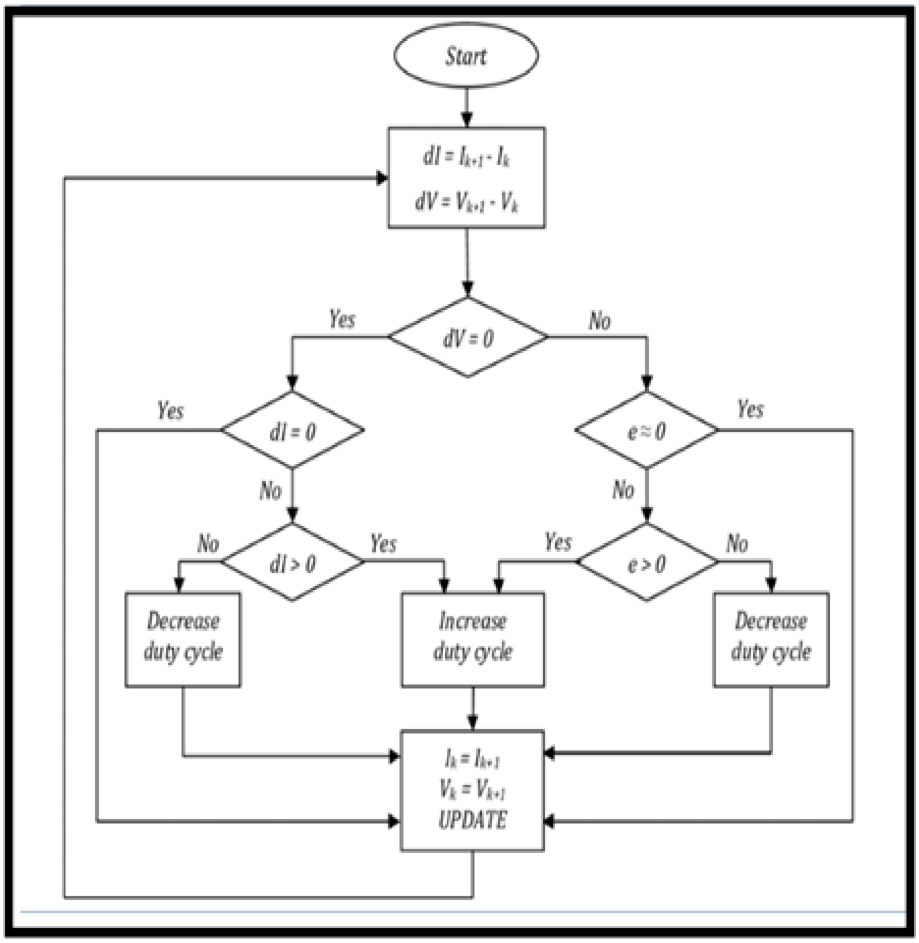


Figure IV .13 :algorithm for an MPPT control based on the Incremental Conductance method

IV.8 Criteria for evaluating an MPPT (Maximum Power Point Tracking) control

The quality of an MPPT control can be defined as the position of the system operating point relative to the MPP.

The actual power Pin delivered by the PV generator depends on the control used at the converter level (MPPT), voltage regulation, direct connection). The resulting operating point efficiency, ηMPPT measures the effectiveness of the control responsible for managing the power converter the performance of an MPPT control is not limited to this single parameter (ηMPPT).

Other criteria, as presented later in the document, such as response time and its ability to operate over a wide range of power, are important for evaluating the qualities of this type of control. We will detail them as they are used throughout this document [34].

IV.8.1 Simplicity and Cost

In addition to its theoretical performance, it is important to know the level of complexity of the algorithm, leading to implementation difficulties and losses directly related to the number of calculations required. In summary, an MPPT control must have a significant level of simplicity favoring low consumption and therefore a reasonable development cost so that its presence compensates for the additional cost generated. Indeed, it should not be forgotten that in a highly competitive energy context, the insertion of an adaptation stage with an MPPT control must provide an energy gain covering the economic surplus.

Otherwise, this solution will never be viable from an industrial point of view. Conversely, the control, no matter how efficient it may be in terms of efficiency, presents too many constraints to be chosen for this type of application [34].

IV.8.2 Dynamical Response

An MPPT control must exhibit good dynamic behavior to be able to drive the adaptation stage and ensure that the search for the new MPP, following changes in irradiance or temperature, is done as quickly as possible.

IV.8.3 Flexibility

An MPPT control must be accurate and stable regardless of its operating conditions. This means it should not be designed to work for only one type of panel. It should be as universal as possible, capable of operating with panels of different technologies with minimal modifications, while maintaining the same level of accuracy and robustness.

IV.8.4 Competitive over a wide range of power

By definition, an MPPT control, used in photovoltaic applications, is supposed to track the Maximum Power Point (MPP) generated by a PV module, regardless of the level of sunlight. The MPPT control is considered competitive if the MPP is reached with a low static error, corresponding to the position of the operating point relative to the MPP, over a wide range of power [34].

IV.9 Result and simulation

IV.9.1 simulation of Perturb and Observe (P&O)

Simulation of the photovoltaic system based on MPPT control of the P&O type (Figure IV.14).

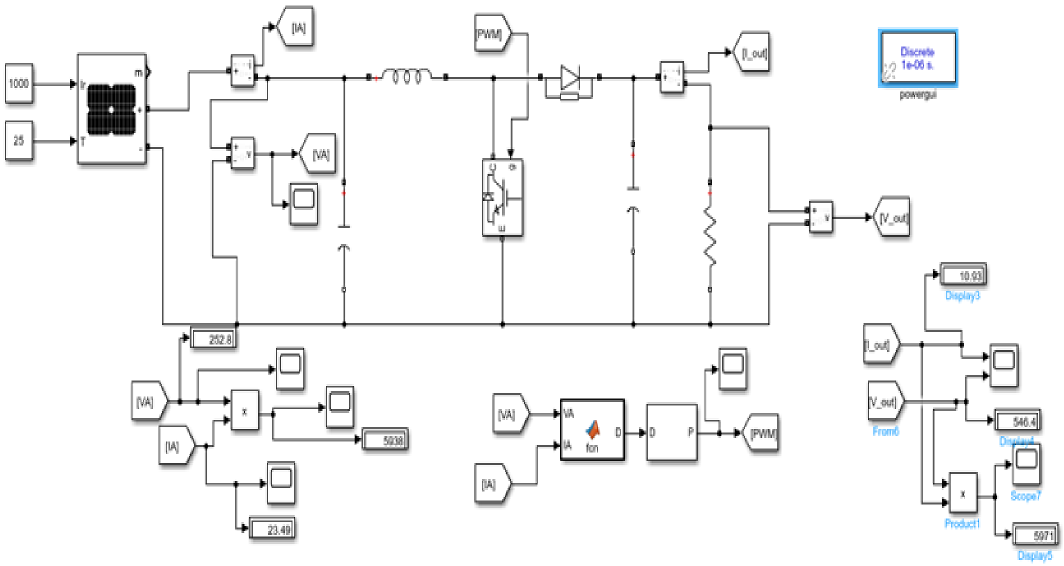


Figure IV.14 : Block simulation of Perturb and Observe (P&O)

The simulation results of the photovoltaic system adapted by the MPPT command of the ‘Disturbance a and Observation’ type under fixed atmospheric conditions (a luminance 1000W\m^2 and a temperature of 25°C) are represented by the figures below.

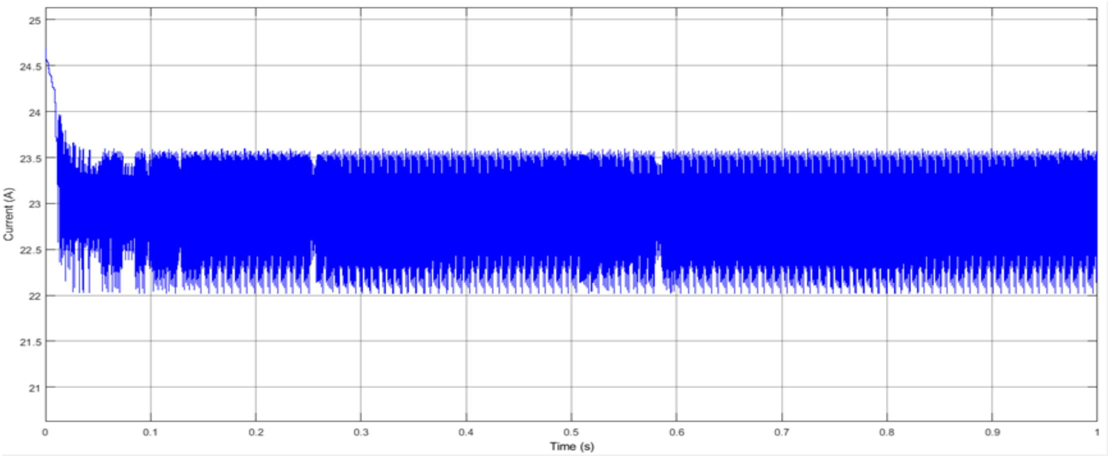


Figure IV.15 : Evolution of the PV panel with the P&O application

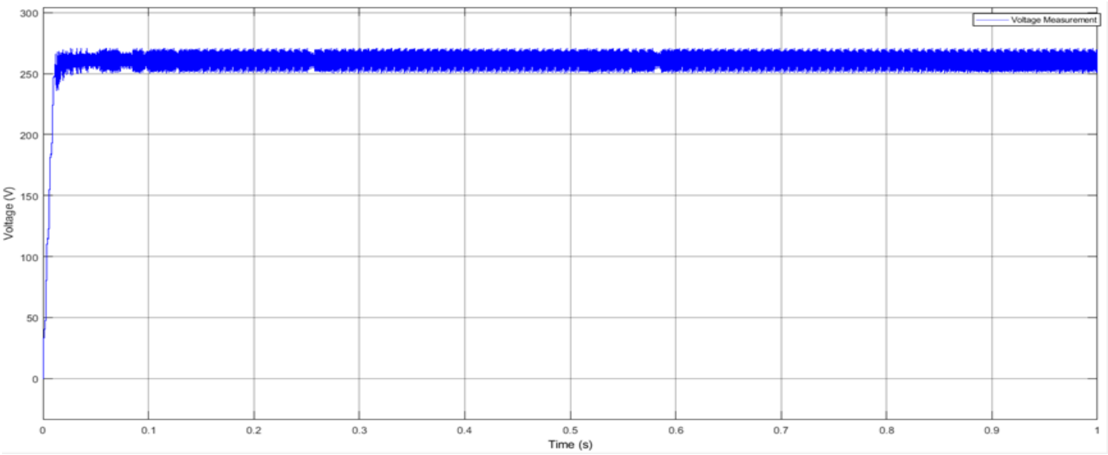


Figure IV.16 : Evolution of PV panel voltage with P&O application

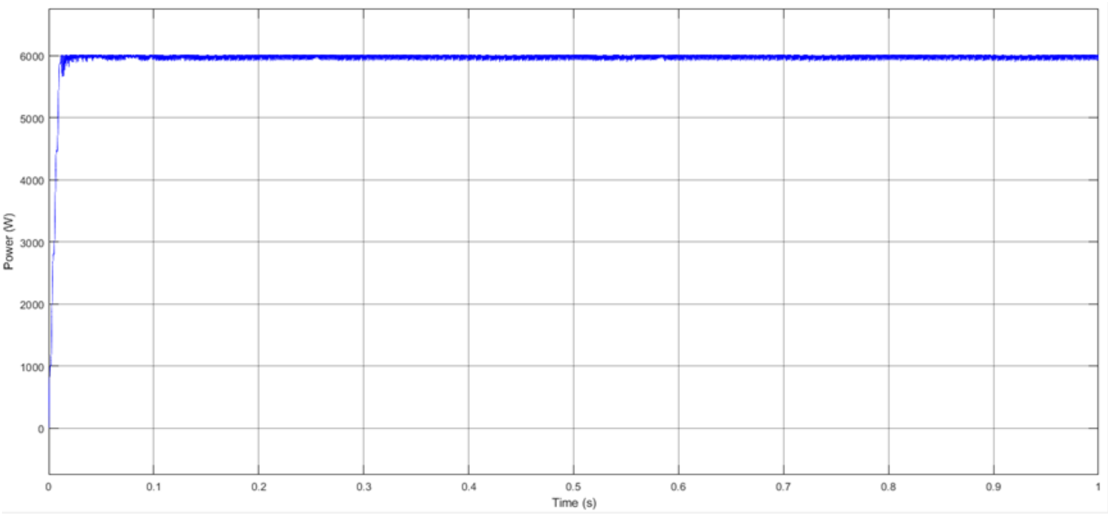


Figure IV.17 : Evolution of the PV panel with P&O application

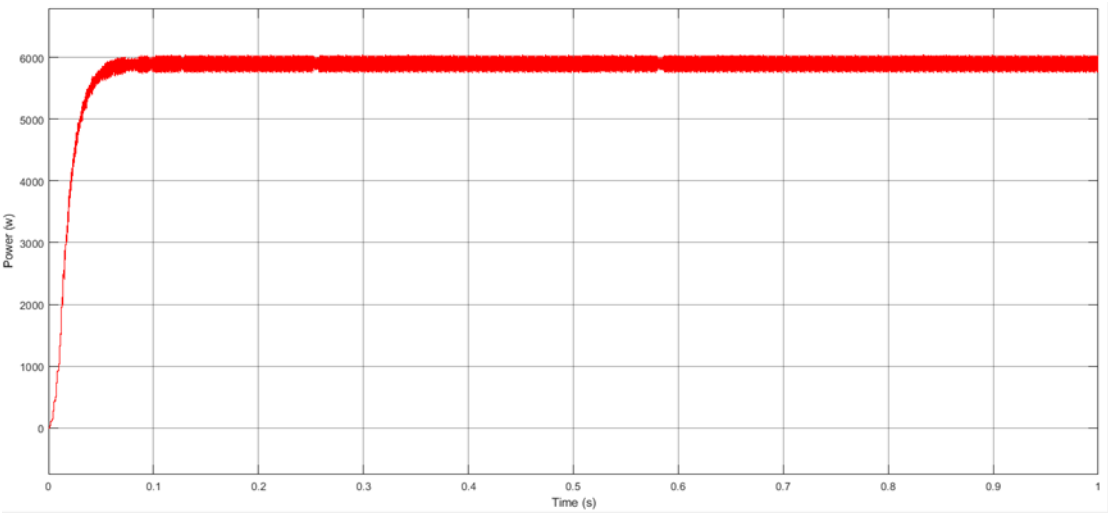


Figure IV.18 : Evolution of the output voltage of the PV panel with the P&O application

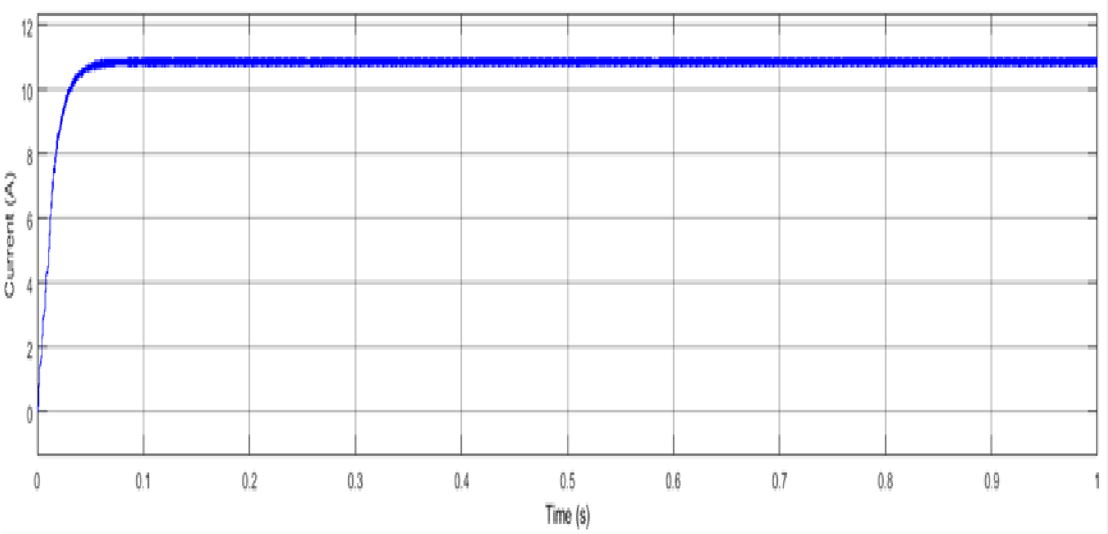


Figure IV.19 : Evolution of output current of the PV panel with the P&O application

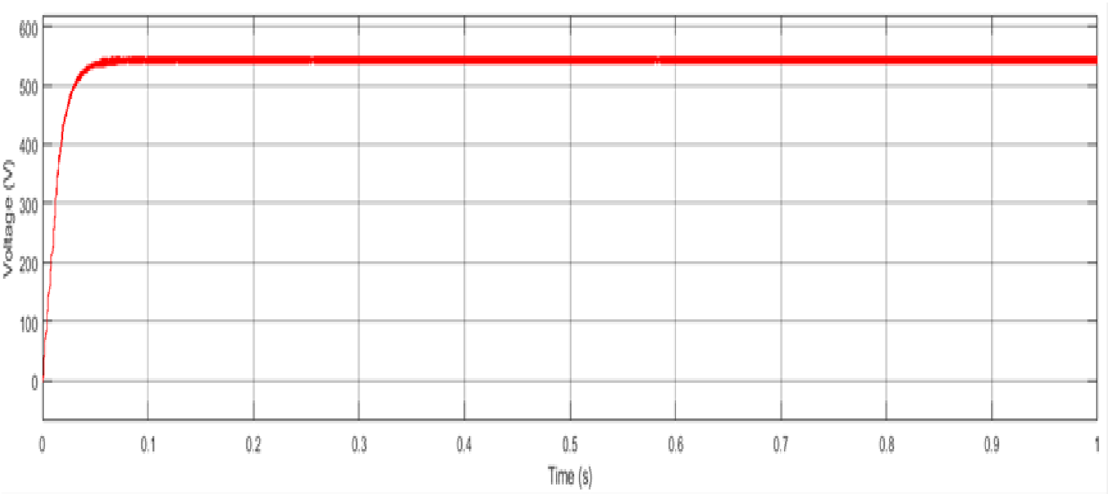


Figure IV.20 : Evolution of output voltage of the PV panel with the P&O application

In Figure IV.17, we can be observed that the P&O control oscillates around the PPM. Witch it's according to Figure IV.16, the PV generator voltage reaches 252.5V, which is additionally compatible with the field characteristics presented in (Figure IV.14).

IV.9.2 Simulation of single-grid connected photovoltaic system

Block diagram utilization

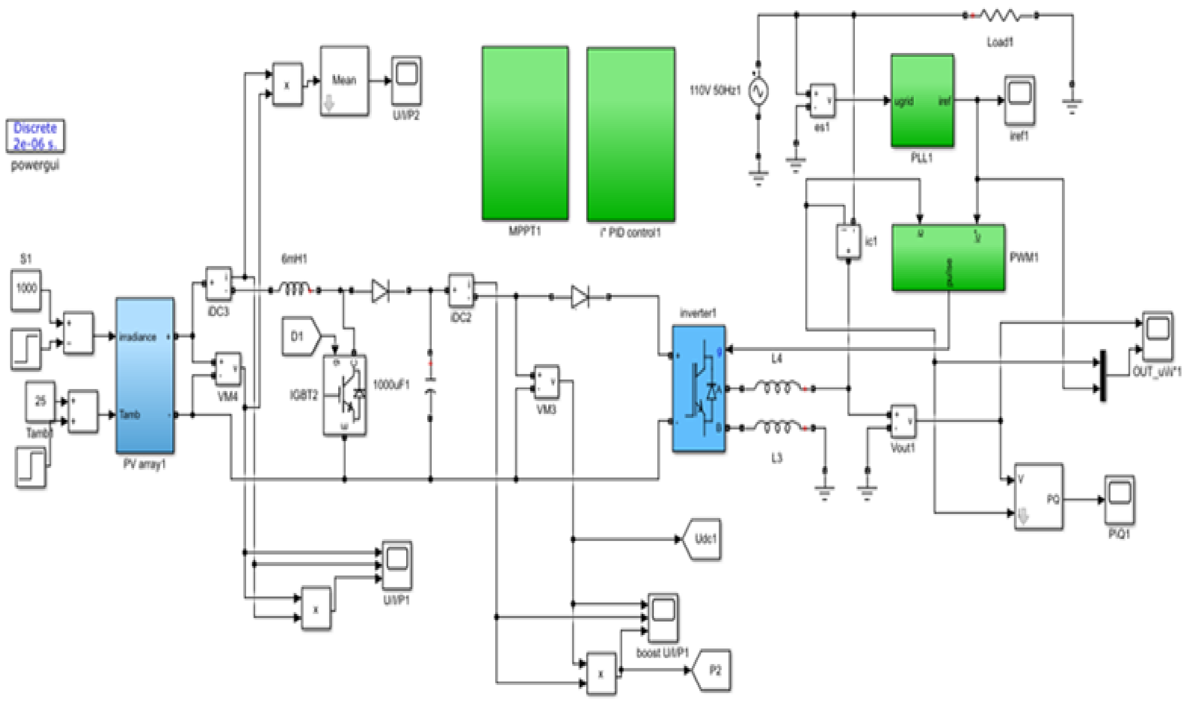


Figure IV.21 :grid-connected photovoltaic system

Results

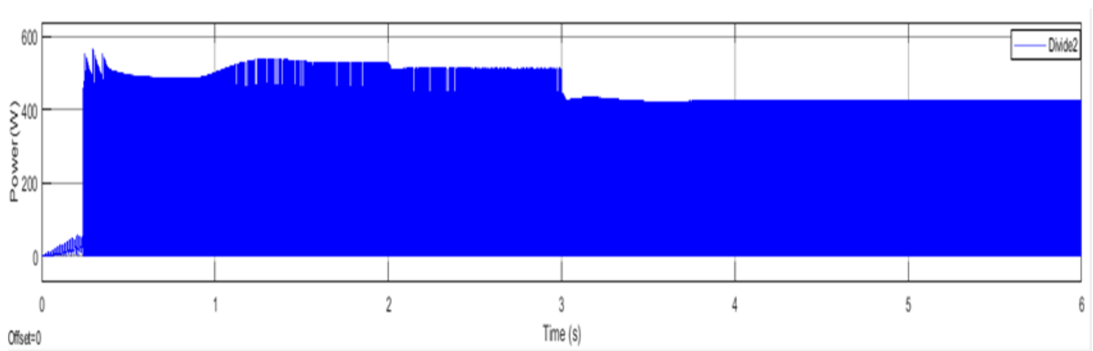


Figure IV.22 :profile of the panel power Ppv

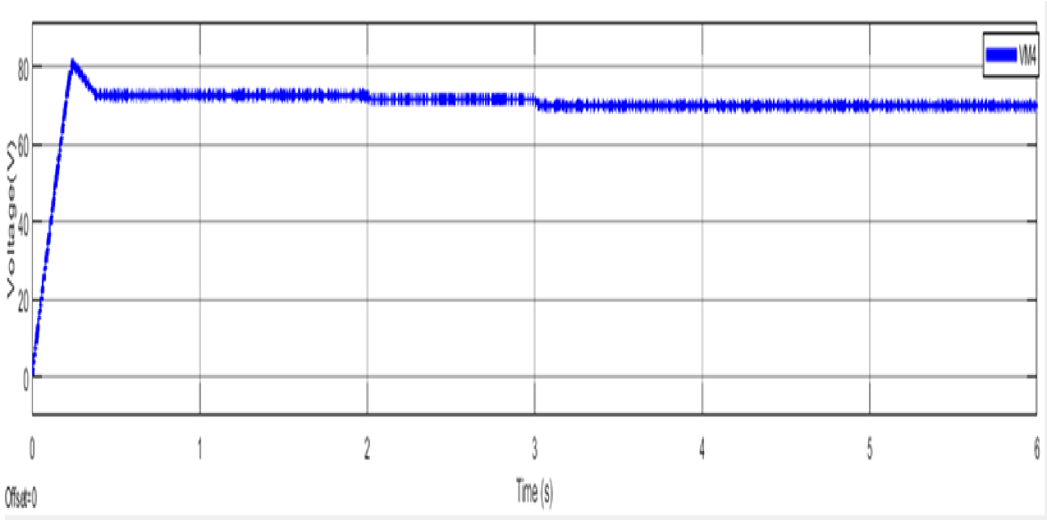


Figure IV.23 :profile of the panel voltage Vpv

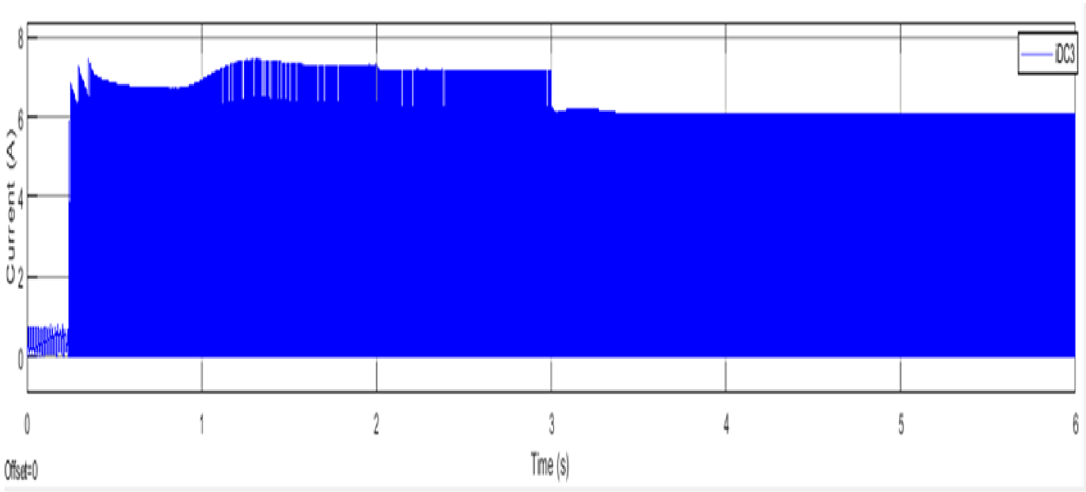


Figure IV.24 :profile of the panel current Ipv

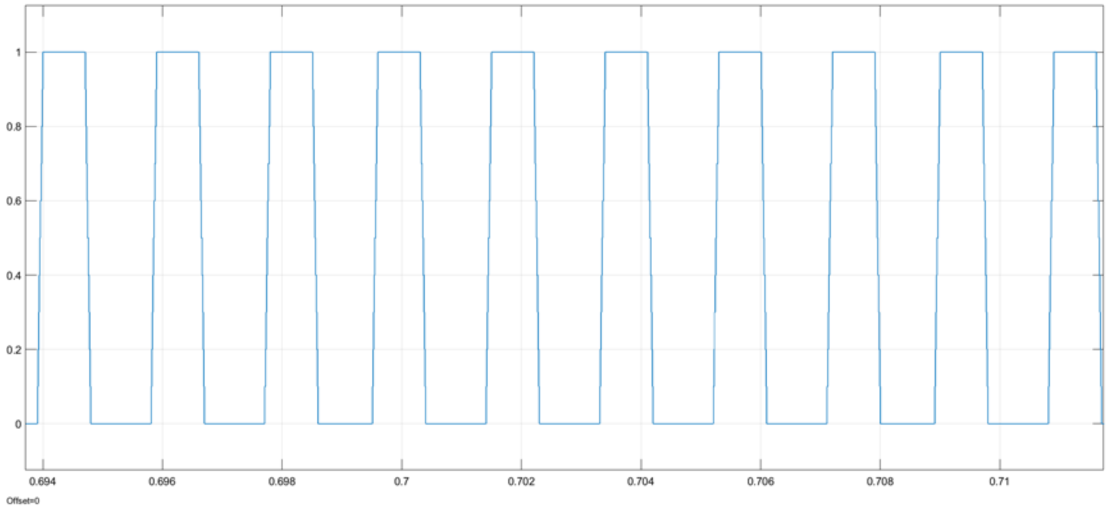


Figure IV.25 :profile of the duty cycle of the MPPT control (D)

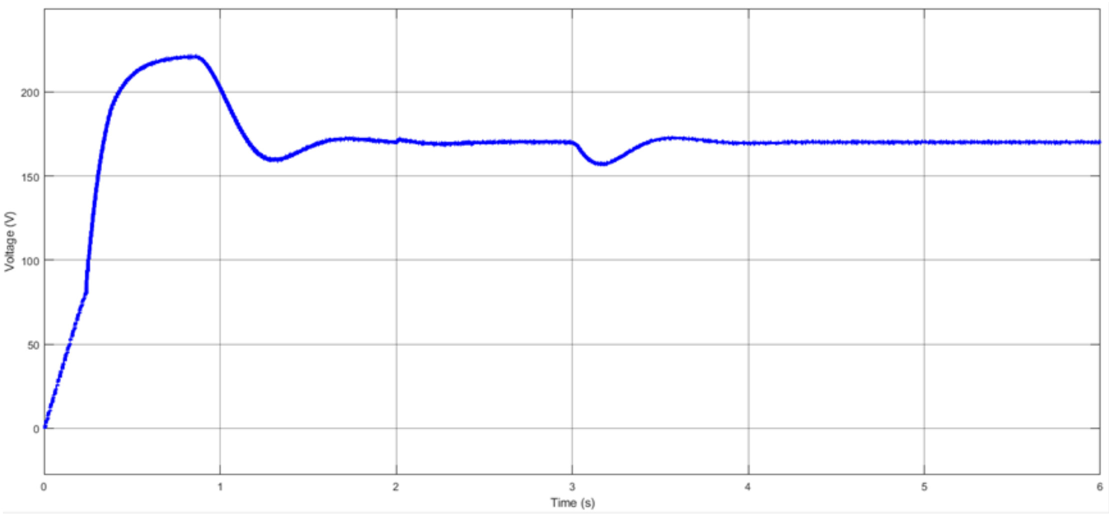


Figure IV.26 :profile of the DC bus voltage Vdc

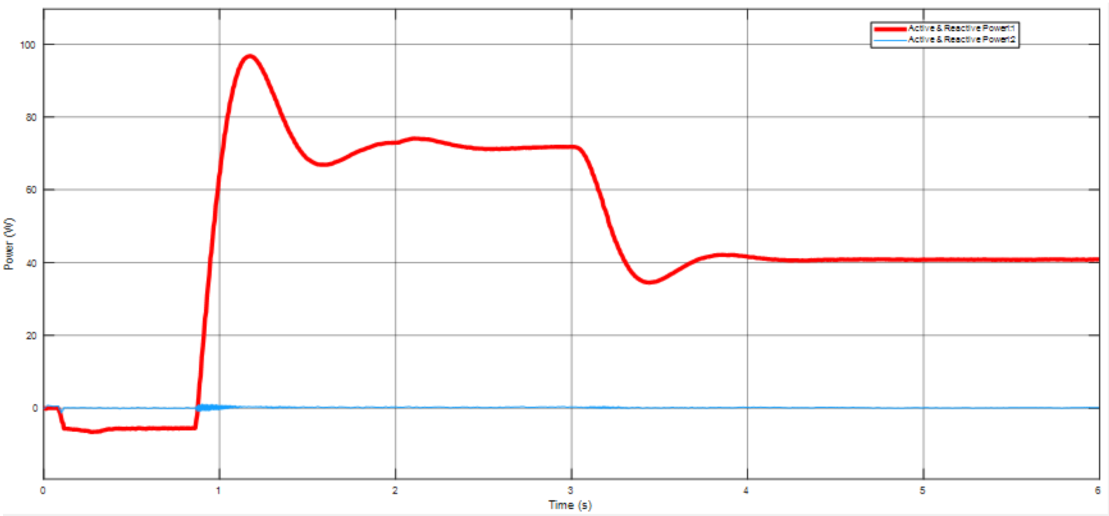


Figure IV.27 :profile of the active power supplied and the reactive power to the grid

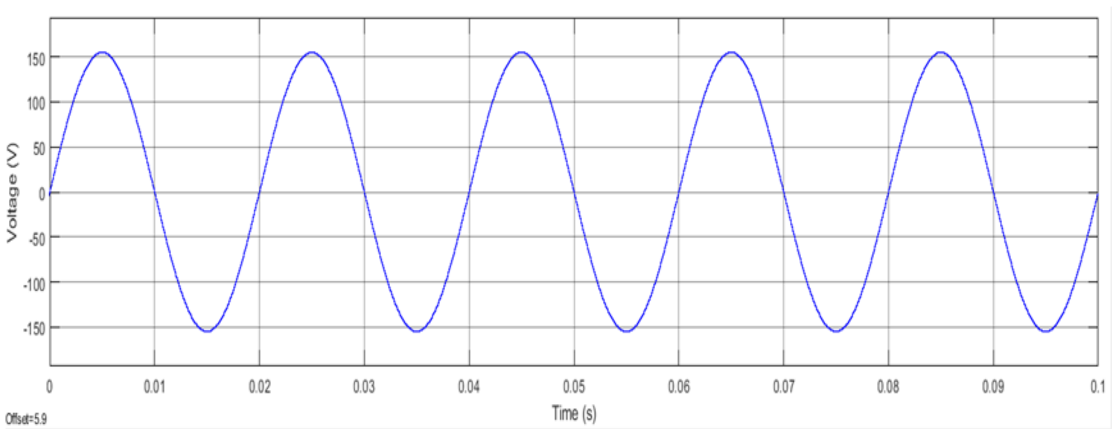


Figure IV.28 :profile of the extracted voltage from the grid

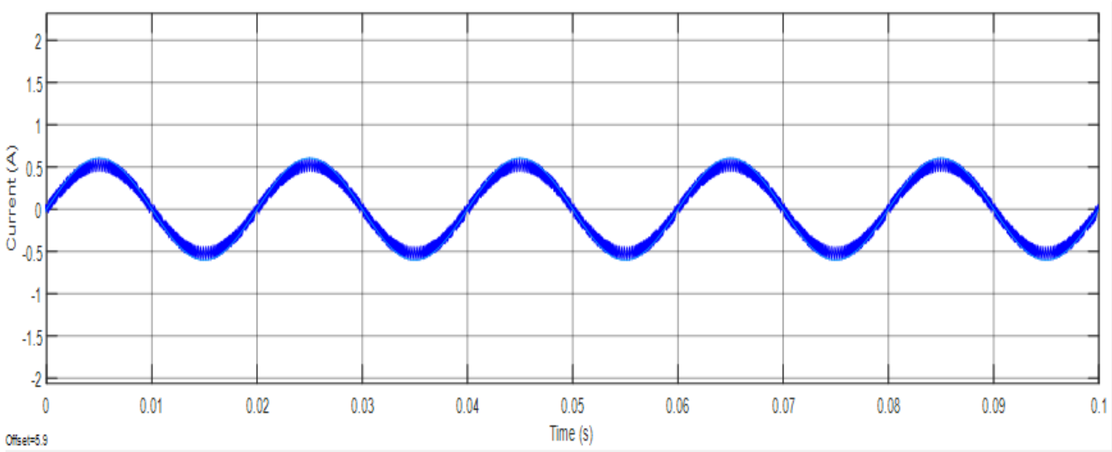


Figure IV.29 :profile of the extracted current from the grid

Discussion

To study the performance of the grid-connected photovoltaic system operating at maximum power over a certain period, we will use variable profiles of sunlight and temperature. The behavior of the power extracted from the photovoltaic panels is shown in (Figure IV.22).

The panel voltage Vpv is shown in (Figure IV.23). The photovoltaic current Ipv varies according to the changes in sunlight, as depicted in (Figure IV.24). The behavior of the duty cycle of the MPPT control is illustrated in (Figure IV.25).

The voltage at the DC bus terminals obtained from perturb and observe control (P&O) type MPPT control is shown in Figure IV.26.

It is well regulated to its reference value of 170 V, even during variations in environmental conditions. The P&O control allows for the extraction of the maximum power point (MPP) even when climatic conditions change rapidly.

The comparison between the photovoltaic power and the power supplied to the grid is shown. It can be seen that the photovoltaic power produced corresponds to the power supplied to the grid. Additionally, it can be observed that the reactive power is zero (Figure IV.27), which corresponds to operation at a unity power factor.

The Figure IV.28 and Figure IV.29 illustrate the voltage and current extracted from the electrical grid, Vref and Iref respectively.

IV.10 conclusion

In this chapter, we have presented several MPPT control methods based on power feedback, such as the Perturb and Observe (P&O) method. This MPPT control directly utilizes the voltage and current of the photovoltaic panel to search for the operating point corresponding to maximum power. We have observed that the P&O algorithm is preferable due to its effectiveness in bringing the operating point of the PV generator as close as possible to the MPP and its simplicity of implementation. We based our MPPT control on perturb and observe (P&O) method, which we will use throughout our work.

General Conclusion

General Conclusion

The global demand for energy is changing rapidly, and natural energy resources such as uranium, gas and oil are decreasing due to major changes. For this challenge, solar energy is considered one of the renewable energies that can meet the demand to cover energy needs, because photovoltaic energy is clean, silent, and free energy as well. This choice is justified by the interest shown by researchers and industrialists in this type of photovoltaic structure.

Modeling, simulation, control and analysis of the conversion system envisaged grid-connected PV power is discussed and adapted via digital controls that ensure continuous maximum power provided by the PV generator.

In our work, firstly, we are studied the photovoltaic generator for different generating powers (cells and modules) and designed a model of the photovoltaic units as well as their electrical parameters.

Next, we are studied some types of chopper (DC-DC converter) used in photovoltaic systems, specially the boost converter. Moreover, we also introduced MPPT control with P&O technique (the simplest technique) only for the voltage and current measurements of the PV module for DC-DC converters to find the point at which the power of the photovoltaic generator reaches its maximum. Our work finally present simulation of single-grid connected photovoltaic system.

All section of our work follow by model or simulation in Matlab\Simulink software Therefore, the simulation results obtained of the models implemented in this work show the validity and effectiveness of the proposed system.

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