People`s Democratic Republic of Algeria

Ministry of Higher Education and Scientific Research

University of Echahid Hamma Lakhdar - El Oued

Faculty of Technology

Department of Electrical Engineering

Dissertation

ACADEMIC MASTER

Domain: Science and Technology

Division: Electrical engineering

Specialty: POWER SYSTEMS

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Entitled:

Grid-Connected Photovoltaic System use Quasi-Z-Source Inverter

Dissertation Submitted in Partial Fulfillment of the Requirements for the Master Degree in Electrical engineering

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Academic Year: 2023/2024

Acknowledgements

I would like to offer my sincere gratitude and appreciation to the Almighty God for keeping me in good health and giving me strength to study and finish my work from the beginning until now. I wish to express my deepest gratitude to my supervisor, **Dr. Hicham Serhou** , for his professional assistance, support, advice and guidance throughout my thesis. Many thanks to all the lecturers.

I would also like to express my gratitude to my family, my brothers, my friends, and all of my relatives and classmates for providing all of the necessary preconditions to complete my studies. Throughout my academic career, they have always been behind me.

الاهداء

بعد مسيرة دراسية دامت سنوات حملت في طياتها الكثير من الصعوبات والمشقة والتعب ها انا اليوم اقف على عتبة تخرجي اقطف ثمار تعبي وأرفع قبعتي بكل فخر فاللهم لك الحمد قبل ان ترضى ولك الحمد اذا رضيت ولك الحمد بعد الرضا لانك وفقتني علي اتمام هذا العمل وتحقيق حلمي... أهدي هذا النجاح

الي من جعل الله الجنة تحت أقدامها واحتضنتني قلبها قبل يدها وسهلت لي الشدائد

بدعائها الي القلب الحنون الي المرأة التي جعلتني فتاة طموحة

والشمعة التي كانت لي في الليالي المظلمات سر قوتي

ومصباح دربي الي ونجاحي

وهج حياتي (والدتي الحبيبة)

وأخيرا من قال أنا لها" نالها" وأنا لها ان أبت رغما عنها اتيت بها ماكنت لأفعل لولا توفيق من الله هاهو اليوم العظيم هنا اليوم الذي أجريت وسنوات الدراسة الشاقة حالمة فيها حتى تواليت بمنه وكرمه لفرحة التمام الحمدلله

الذي به خيرا وأملا الا وأغرقنا سرورا وفرحا ينسيني مشقتي

بسم الله الرحمن الرحيم

ABSTRACT:

This work proposes control methodology for three phase grid connected of PV generator use q-z-source inverter. It consists of a PV arrays; a voltage source inverter, a grid filter and an electric grid. The controller objectives are three fold ensuring the Maximum power point tracking (MPPT) in the side of PV panels, guaranteeing a power factor unit in the side of the grid, ensuring the global stability of the closed loop system. Simulation results that the proposed controller meets all the objectives.

Keywords: quasi-Z-source inverter (qZSI), renewable energy source, grid, MPPT

RÉSUMÉ :

Ce travail propose une méthodologie de contrôle pour un générateur photovoltaïque (PV) connecté au réseau triphasé utilisant un onduleur q-z-source. Il se compose de panneaux photovoltaïques, d'un onduleur à source de tension, d'un filtre de réseau et d'un réseau électrique. Les objectifs du contrôleur sont triples : assurer le suivi du point de puissance maximale (MPPT) du côté des panneaux photovoltaïques, garantir un facteur de puissance unitaire du côté du réseau et assurer la stabilité globale du système en boucle fermée. Les résultats de la simulation montrent que le contrôleur proposé atteint tous les objectifs.

Mots-clés : onduleur quasi-Z-source (qZSI), source d'énergie renouvelable, réseau, MPPT

الملخص

يقترح هذا العمل منهجية للتحكم في مولد كهر وضوئي متصل بشبكة ثلاثية الأطوار باستخدام عاكس مصدر يتكون النظام من مصفوفات كهر وضوئية، وعاكس مصدر جهدي، فلتر شبكي، وشبكة كهربائية. تهدف أهداف وحدة التحكم إلى تحقيق ثلاثة أهداف: ضمان تتبع نقطة القدرة القصوى من جانب الألواح الكهروضوئية، وضمان وحدة عامل القدرة من جانب الشبكة، وضمان الاستقرار العام للنظام ذو الحلقة المغلقة. تظهر نتائج المحاكاة أن وحدة التحكم المقترحة تحقق جميع الأهداف

الكلمات المفتاحية: عاكس مصدر ، مصدر طاقة متجددة، الشبكة، تتبع اقصى نقطة للقدرة MPPT

Contents:

Abbreviations:

VSI	Voltage - Source Inverter
PV	Photovoltaic
q-ZSI	quasi - Z Source Inverter
PWM	Pulse Width Modulation
MPPT	Maximum power point tracking
PLL	Phase Locked Loop
AC	Alternative Current
DC	Direct Current
THD	Total Harmonic Distortion
P&O	Perturb And Observe

List of figures:

General Introduction:

The penetration of photovoltaic (PV)-based distributed generation systems in the energy grid has become very significant these days. The International Energy Agency's annual report reveals that global PV installations reached 98 GW in 2017, a 29% increase from the previous year, with China leading the way with 32% of the total installed capacity.

All these works in common, use lookup data generated from the commercially available PV panel I-V characteristics as a reference. As the PV source can be modeled as a current source input to the system, the PV is then simulated by means of current control using a power electronics circuit such as the DC-DC buck converter, which is simple and effective. As a result, the power produced by the PV emulator can be specifically controlled to emulate the real-world environment. From the perspective of integration between the PV source and the grid-connected inverter, the DC-DC boost converter is preferably used to increase the voltage across the inverter and to implement maximum power point tracking (MPPT) to gain maximum power from the PV source.

The Z-source inverter [ZSI] is proposed, which then evolves into many other types of impedance source inverters, such as the quasi-Z-source inverter (q-ZSI) which has been proven as an alternative to conventional voltage source inverters (VSI) for grid-connected PV systems with equivalent performance.

The q-ZSI eliminates the necessity of having the DC-DC boost converter in between, thus providing an advantage in terms of reducing the number of components as well as the control complexity. From the point of real PV source implementation, however, not much has been discussed, especially in terms of realizing and evaluating the operation and effectiveness of the MPPT. For that, this work is filling the gap by specifically discussing the q-ZSI. We expect the results from this implementation to be applicable to other types of impedance sources as well.

Project organization:

The first chapter summarized the background study and the current status of the renewable energies exactly photovoltaic solar energy; and quasi-Z-Source inverter.

The second chapter discusses the modeling of photovoltaic panels and MPPT control. Is divided into two parts; the first section summarized the modeling of photovoltaic panels, and the second parts covers the converter dc/dc and MPPT control. In addition, the chapter discusses the characteristic of PV module with using MATLAB/Simulink.

The third chapter summarized the modeling and simulation of quasi-z-source inverter. In addition, the chapter discusses; the topology, configuration and operating of a three-phase inverter with quasi-Z-Source structure. It is covers also the control strategies for quasi-Z-source inverter with hysteresis current control method. Design of model it using MATLAB/Simulink. Finally, the general conclusion consists the results of this project for control of the Z-Source three phase inverter applied to a photovoltaic system and recommendations for future works.

Chapter I:

Generalities on Photovoltaic Systems

I.1.Introduction:

Solar energy is one of the most renewable energy. It plays a very important role in meeting energy demands in the near future, since it is a clean type of energy with a multiplicity of applications like solar cell. With rapid growth of solar photovoltaic (PV) and energy storage systems, there is high demand for efficient and reliable power converter solutions. Different families of power transformers aim to connect the renewable solar resource with different applications. One of the most popular topologies for converting power electronics is the q-Z-source inverter (Q-ZSI)

In this chapter, we will discuss renewable energies, with a focus on photovoltaic solar energy.

I.2.Renewable energies:

Renewable energy uses energy sources that are continually replenished by nature the sun, the wind, water, the Earth' s heat, and plants. Renewable energy technologies turn these fuels into usable forms of energy most often electricity, but also heat, chemicals, or mechanical power. Renewable energy is abundant, and the technologies are improving all the time. There are many ways to use renewable energy. Most of us already use renewable energy in our daily lives.

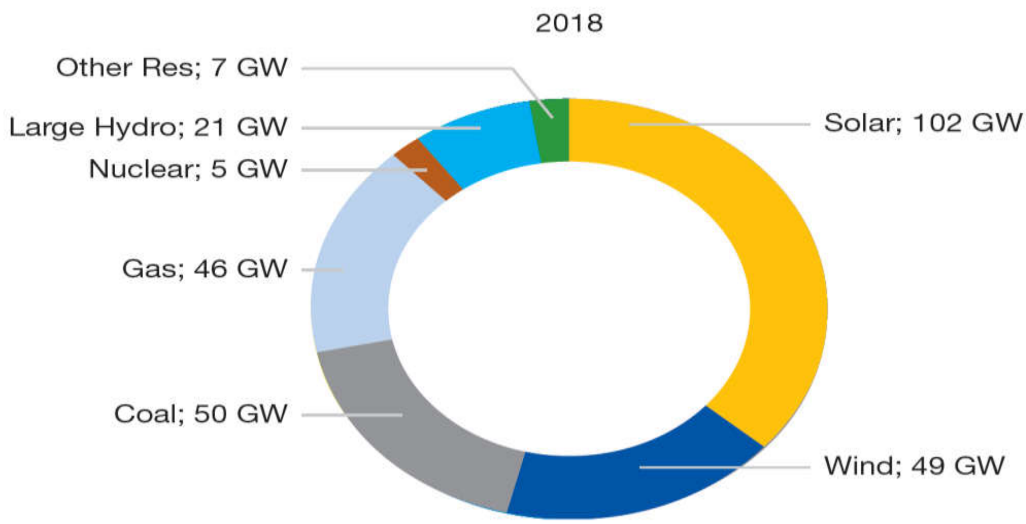


Figure I.1: The evolution of the global photovoltaic energy market.

I.3. Solar energy:

Solar energy is an important source of renewable energy and its technologies are generally characterized as either passive solar or active solar depending on how they capture and distribute solar energy or convert it into solar power. Solar energy is radiant light and heat from the Sun that can be recovered by two methods, as shown in figure (I.2)

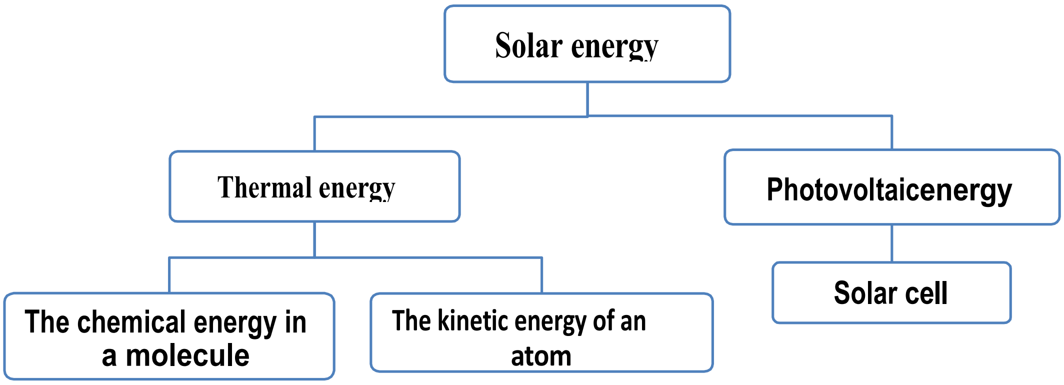


Figure I.2: The Solar energy types

I.4.Applications of solar energy:

The major application of solar energy is: Solar water heating, solar pumping, solar heating of buildings, solar distillation, solar drying of agricultural and animal products, solar furnaces, solar cooking, solar electric power generation, solar thermal power production and solar green houses.

I.5.Photovoltaic energy:

A 0.6% of solar energy depends on the photovoltaic effect which consists of the emission of electrons by a material subjected to light clouds .This generated electricity (energy) can then be stored in batteries or converted using an inverter to distribute in the electrical grid. This makes it possible to create a direct electric current from electromagnetic radiation. Through the use of photovoltaic panels, these solar panels consist of photovoltaic cells made primarily silicon. Since the sunem its this type of radiation; this resource has the advantage of being inexhaustible and usable at any time in an area (at least for the next 4.6 billion years...)

I.6.Historical Development:

Some important at esinhi story less to power it sun ion of photovoltaic:

- **1839:** French physicist Edmond Becquerel discovers the process of the realization of sunshine to produce electric current in a solid material this is the effect photovoltaic. [9].
- **1883:** that the Becquerel's discovery was used by the American Charles Fritts to produce the first photovoltaic cell
- **1875:** warmer von Siemens exhibits an article before the Academy of science in Berlin on the photovoltaic effect in semiconductors. But until the Second World War worldwide, the phenomenon still remains a laboratory curiosity.
- **1945:** There American researchers, Chapin , Pearson and prince, develop acellhigh - efficiency up photovoltaic as then ascent space in dusty seeks new solutions to power its satellites .
- **1958:** A cell with an efficiency of 9 is developed. The first satellites powered by solar cells are sent into space.
- **1973:** The first house powered by photovoltaic cells is built University of law are [9].
- **1983:** The first car powered by photovoltaic energy travels a distance of 4000 km in.
- **1990:** Advances in photovoltaic cell production techniques and increase production volumes have led to a prices. Modules are produced in China (nearly 60% of production total), in Japan, in the USA, in Germany and in Europe [15].
- **2013:** The production world of PV modules has grown to more than 18GWp.
- **2016:** energy solar photovoltaic represented 1.6% of world production and produced 375 TWh against 246 TWh in 2015.
- **2017:** production reached 500 TWh. Its renewable aspect is a significant attraction.
- **2050:** The International Energy Agency predicts that the solar photovoltaic energy produced will reach 16% of global electricity production [16].

I.7.Solar radiation:

Irradiance is a combination of direct and diffuse radiation and will depend on the albedo (reflected solar radiation) of that particular location. That proportion of solar radiation which is scattered, absorbed or re-emitted in the atmosphere is diffuse radiation. Understandably on a sunny day, this scattered diffuse radiation will contribute only to 10 per cent of visible light, but on a cloudy day there will be much more scattering of the solar radiation reaching the Earth's surface which means the amount of diffuse radiation will be much greater. Air mass will also affect the irradiance at a location

I.7.1.Direct radiation:

Direct radiation is received from sun rays travelling in as traight line from sun to the earth. [1]

I.7.2. Diffuse radiation:

Diffuse radiation does not have any fixed direction. When sun rays are scattered by particles present in the atmosphere, the scattered sun rays account for the diffuse radiation [1]

I.7.3.Reflected radiation:

Reflected radiation is the component of radiation which is reflected from surfaces other than air particles. [1]

I.7.4.Global radiation:

Global radiation is the sum of direct, diffuse and reflected radiation. Global radiation is measured with pyranometers, which are radiomet ersdesigned for measuring the total (global) irradiance on a plane surface. [1]

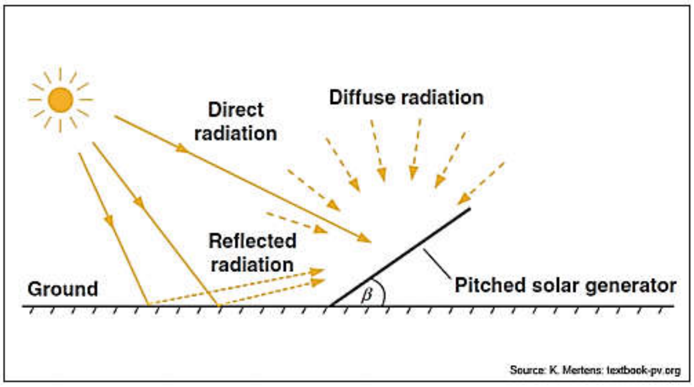


Figure I.3: Type of The Solar energy[1].

The solar spectrum is indeed composed of all kinds of energy radiations. and different colors, characterized by their wavelength range. Photons, grains of light that make up this electromagnetic radiation, are considered as carriers of energy, which is related to their wavelength by the following relationship [3]

$$E{=}h.v = \frac{h*c}{\lambda}$$

- E: photon energy
- h:Planck'sconstant = 6.626×10^{-34}Js
- V: photon fréquence

h**:** is Planck's constant. ***v*****:** the frequency.

c: the speed of light. **λ:** the length wave.

Namely that the shorter the wave length, the greater the energy of the photon. Note that the energy associated with this solar radiation breaks down approximately to:

TableI.2: Wave length distribution

Ultravioletband(UV)	**9%**	**0,20µm<λ<0.4µm**
Visibleband	47%	0.4µm<λ<0.8µm
Infraredband(IR)	44%	0.8µ<λ<10µm

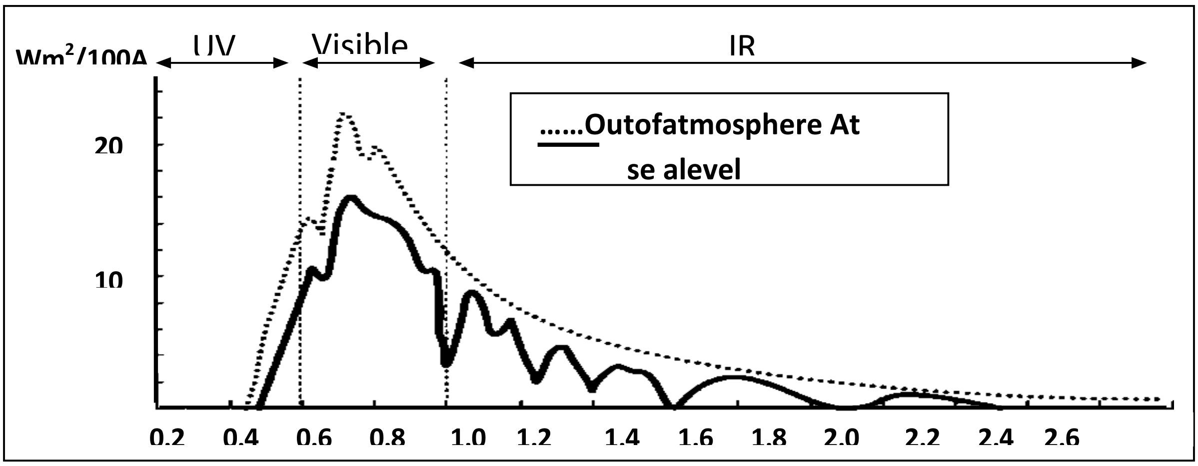


Figure I.4: Spectral distribution of solar radiation outside the atmosphere [7].

I.8.The Photovoltaic Effect:

The photovoltaic effect is a process by which light is converted into electricity. It was first experimented with in 1839 by Henri Becquerel when he submerged a platinum (Pt) foil coated with a thin layer of silver chloride in an electrolytic solution and then exposed the foil to light while it was connected to a counter electrode .

In PV technology, electrical power in direct current (DC), measured in watts (W) or kilowatts (kW),is generated from semiconductor materials when they receive photonsinalighting process Functionally, individual PV elements, primarily known as solar cells, include a p-n junction within a semiconductor material where light absorption has occurred. Solar cells never need recharging to produce electricity again, as is the case with a battery. Therefore, the production of electrical energy continues as long as light is projected onto a solar cell. Once the illumination is interrupted, electricity production also ceases.

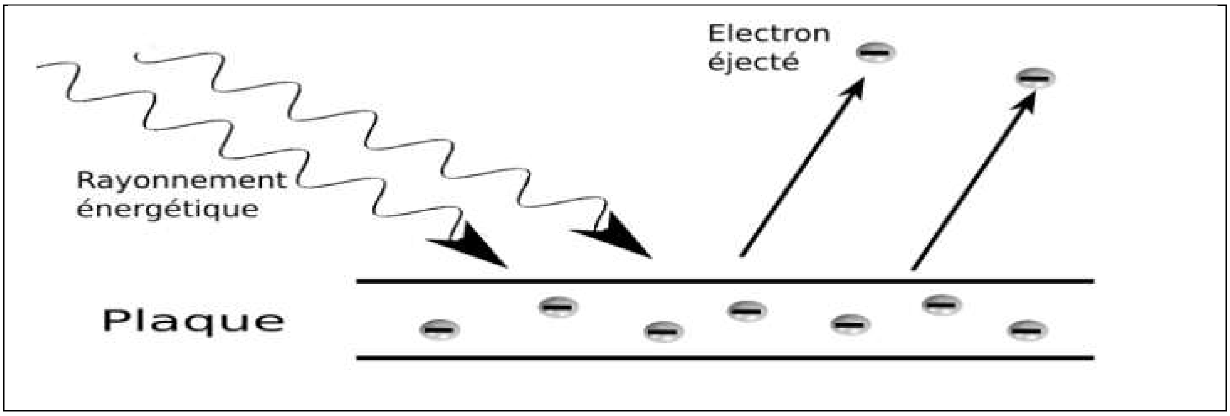


Figure I.5: Principle of the photoelectric effect.

I.9.Operation of a Photovoltaic Cell:

The penetration of "grains" of light (photons) into the silicon displaces some of the electrons from the material. A semiconductor material allows electrons to move in only one direction, and the electrons struck by light must pass outside a circuit to return to their original state, generating current

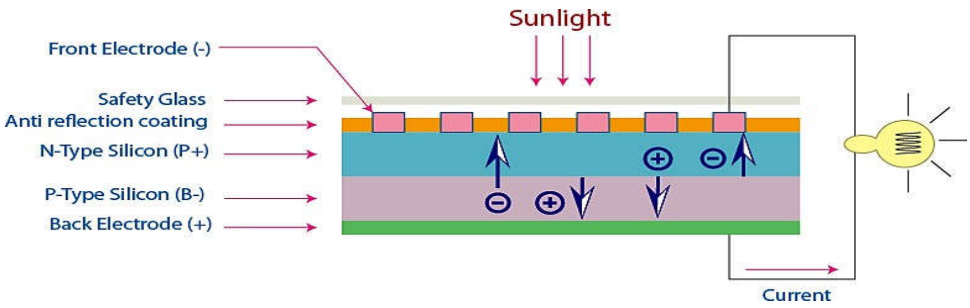


Figure I.6: Photovoltaic conversion.

I.10.General Principle of a Photovoltaic Cell:

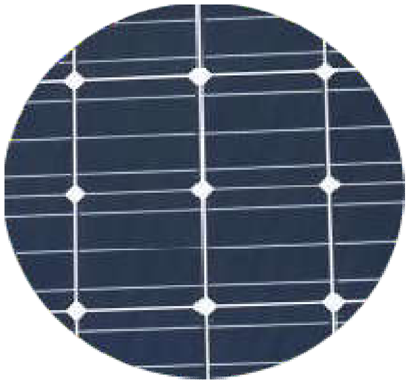
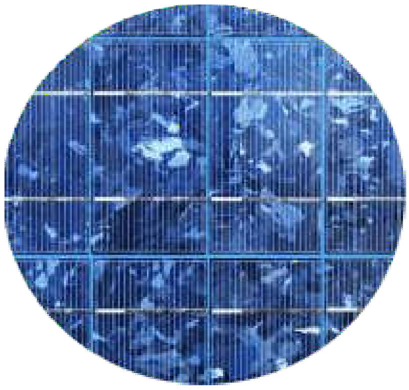
The operation of a photovoltaic cell is based on the properties of semiconductors, which, when struck by photons, set in motion a flow of electrons. Photons are elementary particles that carry solar energy at a speed of 300,000 km/s and were referred to by Albert Einstein in the 1920s as particles of light. When they strike a semiconductor element like silicon, they dislodge electrons from its atoms. These electrons move in a disorderly fashion, seeking other "holes" to reposition the mselves. However, for an electric current to flow, these electron movements must all go in the same direction To facilitate this, two types of silicon are combined. The side exposed to the sun is "doped" with phosphorus atoms that contain more electrons than silicon, while the other side is doped with boron atoms containing fewer electrons. This double-sided structure becomes a sort of stack: the side heavily laden with electrons becomes the negative terminal (N), and the side with fewer electrons becomes the positive terminal (P). A built-in electric field is created between them

When photons excite the electrons, they migrate to the N-zone thanks to the electric field, while the "holes" move toward the P-zone. They are collected by electrical contacts at the ends of the zones, entering the external circuit as electrical energy. A direct current is generated. An antireflective layer prevents too many photons from being lost by being reflected from the surface

I.11.Photovoltaic Cells Technologies:

The most important material for solar cells production is silicon. At the time being it is almost the only material used for solar cell mass production. As the most often used semiconductor material it has many important advantages. In nature it can be easily found in large quantities. Silicon oxide forms one thirty of the Earth's crust. It is not poisonous, and it is environment friendly, its waste does not represent any problem. Due production technology used solar cells can be divided into silicon solar cells, produced from Si wafers, and thin-film solar cells produced with vacuum technologies. According to the crystalline structure: amorphous, poly-crystalline and single-crystalline solar cells are distinguished, as shown in Table (I.1):

Table I : Classification of the Solar panels according to the crystalline structure.

• **Mono crystalline Solar Panels(Mono-SI):** This type of solar panels (made of mono crystalline silicon) is the purest one. You can easily recognize them from the uniform dark look and the rounded edges. The silicon's high purity causes this type of solar panel has one of the highest efficiency rates, with the newest ones reaching above 20% [7].	
• **Poly-crystalline Solar Panels(Poly-SI):** You can quickly identify these panels because this type of solar panels has squares, its angles are not cut, and it has a blue, speckled look. They are made by melting grew silicon, which is a faster and cheaper process than that used for monocrystalline panels. This leads to lower in alp rice but also lower efficiency (around 15%) . [7].	
• **Amorphas Stilicon Solar Cell (A-Si):** Then on-crystalline form of silicon used as semiconductor material for A-SI solar cells, or thin-film silicon solar cells. Amorphous silicon cells generally feature low efficiency (from 7 to 10%), but are one of the most environmentally friendly photovoltaic technologies, since they do not use any toxic heavy metals [8].	

I.12.PV Cell, Module or Panel and Array:

Numbers of PV cells are required to produce high power in solar power generation system so for higher power demand they are connected in series or in parallel for formation of Solar Module or Solar panel and also form Array.

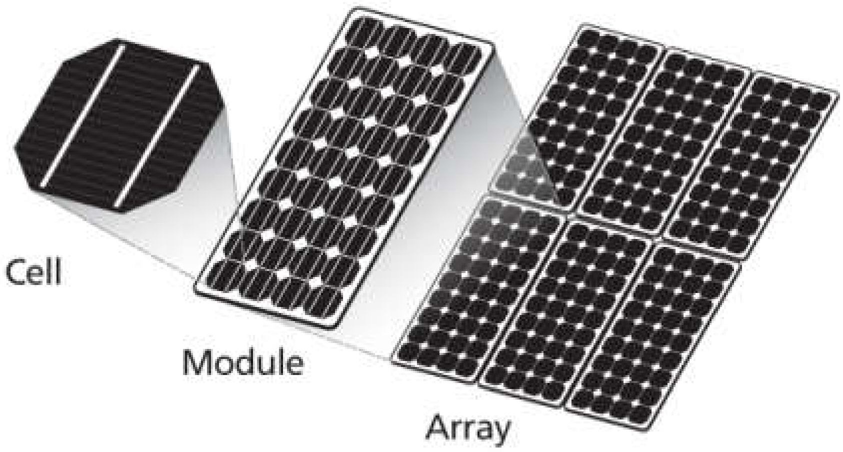


Figure I.7: PV cell, Module and Array [9]

A.PV Module:

A group of PV cells are in series connection to form solar panel or module. A photovoltaic module is a systematic arrangement of series connected PV cells. [9].

B.PV Array:

A group of solar panels or modules connected together electrically in series and parallel structure to form solar array and this solar array is responsible to produce higher amount of power [9].

I.12.1.Electrical configuration of modules:

A single normal solar cell is meant to give an amount of power of about 1 Wp in Standard Test Conditions(STC; *AM*1.5, T=25 ºC, 1000 W/m2). When arranged in series on a module, normally 60 to 72 cells are used [14].If modules are connected in series, a solar panel or string is created. Otherwise, when several strings are connected in parallel they form a solar array (Fig.4).

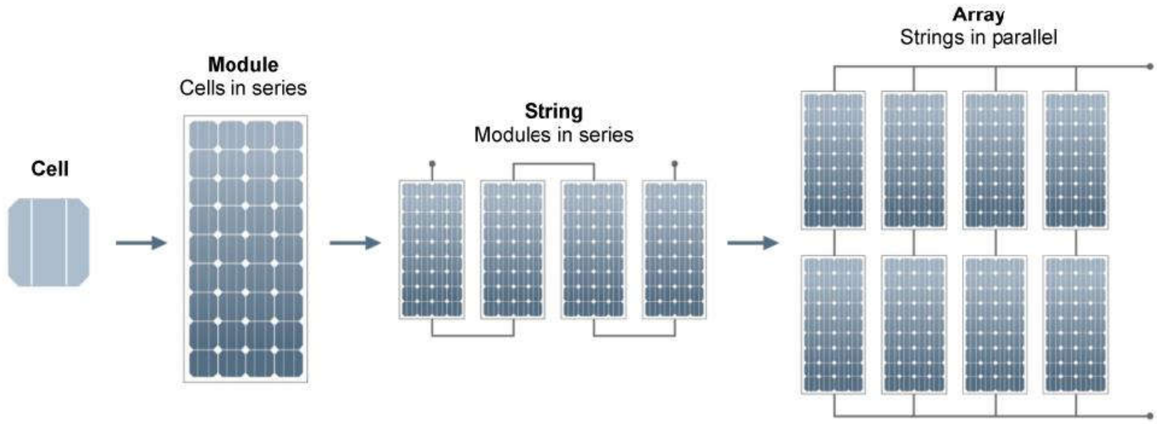


Figure I.8: Electrical configurations of solar cells [8].

Under uniform operating conditions, that is, with identical cells and subject to the same irradiance and temperature values so that there are no mismatch effects, differences between these two types of arrangement can be spotted. When stringing in series each individual module works with the same current as the others, but adds to the total voltage of the string. However, the main drawback would be that when a module is shadowed, the entire string's current is reduced to that of the module with the lowest current. [6].

Nonetheless, when creating arrays by connecting panels in parallel, the voltage for each panel remains the same, while the amperage increases with each additional panel. When a panel is shadowed, the rest of the array continues with the normal operation without reductions (Fig. 5). This will be further explained in the following sections.

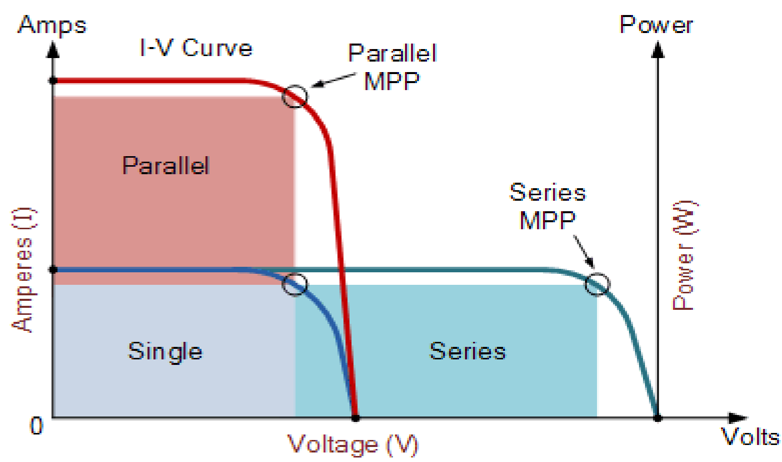


Figure I.9: Comparison of the I-V curves depending on the electrical configuration of the modules [8].

I.13 Effects of temperature and irradiance:

Characteristic curves are measured under STC, but the truth is that under different conditions and depending on environmental changes, the curves may vary notoriously [14]. As solar irradiance impacting a PV cell increases, so does proportionally its short-circuit current, whilst the open-circuit voltage rises as well following a logarithmic function, as seen in its formula. Thus, total power and the maximum power point obviously increase. On the other side, a detrimental effect to the performance of a solar cell has been shown when it is heated. With the rise of temperature the band gap energy of the p-n junction is reduced, so bonding is weaker and more photons are able to create pairs. While it is true that short circuit current may remain approximately the same, or even increase its value, the open circuit voltage decreases dramatically, and therefore so does the total power

I.13.1. Mismatch effects:

Sometimes in a structure of interconnected modules it happens to appear losses and malfunctions due to cells or modules behaving differently from one another under different conditions. For example, the cells or modules can be shadowed by trees, clouds, dust, etc… Whenever the electrical parameters of a cell or module are altered in relation to those of other cells or modules, mismatch losses appear. The semismatch effects cause, in the majority of cases, the module or panel to work with the lowest output in the series, as explained before. Additionally, this can lead to highly localized energy dissipation, resulting in local heating that may cause irreversible damage to the devices [14].The impact the effects may have depend on the type of device (hence their parameters), the electrical configuration and their operating point. Short-circuit current or open-circuit voltage, commonly causes the most usual mismatches, although others can happen.

I.13.2. Hotspots:

Hotspot heating appears as a result of the generation of low current by a single solar cell (maybe due to shading) in a series connection (Fig. 8). When this occurs, the operating current of the entire string starts lowering down to the short-circuit current of the shaded cell, and then the overall current suffersa limitation [14]. Despite that, the extra current produced by the normal operating cells follows a forward bias through them, but when the string is short circuited, this forward bias can cause a reverse bias due to a higher voltage production of the properly working cells on the shaded one. Therefore, the whole capacity of power generation the string has dissipates on that bad cell. This huge dissipation in a local spot heats the cell, leading to great and destructive damage, such as glass cracking, circuit paths soldering, cell degradation or melting, and reduction of the cell's lifetime

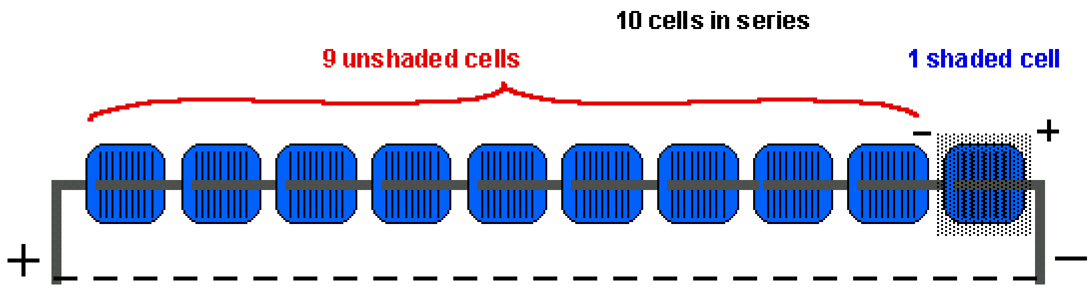


Figure I.10: Scheme of a shaded cell on a series, cause of a hotspot [21]

The output power production of a cell is proportional to the irradiance they receive. When shading of a cell occurs, this output declines proportionally to the amount of shading. As explained before, hotspots and other defects can appear due to shading [14], when a cell starts acting as a resistive load. Thus, it is important to protect the system from these kind of destructive effects by placing diodes in the circuit that block the current flowing through the shaded devices. When modules are connected in series, by-pass diodes are installed in parallel, so in case one of the modules is shaded and working as are resistive load, the current can pass through the diode and not through the module. If the modules are put in a parallel configuration, like arrays, and one of them is shaded, the Kirchhoff Laws are contradicted, as all the modules should have the same voltage. In this case, the shaded module works as a resistive load at a voltage imposed by the other units in an unstable configuration. In this situation, blocking diodes installed in series with the devices are needed, so they can isolate the shaded branches (Fig. 9).

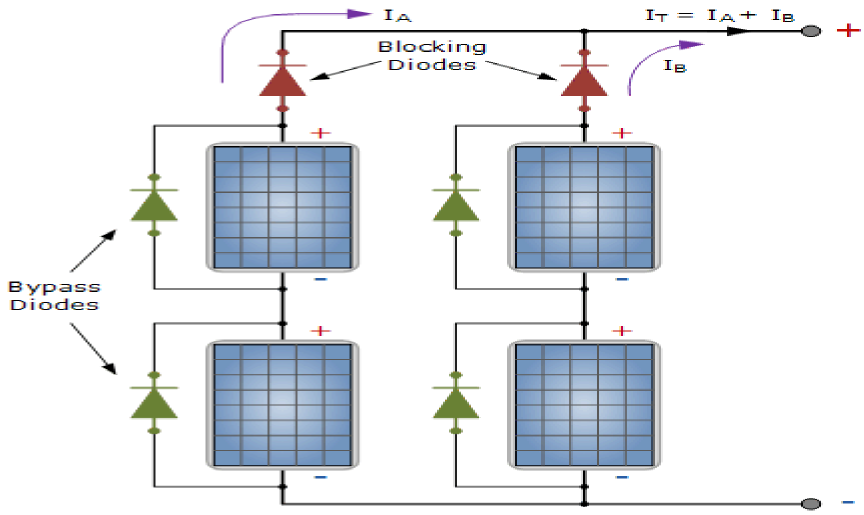


Figure I.11: Diodes configuration in panels connected in series and parallel [21]

I.14. Photovoltaic system types:

Photovoltaic systems can be generally divided into two basic groups:

1. Photovoltaic systems not connected to the network, stand-alone systems (off-grid)
2. Photovoltaic systems connected to public electricity network (on-grid)

I.14.1. Grid-connected systems:

Nowadays, it is usual practice to connect PV systems to the local electricity grid. This mean that, during the day, the electricity generated by the PV system can either be used immediately (which is normal for systems installed in offices, other commercial buildings, and industrial applications) or be sold to one of the electricity supply companies (which is more common for domestic systems, where the occupier may be out during the day). In the evening, when the solar system is unable to provide the electricity required, power can be bought back from the grid. [19].

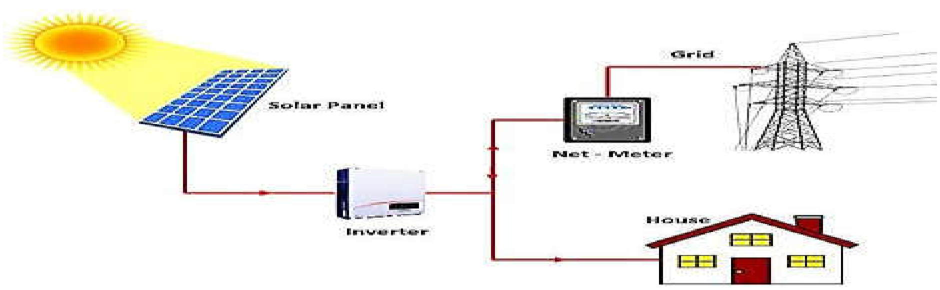


Figure I.12: Grid-connected systems. [19].

I.14.2. hybrid system:

In a hybrid system another source of energy, such as wind, biomass or diesel, can be hybridized to the solar PV system to provide the required power. Here the objective is to bring more reliability into the overall system at an affordable way by adding one or more energy source(s)

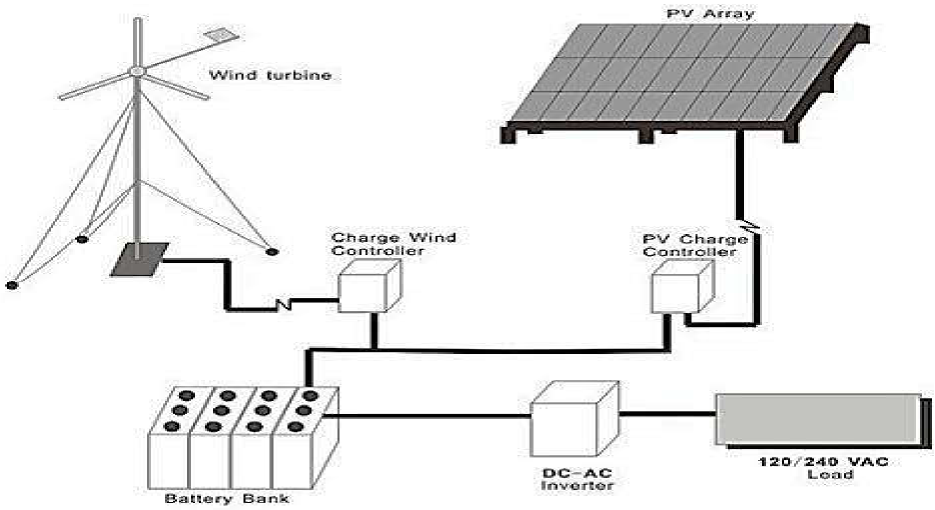


Figure I.13: Hybrid system (Solar and wind). [19].

I.15. Types of inverters:

Inverters can be classified by their structure into two principal forms: a **Single-phase** and **Three-phase** inverter.

But, inverters are also classified based on the type of input source into two broad types: **voltage source inverter** (VSI) and **current source inverter** (CSI).

I.15.1. Z-source inverter topologies:

Ever since the evolution of Z source inverter, it has been an area of wide research especially due to its application in power generation based on various renewable energy sources. Many improvements are made in the basic topology of ZSI to arrive at numerous topologies, some of them are:

A. Bidirectional-Z source inverter: A bidirectional ZSI is formed by replacing of input diode D with bidirectional switch S1 from the traditional version of ZSI

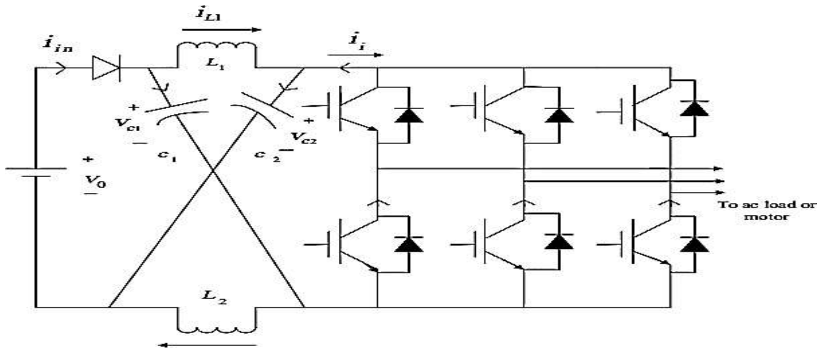


Figure I.14: Bidirectional-Z source inverter. [10].

B. Trans-Z-source inverter: Trans-Z-source neutral clamped inverter is developed by using a transformer and a capacitor to constitute the Z network. [10].

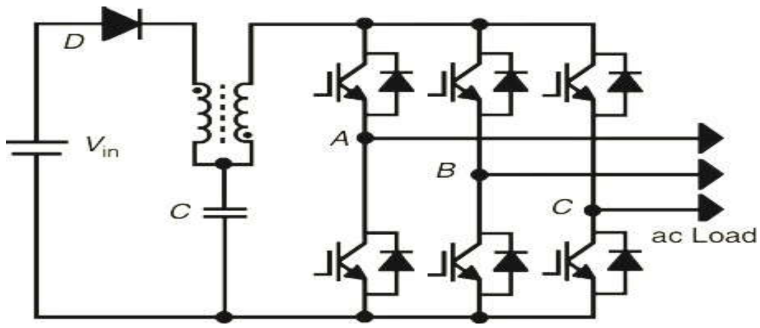


Figure I.15: The transformer-based ZSI topology.

C. **Quasi-Z-source inverter:** this type is developed by just adding inductors, capacitors and diodes to the traditional topology to form switched inductor type, two stage network type

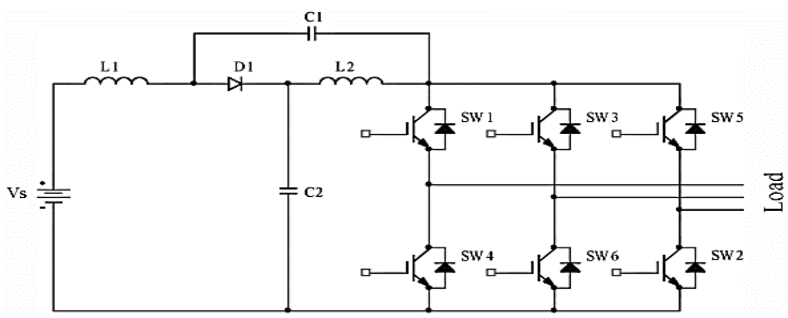


Figure I.16: Quasi Z-source inverter. [10].

I.16. Conclusion:

Photovoltaic panels are of great importance in the production of power in the world, in this chapter, we have presented a state of the art on photovoltaic systems and the z-source inverter. We started with a definition of renewable energies Thus, photovoltaic energy in details; we presented solar radiation and their different components. Next, we introduced photovoltaic cell and their historical development also their technologies, as well as photovoltaic systems and their various types. Finally, we presented general information about the z-source inverter.

Chapter II:

Modeling of PV system and MPPT Control

II.1.Introduction:

In this chapter, we delve into the pursuit of the Maximum Power Point Tracker (MPPT), a pivotal component in solar energy systems. It plays a crucial role in harnessing energy generated by solar cells and regulating DC power output according to the system's voltage requirements.

The MPPT operates as a DC/DC converter, modulating current flow in pulses, similar to PWM, but with the advantage of optimizing energy utilization from the solar cells by reducing voltage while increasing current.

II.2.The Photovoltaic Generator (PVG):

The photovoltaic system is controlled by the MPPT control, as shown in Figure (II.1).

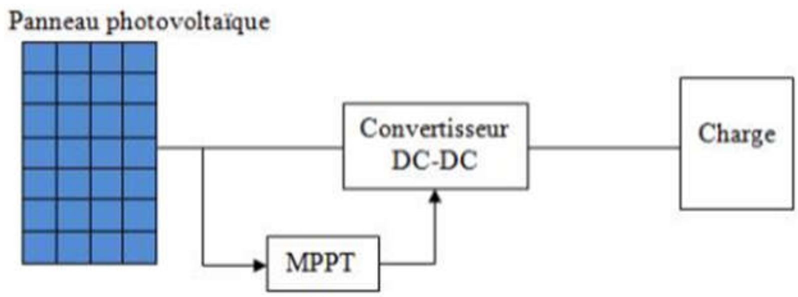


Figure II.1: Photovoltaic system.

II.3.Modelisation of a PV Cell:

To accurately predict the power output of solar modules and plot the current-voltage (I-V) characteristics, it is essential to create a model of the solar cell. One commonly used model is the single-diode model, as shown in Figure (II.2). This model consists of a photo-current source (I_{ph}), a diode, a series resistor (R_s), and a shunt resistor (R_{sh}). In an ideal scenario, the series resistor would have zero resistance (R_s=0), and the shunt resistor would have infinite resistance (R_{sh}=∞).

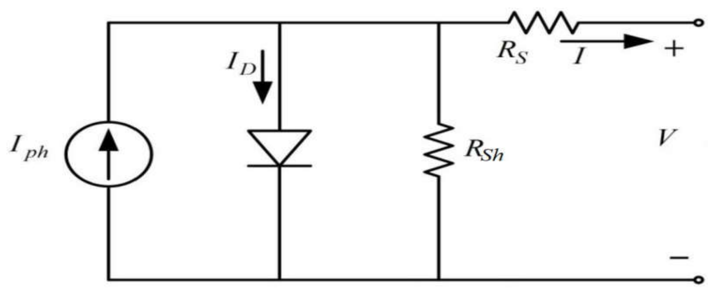


Figure II.2: Model of a PV cell

II.3.1.Ideal Photovoltaic Cell:

The basic equation that mathematically describes the I-V characteristic of the ideal photovoltaic cell is:

$$I = I_{ph} - I_d \tag{1.1}$$

$$I_d = I_{0,cell}\left[exp\left(\frac{qV}{\alpha KT}\right) - 1\right] \tag{1.2}$$

by replacing (1.2) in (1.1) we get:

$$I = I_{ph} - I_d\left[exp\left(\frac{qV}{\alpha KT}\right) - 1\right] \tag{1.3}$$

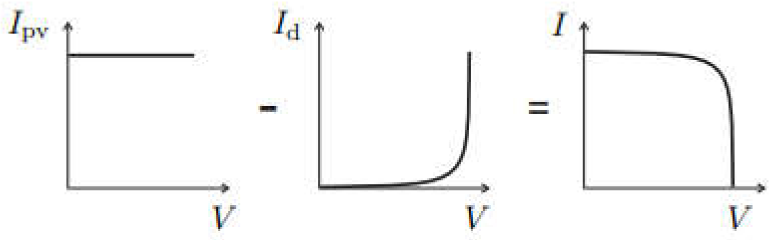


Figure II.3: The characteristic I-V of an ideal photovoltaic cell

II.3.2.Modeling of Photovoltaic Array:

The I-V characteristic equation (1.3) of a single photovoltaic cell does not accurately depict the behavior of a real-world photovoltaic array composed of multiple interconnected cells. To properly analyze the characteristics of the photovoltaic array, additional parameters must be added to the basic equation (1.3) as in [5]

$$I = I_{ph} - I_d\left[exp\left(\frac{V+IRs}{\alpha Vt}\right) - 1\right] - \frac{V+IRs}{Rsh} \tag{1.4}$$

where:

I: is the output current
*I*ph: is the light generated current (it's directly proportional to the Sun irradiation) in (A),
*I*0: is the reverse saturation or leakage current of the diode in (A),
V: is the output voltage,
*R*s: is the series resistance,
*R*sh: is the shunt resistance,
a: is the ideality factor
Vt: is the thermal voltage, with:

If the array is composed of *Np* parallel connections of cells the photovoltaic and saturation currents can be expressed as: $I_{pv} = I_{pv,cell}\,Np$, $I_0 = I_{0,cell}\,Np$.

$$V_t = \frac{NsKT}{q}$$

II.4.Characterization of the PV module:

In this study, we simulated the KC200GT photovoltaic module, which consists of 54 monocrystalline silicon solar cells measuring 125.125mm connected in series.

The module can produce a maximum power of 200 watts at 32 volts. This allowed us to determine the power as a function of voltage and the current as a function of the voltage of the module studied for an irradiance of 1000 W/m2.

The electrical characteristics of the KC200GT Photovoltaic module under standard test conditions are shown in Table (2.1).

Table (2.1): Electrical characteristics of the PV module KC200GT under standard test conditions.

Total number of cells in series (N_s)	54
Rated power(W)	200.143 W
Short-circuit current(I_{sc})	8.21 A
Open circuit voltage(V_{oc})	32.9 V
Current at Maximum power (I_{mp})	7.61 A
Voltage at Maximum power (V_{mp})	26.3 V

II.5. Simulation of the PV module:

Based on the mathematical model of the solar cell developed in the MATLAB /SimPower Syste tool, the SIMULINK schematic block is shown in Figure (II.4),

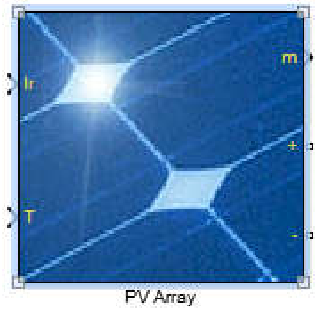


Figure II.4: Block diagram of the solar module in SIMULINK.

The characteristic (Ipv = f(Vpv)): At constant temperature and solar radiance, particularly under standard test conditions (STC) (E = 1000 W/m2, T = 25°C). Given by the following figure.

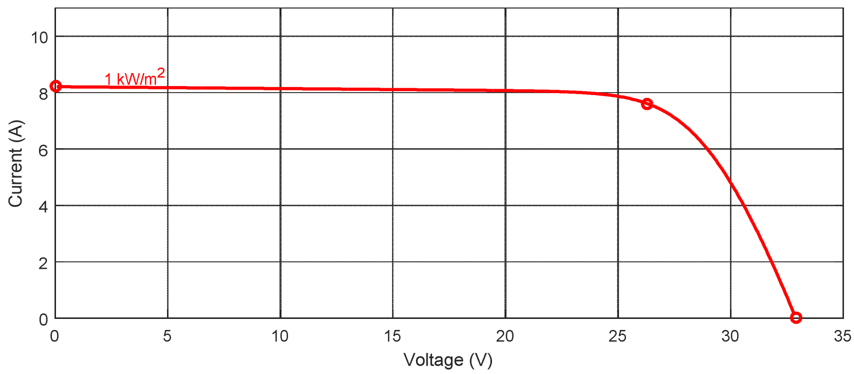


Figure II.5: Simulation results of the characteristics of the KC200GT module.

The characteristic (Ppv = f(Vpv)): At constant temperature and irradiance, particularly at standard test conditions (STC) (E = 1000 W/m2, T = 25°C), given by Figure (II.3),

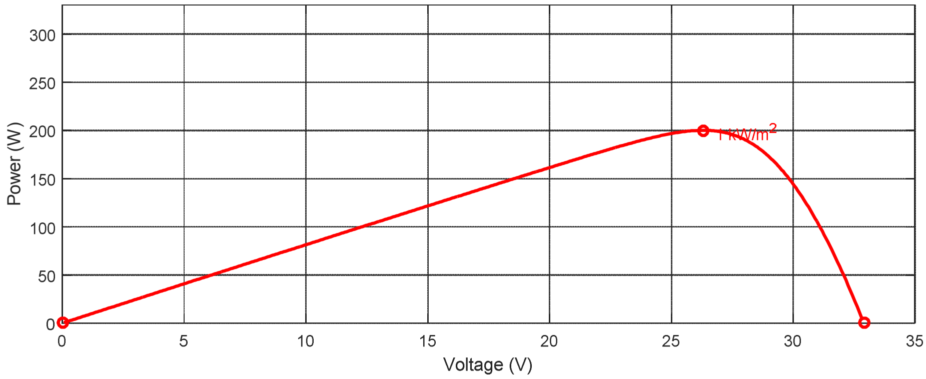


Figure II.6: Simulation results of the characteristics (power-voltage) of the PV generator.

To increase the output power, PV modules are connected together in the panel. In this structure, modules can be connected in series, in parallel, or both, in our case (NS=3, NP=2).

To visualize the influence of irradiance, we fix the temperature (T = 25°C) and vary the irradiance over a sufficient range.

According to Figure (II.7), we notice a significant decrease in the short-circuit current relative to the irradiance (E) and a minor decrease in the open-circuit voltage.

This demonstrates that the short-circuit current of the cell depends on the irradiance, whereas the open-circuit voltage undergoes a slight increase as the irradiance varies from 200 W/m² to 1000 W/m².

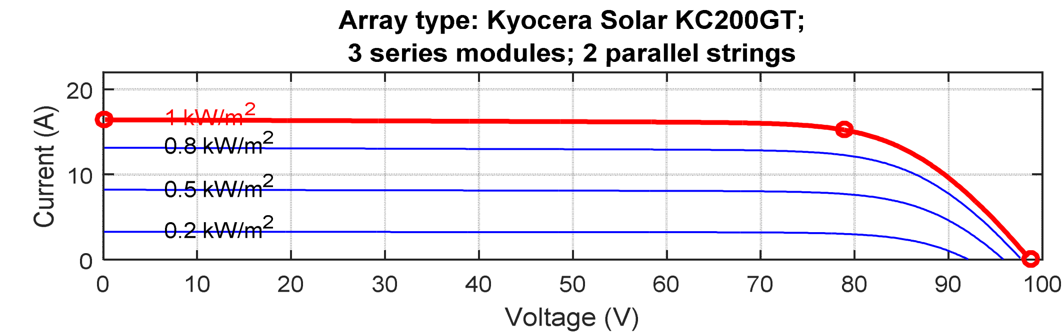


Figure II.7: Simulation results of the Current-Voltage characteristics for various irradiance.

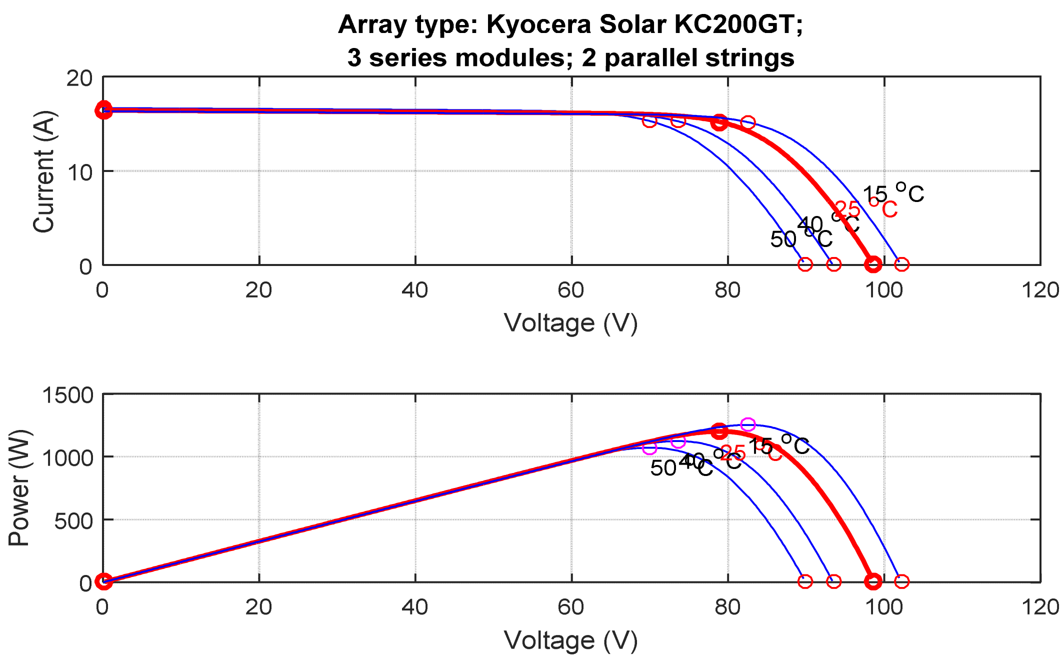


Figure II.8: Simulation results of the Current-Voltage characteristics for various temperatures and an irradiance of E=1000 W/m2.

According to Figure (II.8), we observe that the increase in temperature leads to a decrease in the open-circuit voltage of the PV generator, unlike the short-circuit current, which remains constant.

We also notice from Figure (II.8) that irradiance proportionally influences the power and open-circuit voltage of the PV generator.

The chosen model has yielded results consistent with those obtained in the literature and accurately reflects the physical behavior of a PV cell in response to variations in temperature and irradiance, validating the model used.

II.6.Boost converter:

Boost converter also called as high efficiency step-up converter or parallel chopper, which has an output DC voltage greater than its input DC voltage. It consists of two semiconductor switches and one storage element. Figure (II.9) shows the circuit diagram of a boost converter. It consists of an inductor, an MOSFET switch, a fast switching diode and a capacitor.

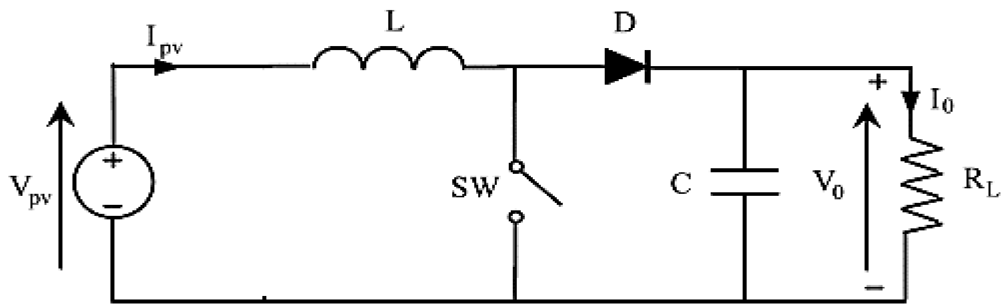


Figure II.9: Circuit diagram of a Boost converter

To demonstrate the role of boost converters, we used Matlab software for the simulation and we take (E=100V, L= 1e-3 H, R=200, D = variable).

Table II.1: Parameters of the DC-DC boost converter.

C1	C2	L
4700e-6	1200e-6	4e-4

Figure (II.10) shown is a SIMULINK implementation of DC/DC Boost converter

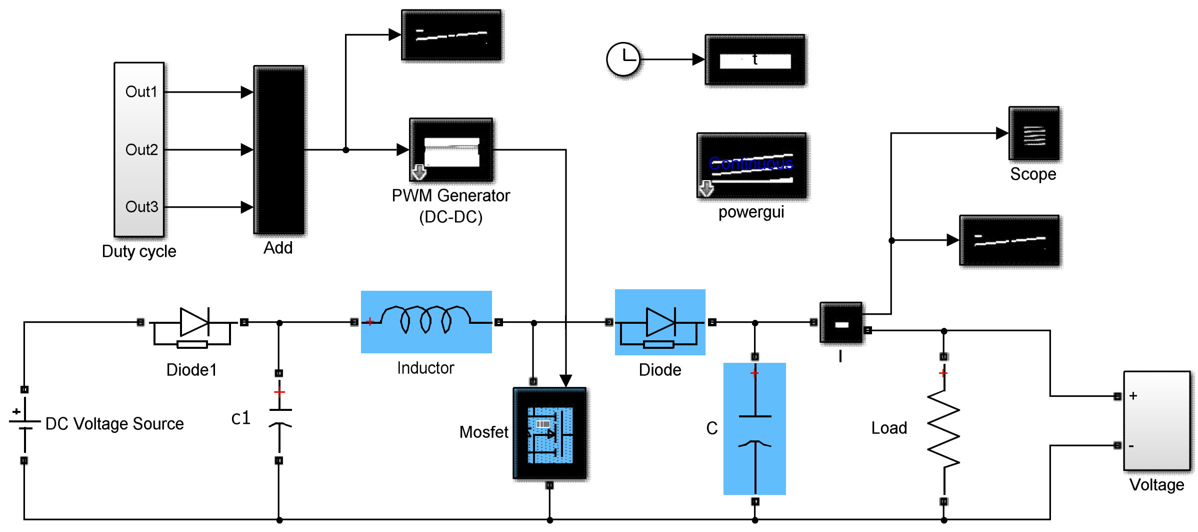


Figure II.10: Block diagram of a Boost converter

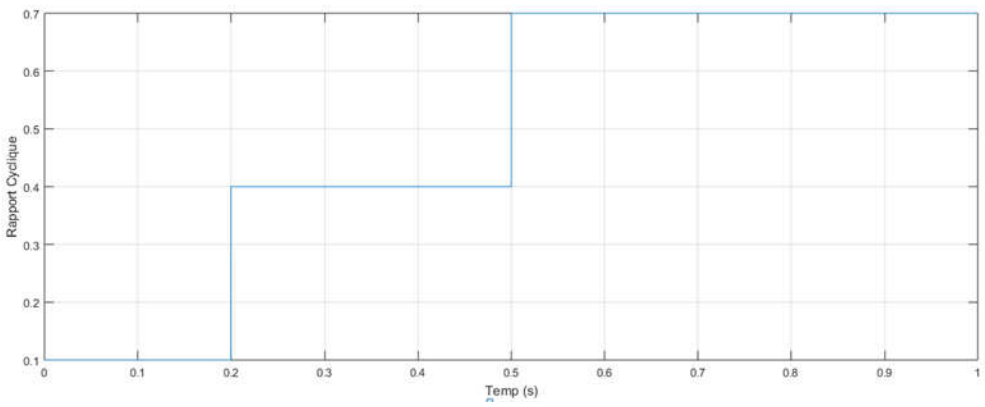


Figure II.11: Duty cycle of a DC-DC converter

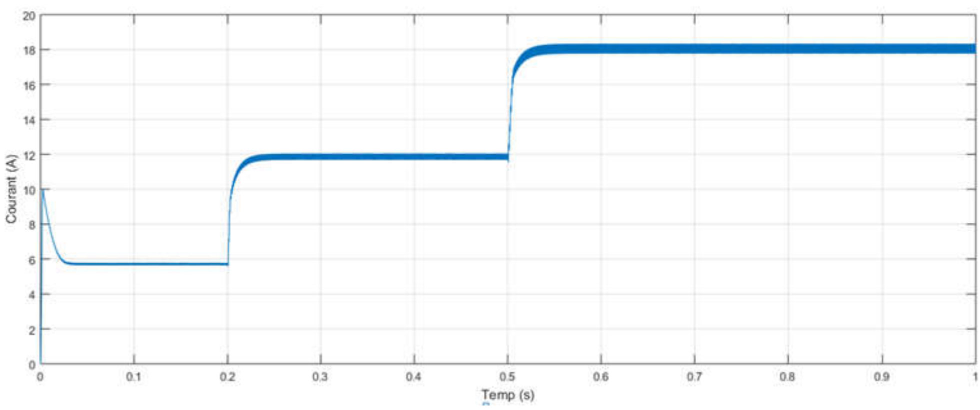


Figure II.12: Output current of a DC-DC converter

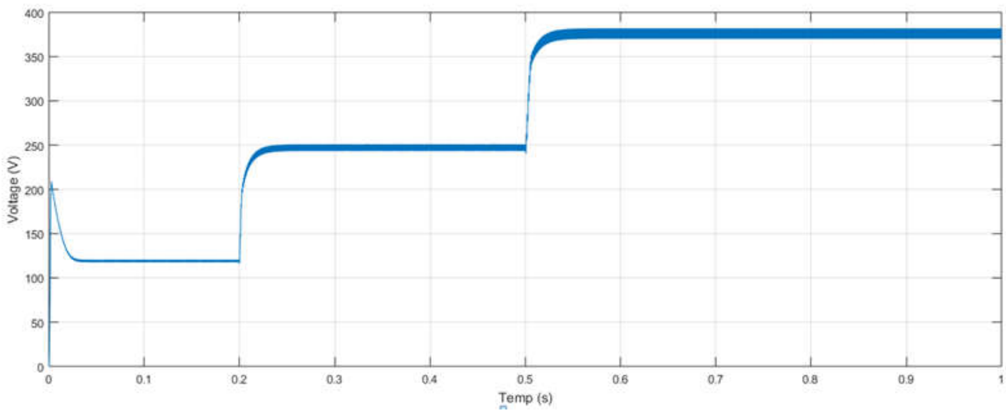


Figure II.13: Output voltage of a DC-DC converter.

The figures (II.12) and (II.13) represent simulation results of boost converters through a parametric variation of the duty cycle, as shown in Figure (II.11)

Where one notices as light oscillation at takeoff of about 0.01 seconds before returning to its value and settling at a certain value. It also demonstrates the direct relationship between changes in the duty cycle, as its increase is accompanied by an increase in the level of current and output voltage.

So the results of the boost converter performed correctly without failure since the output voltage of the boost converter is higher than its input voltage.

II.7.Pursuit of the Maximum Power Point Tracker (MPPT) :

The maximum power of solar panels corresponds to a single operating point called the maximum power point (MPP). This point depends mainly on the irradiance, the temperature and the variations of the load which are variable with time. The output voltage and current of the photovoltaic modules results in the maximum power output. In most photovoltaic power systems, a particular control algorithm, namely, maximum power point tracking (MPPT) is utilized to take full advantage of the available solar energy. The operation of maximum power point tracking is to adjust the power interfaces so that the operating characteristics of the load and the photovoltaic array match to ensure the transfer of the maximum power.

II.8.Perturb and Observe Approach :

The principle of Perturb and Observe (P&O) type MPPT control is to perturb the PV voltage VPV with a low amplitude around its initial value and analyze the behavior of the resulting power variation PPV. As illustrated in Figure (II.14), one can deduce that if a positive increment in voltage VPV results in an increase in power PPV, it means the operating point is to the left of the MPP. Conversely, if the power decreases, it implies that the system has exceeded the MPP. Similar reasoning can be applied when the voltage decreases. Based on these analyses of the consequences of voltage variation on the PPV (VPV) characteristic, it is then easy to position the operating point relative to the MPP and converge it towards maximum power through an appropriate control command.

In summary, if, following a voltage disturbance, the PV power increases, the perturbation direction is maintained. Otherwise, it is reversed to regain convergence to wards the new MPP

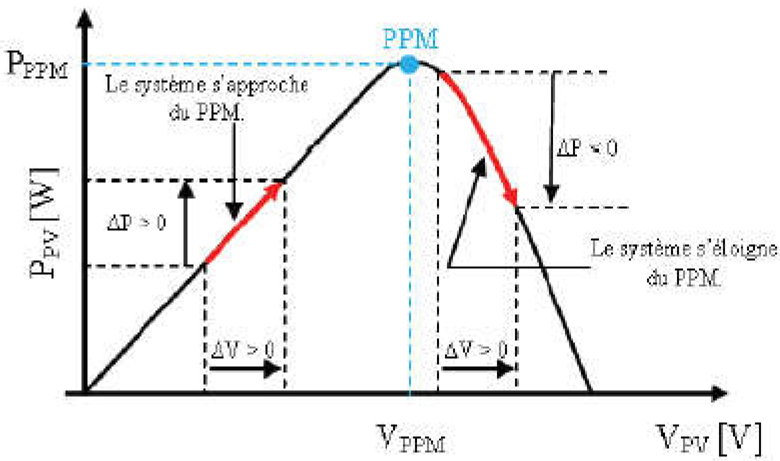


Figure II.14: PPV Characteristic and Operation of the Perturb and Observe Method

Figure (II.15), represents the classic algorithm associated with P&O type MPPT control, where power evolution 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 PV power at each instant.

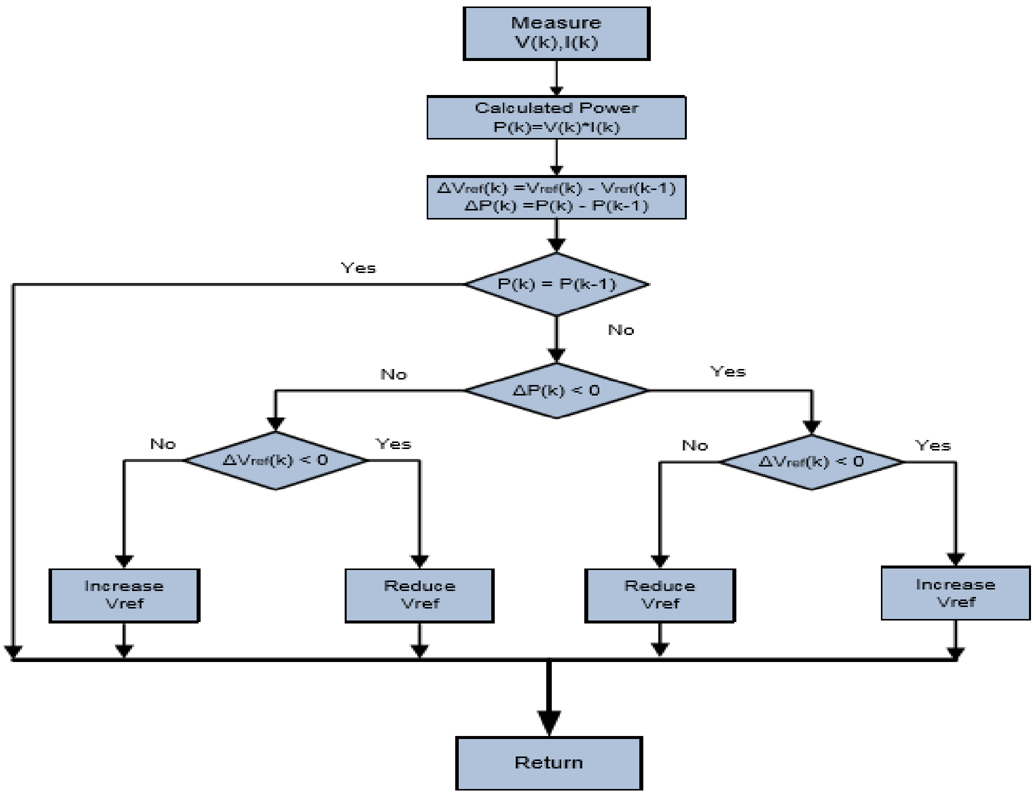


Figure II.15: Flowchart of the Perturb and Observe Method [20]

II.9.Simulation of the "P&O" MPPT Control:

The system was tested using MATLAB / Simulink:

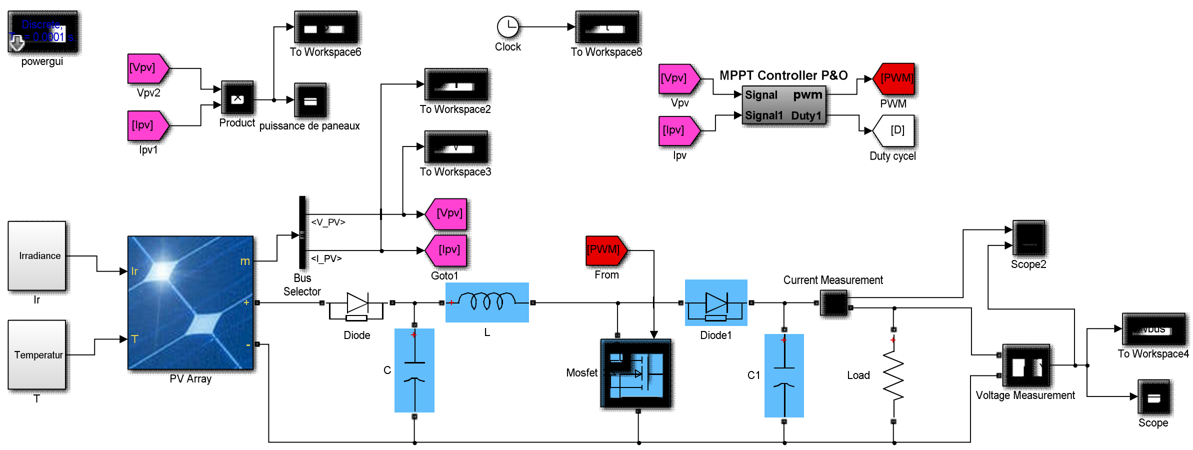


Figure II .16: Scheme SIMULINK of the system Photovoltaic with MPPT

II.10.Simulation Results:

The following figures represent simulation results of the PV panel with MPPT for different irradiance [1000w/m2;800w/m2;600w/m2] and T=25°C:

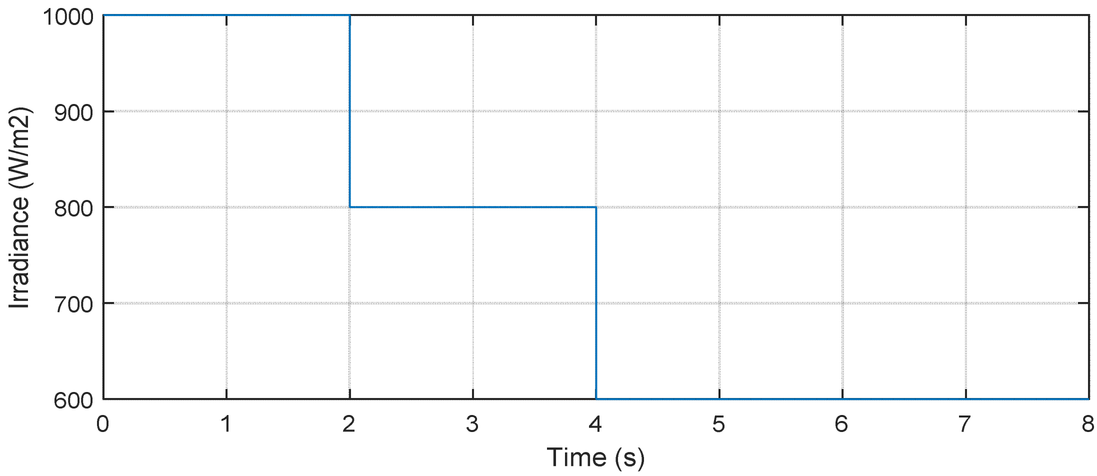


Figure II.17: irradiance profile over time

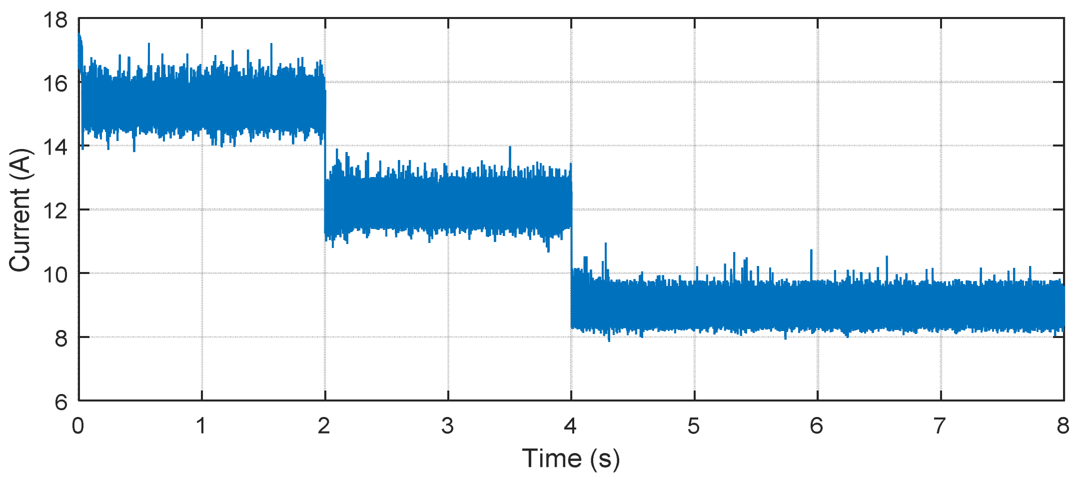


Figure II.18: Output current profile over time

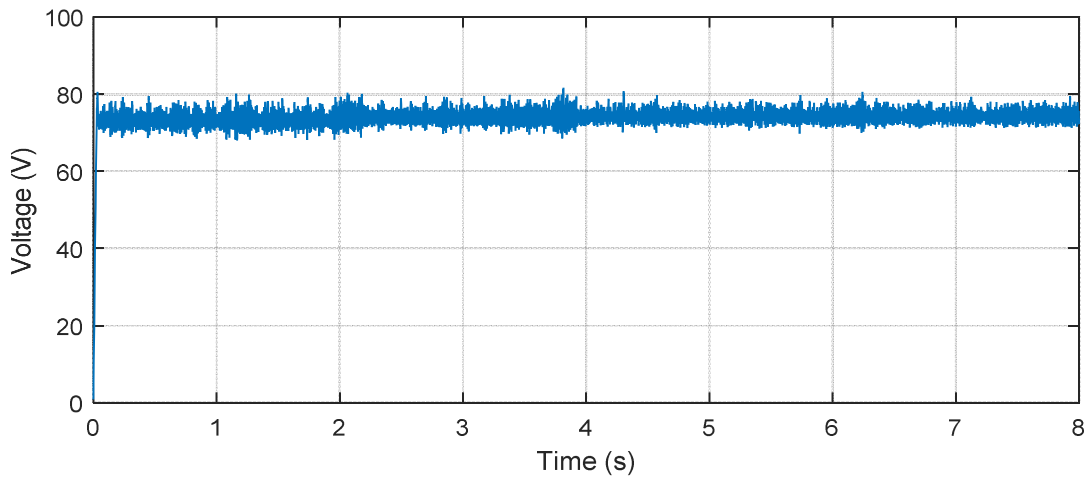


Figure II.19: Output voltage profile over time

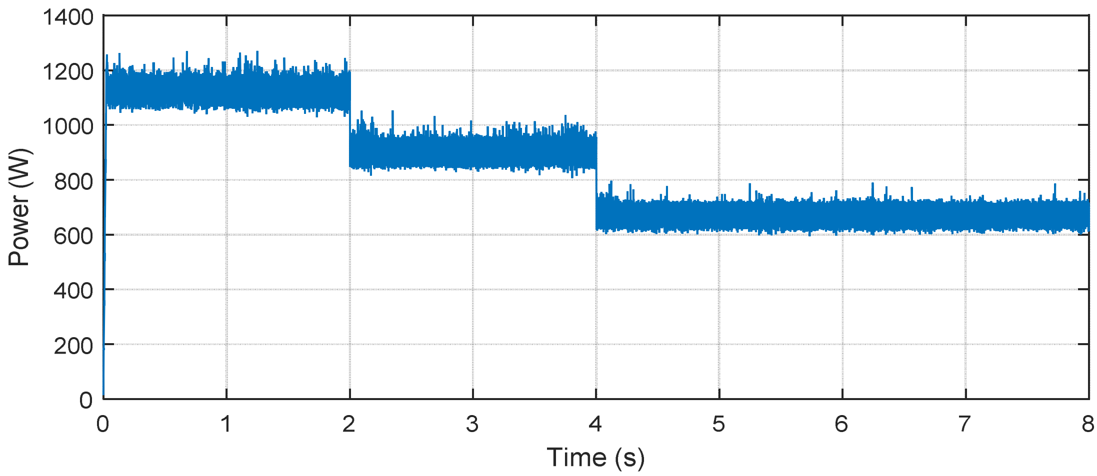


Figure II.20: Power profile over time

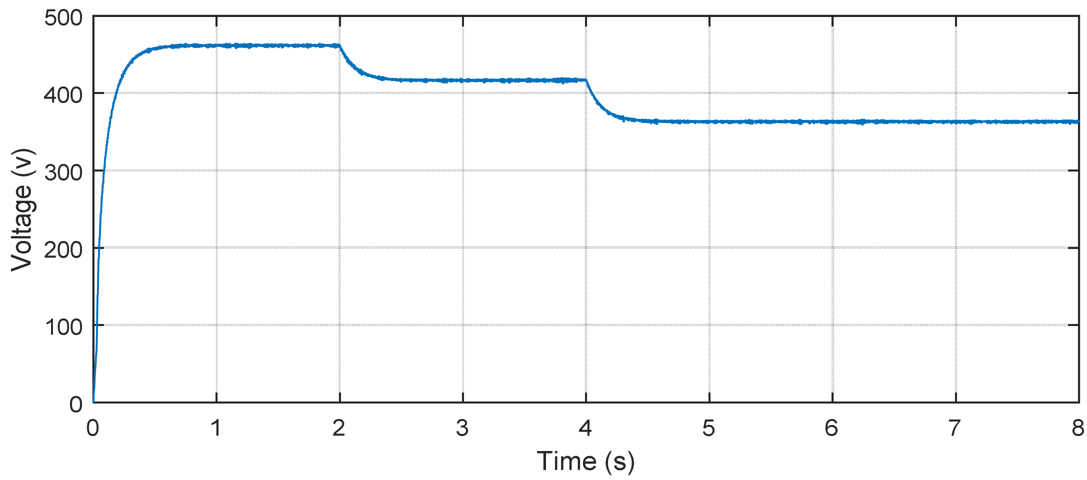


Figure II.21: Bus voltage profile over time

Simulation results under changing atmospheric conditions.

Figure (II.20), shows the perfect MPPT in the presence of radiation step changes mean while, the temperature is kept constant, The figure shows that the PV power captured varies between (12 - 6 kW) and These values correspond to maximum points.

II.11.Conclusion:

This chapter studies the P&O MPPT algorithm with a DC-DC boost converter. The mathematical modeling of PV array is discussed with MPPT algorithm. The P-V and V-I curves obtained from the simulation of the PV array designed in MATLAB environment explains its dependence on the temperature and irradiation levels. Thus, the Photovoltaic system works most of time with maximum efficiency and stabilization around the MPP point during sudden changes in solar irradiation and ambient temperature.

Chapter III:

Grid connected three-level quasi-Z-source inverter

III.1. Introduction:

PV systems connected to the grid have an important role in distributed generation systems. In order to keep up with the current trends regarding the increase in PV installations, PV inverter should have the following characteristics: Low cost, small weight and size, due to residential installations, high reliability to match with that of PV panels, high efficiency and be safe for human interaction.

This chapter highlights the System Description and Modelling of the Photovoltaic System connected to the grid with q-Z-source inverter, with a controller for the maximum power point, which is used to track the MPP of the PV.

III.2. Grid-connected system:

The grid-connected systems figure (II.3), proposed in this study, meaning the system connected in parallel to the public electrical grid, are designed to inject the electrical energy produced by the PV fields into the grid. In grid-connected systems, standard power consumers are connected to the generator via an inverter (DC-AC converter). The inverter is the most important part of any grid connected system. The inverter extracts as much DC (direct current) electricity as possible from the PV array and converts it into clean mains AC (alternating current) electricity at the right voltage and frequency for feeding into the grid or for supplying domestic loads.

In grid-connected systems, it is the inverter that replaces the batteries; in this case, it is the basic component in these types of systems.

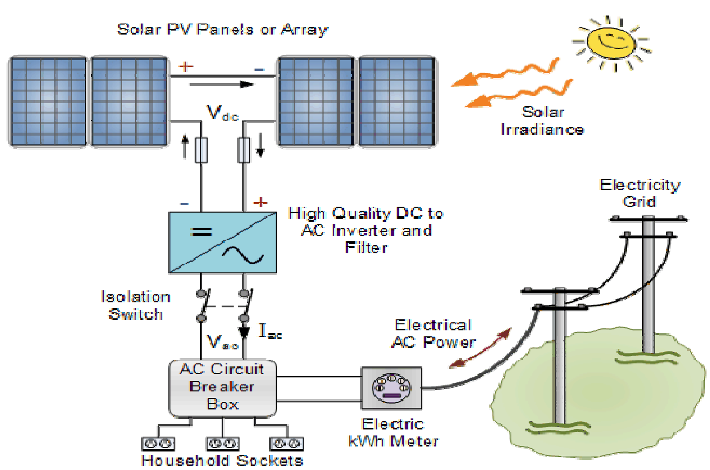


Figure III.1: Diagram of a grid-connected system.

III.3. Advantages and disadvantages of grid-connected systems:

a-Advantages:

• Grid-connected systems do not require energy storage and thus eliminate the most problematic (and costly) component of an autonomous setup. In fact, it is the network as a whole that serves as an energy reservoir.

• No waste - any surplus is delivered to the network..

•You don't have to meticulously calculate your electricity needs and anticipate exceptionally high demand levels, even if they are very rare..

• One can meet a portion or all of their needs.

b - Disadvantages :

• Grid-connected systems enable solar panels or photovoltaic modules to make a breakthrough in our lives; however,

• Consumption may become relatively "invisible" again, and we could fall back into the trap of thoughtless consumption.

• The electrical constraints imposed by electricity companies can be stringent, and synchronous inverters must meet the technical requirements of energy production and transmission companies.

• However, the most important aspect is the question of the price paid for kWh delivered to the grid... The current cost of PV technology is much higher than that of traditional energy. It is difficult to say how long it will take to reach a price level where the photovoltaic kWh will be competitive with conventional kWh, derived from fossil fuels (oil, gas, or coal) or fissile (nuclear).

III.4 Classifications of Grid-Connected Photovoltaic:

A first classification of Grid-Connected Photovoltaic Power Plants (GCPPP) based on their size can be made as follows:

A-Small-scale power plants (Pw = 1 to 10 kW):

For applications on the roofs of individual houses or public institutions such as schools, parking lots, etc.They connect to the low-voltage grid .

B- Medium-Scale Power Plants (Pw =10 to 100 KW):

This type of system can be installed and integrated on a building, on a roof, or a facade. It can be connected to the low or medium voltage of the electrical distribution network depending on its size.

C- Large-Scale Power Plants (Pw > 500 KW):

These are centralized systems and are owned by electricity companies. These systems can also be classified based on whether they are equipped with storage batteries or not.

III.5 General Structure of a Photovoltaic System

There are two types of photovoltaic system structures:

Direct grid-connected systems: This installation consists of a photovoltaic generator directly connected to the electrical grid using an inverter.

The intermediate DC bus system: The photovoltaic generator is connected via a DC-DC converter. An inverter delivers a modulated voltage, which is then filtered to reduce harmonic distortion. The output of this device is then a us able voltage that can be injected into the grid.

There are several architectures for devices that convert the DC voltage from the photovoltaic generator into a usable sinusoidal voltage (230V).

In the following part, different configurations will be described, specifying their advantages and disadvantages.

III.6 PV Systems Directly Connected to the Grid:

III.6.1 Single Converter Structure:

The device shown in Figure (II.3), is the simplest because it has the fewest possible components. Multiple photovoltaic modules are connected in series to obtain a sufficiently high DC voltage.

This solution is an alternative to a boost converter. Also, The DC voltage obtained directly powers a central inverter, which provides the desired sinusoidal voltage (230 V).

It could be advantageous to insert a transformer to isolate the photovoltaic system from the grid.

The major disadvantage of this device is the complete and immediate halt of energy production when a problem occurs upstream of the inverter. the control of the maximum power point is challenging because all cells do not deliver the same current due to their differences in internal structure and sunlight exposure.

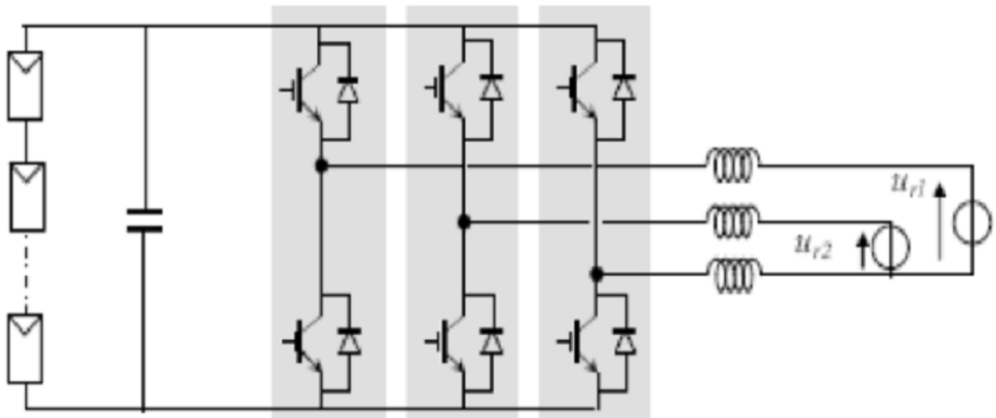


Figure III.2: Multiple PV modules in series connected to a single inverter.

III.6.2 Structure with low voltage AC bus:

Figure 3.8 shows an inverter associated with a control circuit that is directly connected to the photovoltaic module. The voltage output of the latter is converted into an alternating voltage of frequency 50 Hz. This voltage is transported via an AC bus (220 V - 50 Hz, example from the diagram) to a central transformer which raises it to the desired level.

The low voltage level in the bus is the major advantage of this type of configuration, as it ensures personnel safety. However, the distance between the transformer and the module must be kept short due to the significant current passing through the cables, which generates joule losses. There is a compromise to be made regarding the voltage of the AC bus. On one hand, its peak value must be lower than that delivered by the modules (even with low sunlight). On the other hand, a low voltage in this bus reduces efficiency.

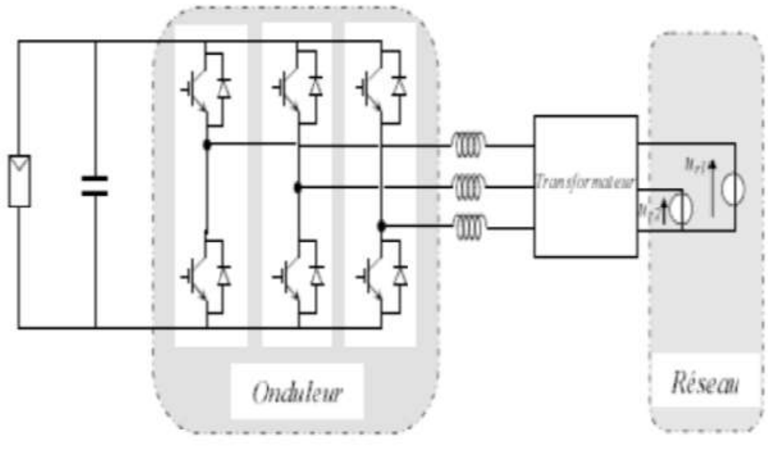


Figure III.3: Low voltage AC bus.

III.6.3The problem of connecting photovoltaic systems to the grid:

Disconnection of the photovoltaic system in case of grid failure

-Protection against lightning

-Power quality supplied to the grid

-The effects of multiple systems on a section of the network, especially unbalanced single-phase systems.

-The weak dosage of power flows.

-Technical and financial risks

III.6.4 Disturbances in electrical networks:

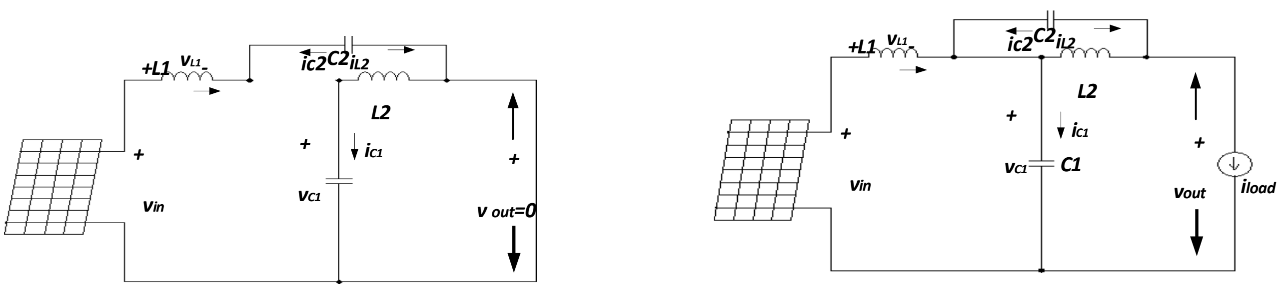
Electric energy is supplied in the form of voltage comprising a three-phase sinusoidal system, with the following characteristic parameters:

- ✓ The fréquence.
- ✓ The amplitude of the three voltages
- ✓ The waveform, which should be as close as possible to a sine wave.
- ✓ The symmetry of the three-phase system (equality of the magnitudes of the three voltages, their phase shift, and the order of phase sequence).

III.7 Integration of PV Emulator with Grid-connected q-ZSI:

The voltage and current output from the PV is connected to the q-Z-source network which consist of asymmetrical LC network *L1*, *L2*, *C1*, and *C2* plus a diode *D1*. There are two states of operation in the conventional voltage source inverter (VSI), the active voltage exists across the bridges and the zero states when either all upper and lower transistors are in OFF condition to produce a zero voltage condition across the bridges.

In the q-ZSI, a shoot through condition (short-circuit of inverter switches) is purposely introduced during the zero states. Figure 3.4 shows the equivalent circuit of q-ZSI during both shoot-through and non shoot-through operation.



(a) (b)

Figure III.4: Equivalent circuit of q-ZSI during (a) shoot-through and (b) non-shoot-through

The shoot through interval is defined as *T0*, the non-shoot-through interval as *T1* and the switching period as *Ts* where *Ts=T0+T1*. The shoot-through duty ratio *d* is defined as *d=T0/Ts*. When the qZSI is in a shoot through condition for a duration of *T0* from switching cycle of *Ts*, using the KCL, KVL, the following equations can be defined.

III.7.1 Proposed grid-connected photovoltaic system:

The system we propose for study and simulation is schematically represented by Figure (III.5),

The main simulation parameters are: the quasi-Z-source capacitor is C1 = C2 = 400 μF; inductor is L1 = L2 = 500 μH; the grid line voltage is 320 V, and the grid frequency is 50 Hz; the command peak dc link voltage, Vdc *, is 800 V.

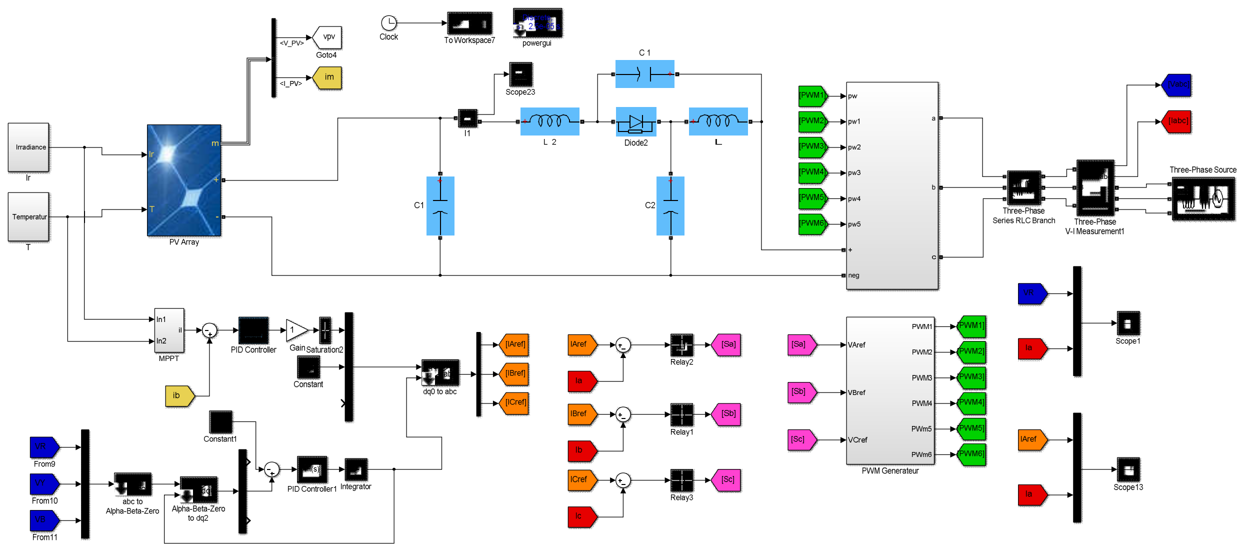


Figure III.5: Block diagram of the overall grid-connected q-ZSI PV inverter system.

III.8 The load:

In this study we have chosen a balanced load (RL) on the AC (alternating current) side.

III.8.1 Modeling of the network interface:

Charges are the elements consuming electrical power in a system. The consumption of this electrical power depends on the characteristics of the load. A correct modeling of these characteristics is essential to accurately represent the behavior of the load. Figure (III.5), shows us the model of the load connected to the voltage inverter.

It represents the public distribution electrical network with a voltage of V = 380 V and a frequency of f = 50 Hz.

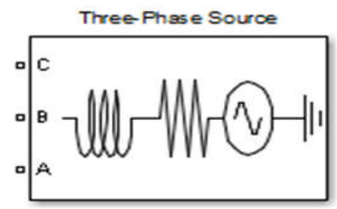


Figure III.6: Three-Phase Source.

III.8.2. Direct Current to Alternating Current Converter (DC-AC)

In the case of Pulse Width Modulation (PWM) control, the state of the switch is varied at a rate that does not depend on how the quantities related to the systems interconnected by the power electronic converter evolve. This rate is essentially set based on the switching speed of the switch. In digital form, this type of control is achieved by setting the conduction intervals of the different switches for each modulation period or each half modulation period, using timers, as shown in the following figure.

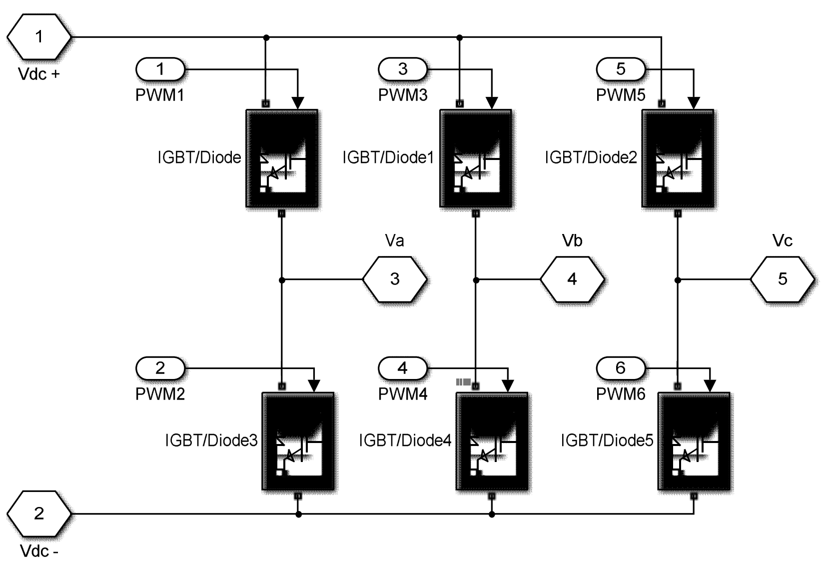


Figure III.7: Inverter schematic.

III.8.3 Hysteresis Control of Inverter:

In the application, the hysteresis control strategy is used on the inverter, with a conventional (PI) controller for the DC bus voltage.

III.8.4 Current Control:

Current control is recommended in all applications centered around a voltage inverter because it ensures, on one hand, good protection and stability.

In addition, it allows the control of the current waveform during a period of the network, which enables compensation for disturbances caused by load transients, nonlinearities, and switching delays. Indeed, control strategies are applied to achieve rapid modulation of the voltage at the input/output of the converter such as PWM techniques. Also, current control is essential in certain applications such as active rectification and filtering, where the current must be instantly controlled to impose given active and reactive powers, to minimize harmonic currents, and to improve the power factor of the system.

Hysteresis Current Control (HCC) involves maintaining the current within a band enveloping its reference. Each violation of this band gives a switching command to the switches. Figure (III.8), illustrates the principle of hysteresis current control with fixed two-level band. The difference between the reference current and the measured current is applied to the input of a hysteresis comparator, whose output provides the control command for the corresponding arm of the bridge.

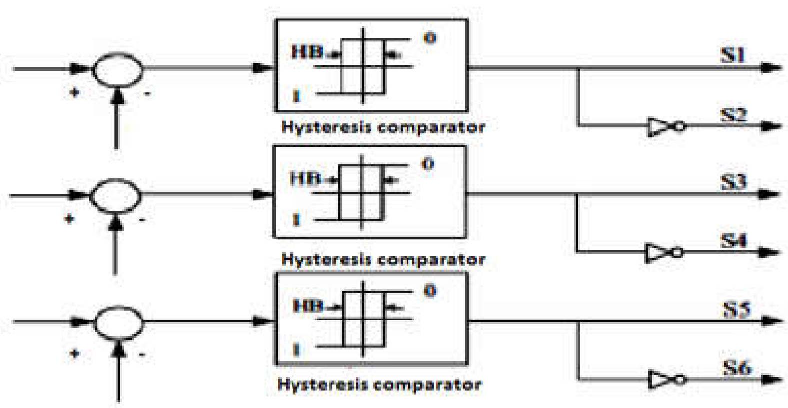


Figure III.8: current control.

The three currents at the input of the bridge are controlled using three fixed-band hysteresis comparators. The combination of the three outputs of these comparators determines the control commands for the switches constituting the bridge. Indeed, the determination of the switching instants follows the following logic:

$$\begin{cases} i_i^* - i_i = \dfrac{\Delta I}{2} \Rightarrow S_i = 0 \\ i_i^* - i_i = -\dfrac{\Delta I}{2} \Rightarrow S_i = 1 \end{cases} \qquad i = a, b, c$$

III.9 DC Bus Voltage Regulation Loop :

The role of the regulation loop of the inductor current is to maintain this current at a constant reference value. The regulation of this is achieved by adjusting the amplitude of the current references used to control the active power flow between the grid and the DC bus.

The MPPT method to be used is based on the modified perturbed and observed (P&O) method considering its simple function which is used. Based on the equation of PV it is known that while regulating the inductor current at the optimal current for the PV array .

III.9.1 Model a *phase-locked loop* (PLL) :

PLL techniques have been used to synchronize converters connected to the electrical grid. An ideal PLL can provide fast synchronization information with a high level of immunity to disturbances, harmonics, imbalances, and distortions in the input signal.

III.9.2 Filtre :

The filter eliminates switching harmonics almost perfectly, and its behavior is nearly ideal when operating at no load (zero output current) and with signals of frequencies close to the fundamental frequency.

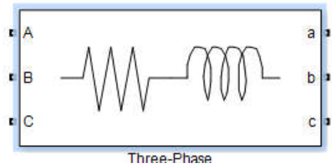


Figure III.9: Block diagram of an RL filter on Matlab / Simulink.

III.9.3. S IMULATION RESULTS :

The model of system was simulated in a MATLAB/Simulink environment. To evaluate the results of the control scheme, the overall system performance is tested under different irradiance levels where the solar insolation is reduced from1000 W/m2 to 800 W/m2 and temperature increased from 25 to 45^0.

Figure (III.14), shows the PV panel output voltage,. It is clear that when the temperature and irradiation change, the PV panel output voltage is still working at the MPP voltage, and the shoot through duty ratio is automatically regulated to keep the peak current pf PV invariable under the designed control strategies. Figure (III.12), and Figure (III.13), shows the system output power and grid current. Compared the simulated PV voltage and output power with the power characteristic section 2 , it is obvious that they are consistent, which verifies the proposed MPPT method.

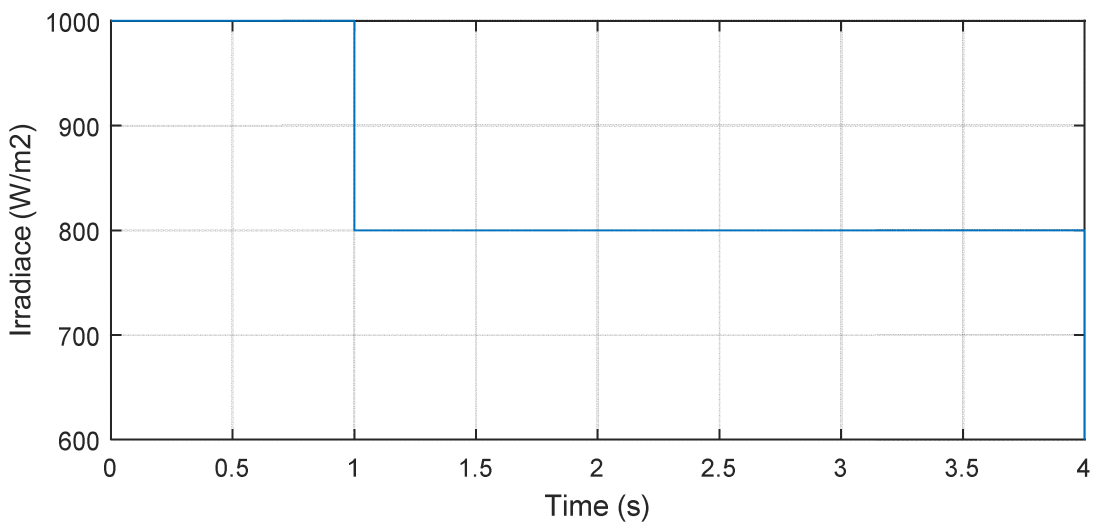


Figure III.10: Solar Irradiante [W/m^2].

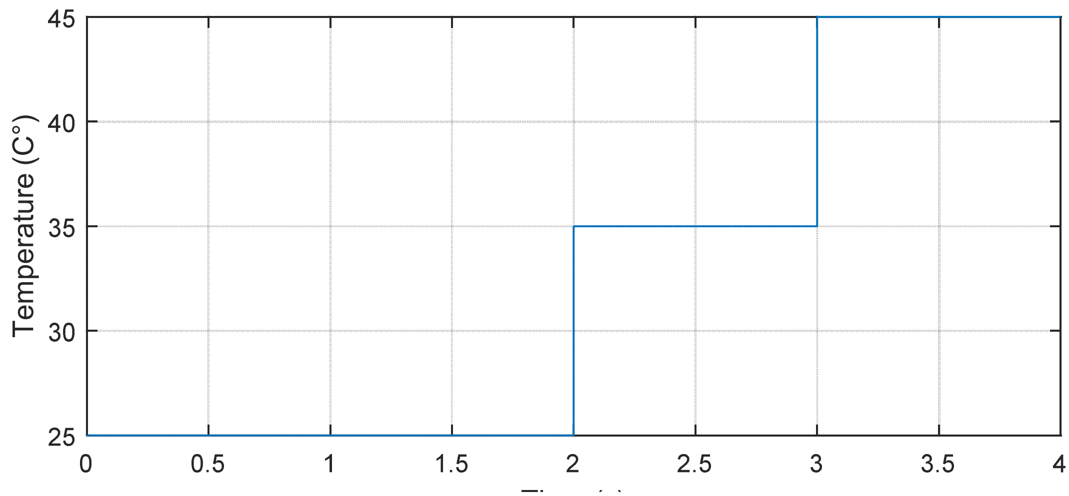


Figure III.11: Temperature [°C].

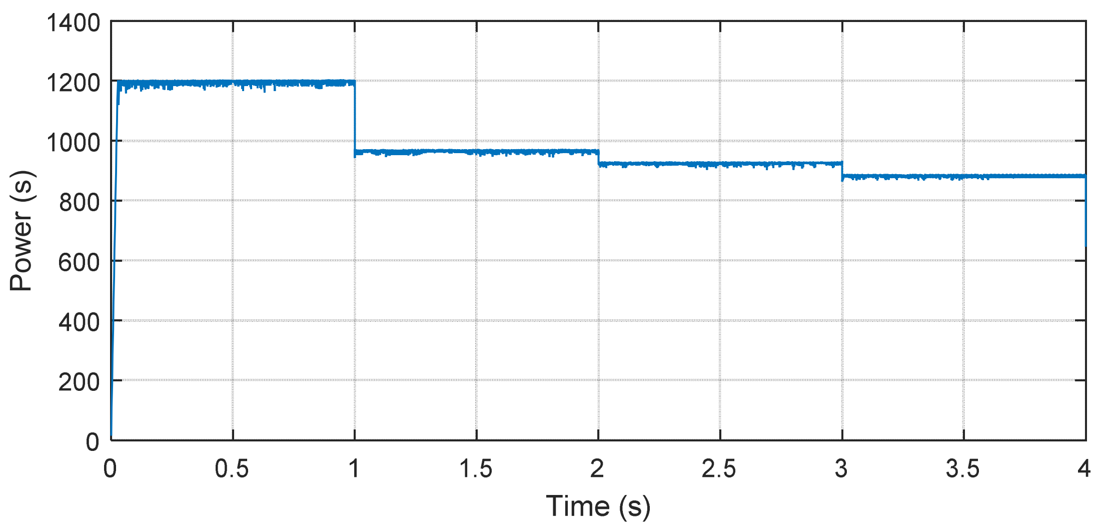


Figure III.12: Waveform of output power of PV.

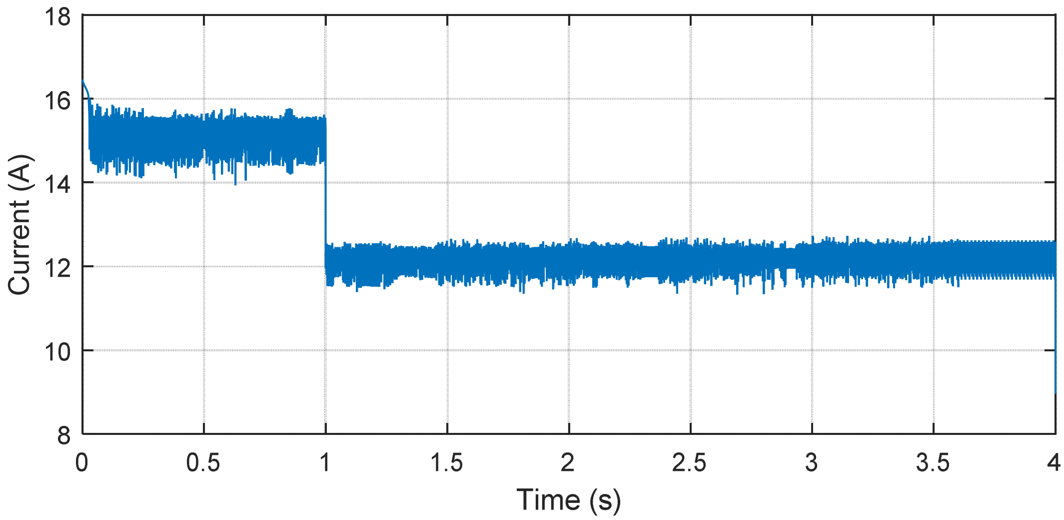


Figure III.13: Waveform of output current of PV.

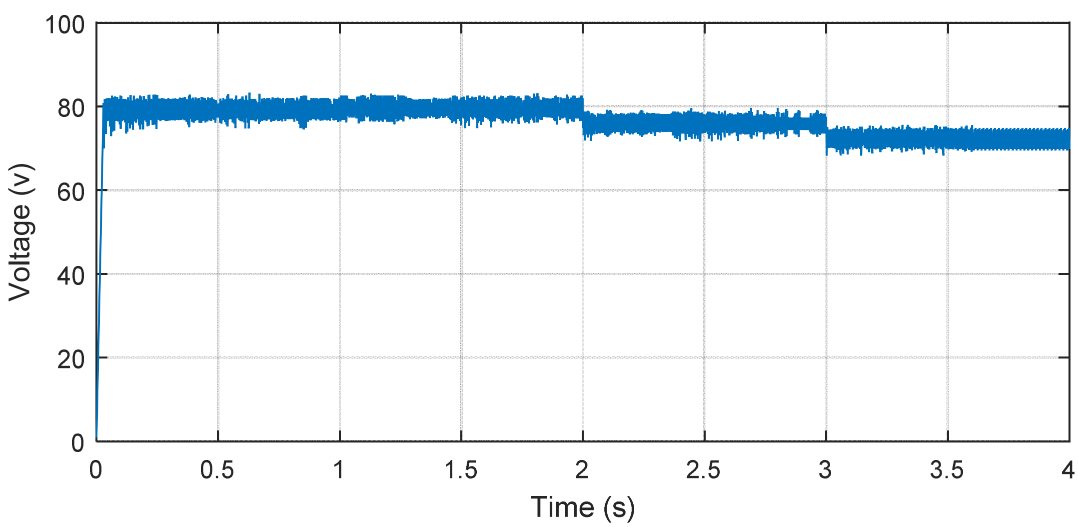


Figure III.14: Waveform of output voltage of PV.

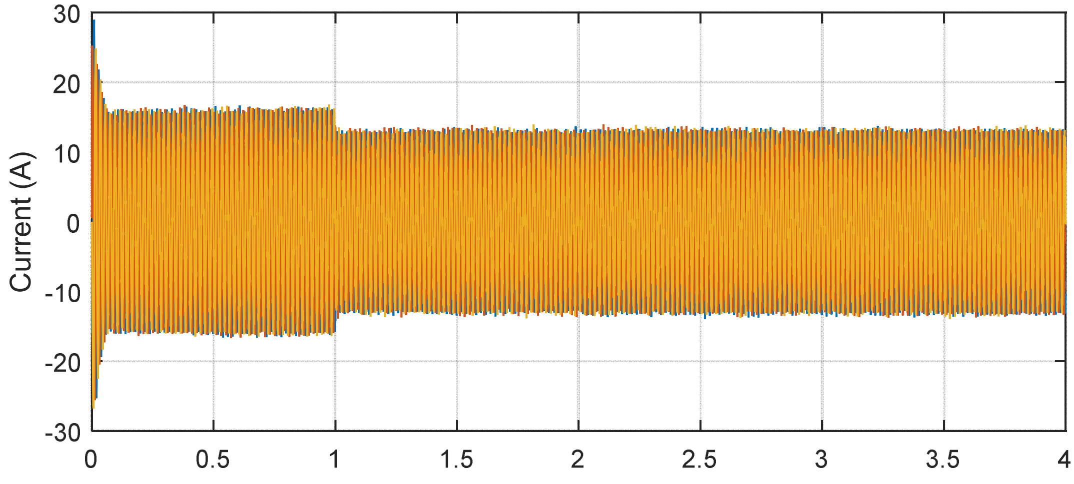


Figure III.15: waveforms of the alternating currents injected to the grid.

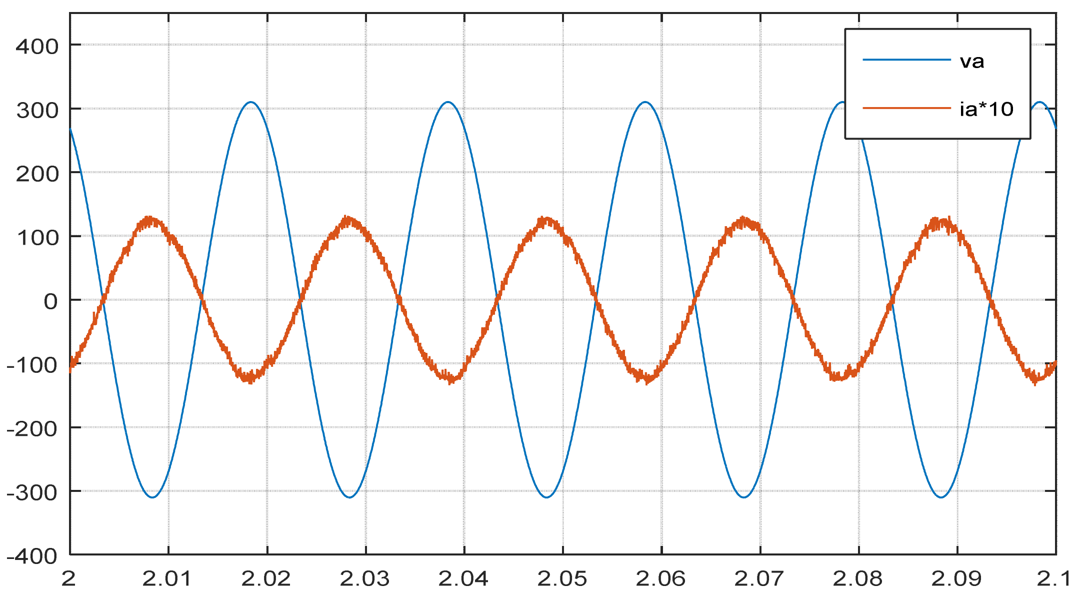


Figure III.16: Phase comparison between grid voltage (blue) and current (red) during.

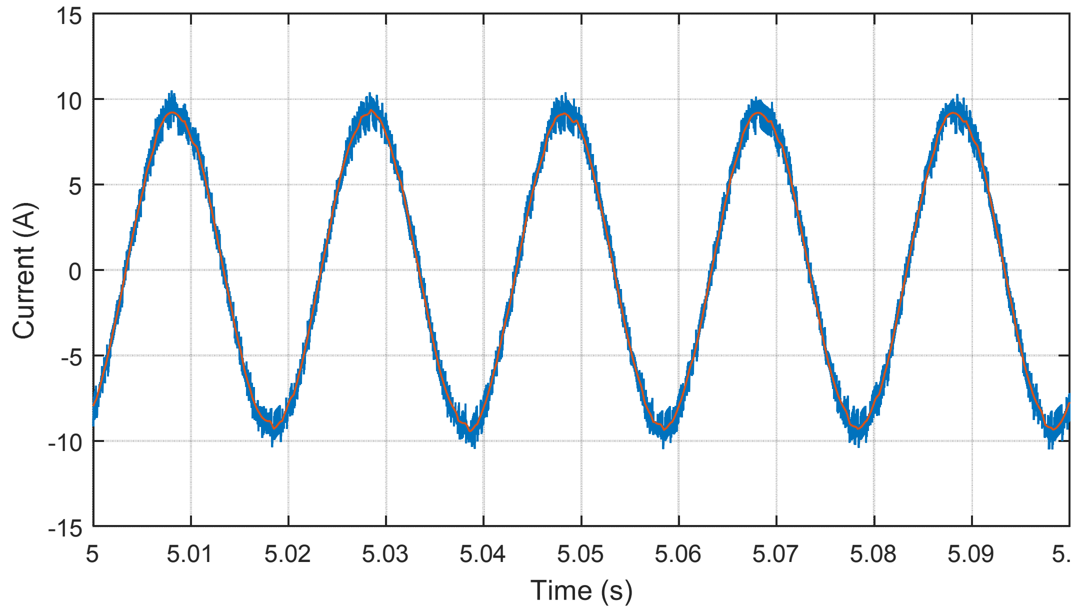


Figure III.17: Phase comparison between grid current (blue) and reference (red) during.

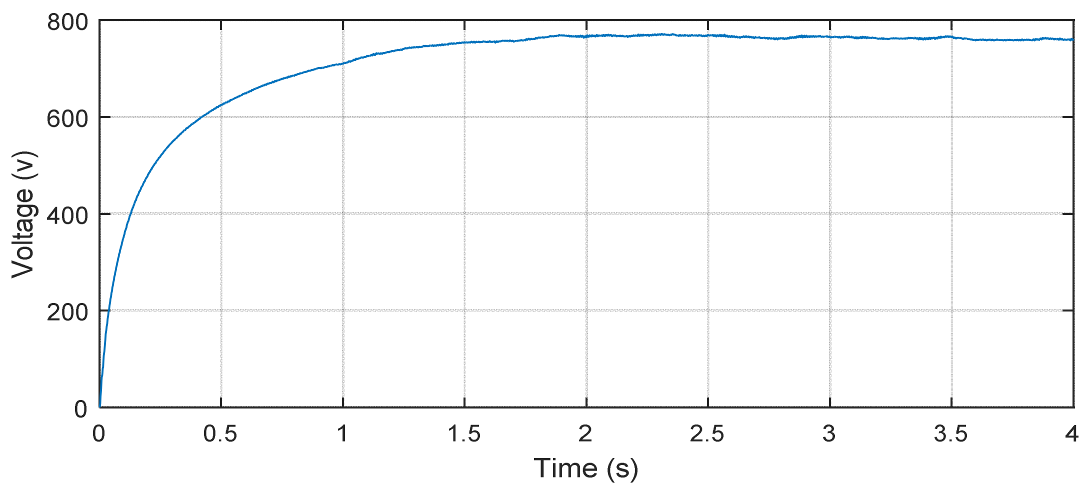


Figure III.18: Voltage across C1 controlled.

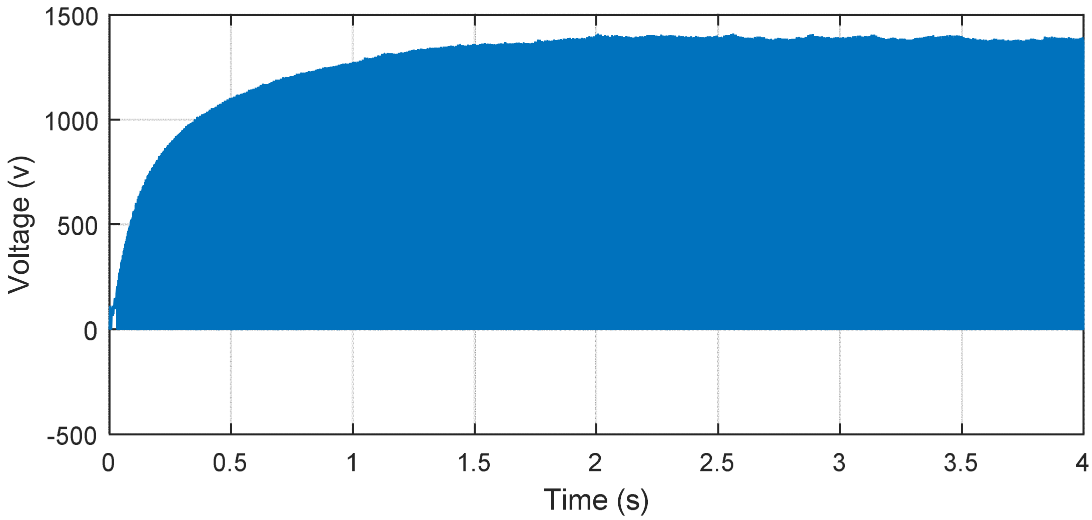


Figure III.19: Waveform of output DC bus voltage.

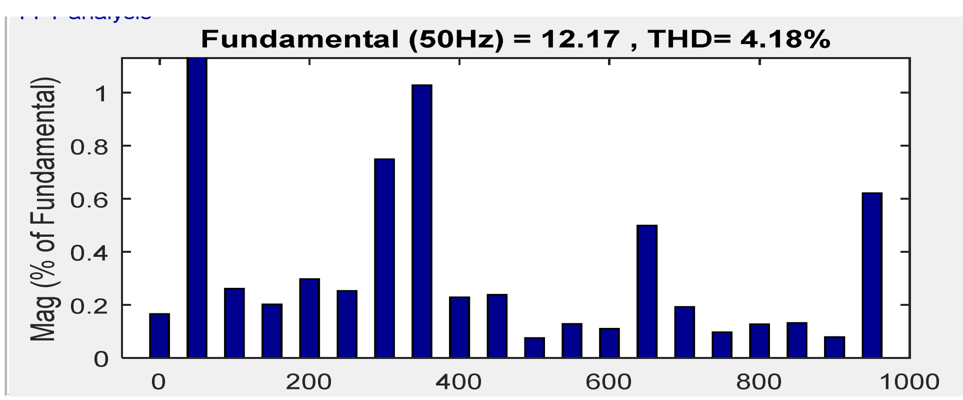


Figure III.20: THD of current integrate to the grid

Figure (III.18), shows the successful control of capacitor voltage VC1 at 780 V while power from the PV source is varied between 12 kW to 9 kW. This is achieved through the current control operation shown in Figure (III.17), where the inverter output current Isd is tracking the reference value from the PV MPPT current controller Iref. Since all the output current is fed to the grid without a load in between, the reactive component Isq is controlled at 0. The three phase output current of the inverter is well proportional to the power fed to the inverter..

A closed loop control system based on the reference current value is easily designed and demonstrated. The concept of regulation consists in a variable auxiliary shoot- through band that maintains the required DC-link or capacitors voltage.

The simulation results show that the reference output current is quickly tracked by hysteresis current controller. The capacitor voltage is approximately fixed during the step change in the input power in order to give a fixed output voltage. Also, the results point out that the inductor current is tracked in order to enable the change in the output current. These results give an overview of the possible quality and while it is a simple and powerful method and it does not need any modulation techniques. Based on the circuit analysis, it is shown that the q-ZSI can be simulation together with the system to achieve the MPPT.

III.13. Conclusion

In this chapter, an improved maximum power point tracking method applied for a quasi-Z-source PV inverter is proposed to track the maximum power of the PV power system. Furthermore, the DC-link stable voltage control and AC-side power control of the entire system are designed. The simulated results illustrate the validity and correctness of the proposed approach, and an efficient method for PV power generation.

General conclusion:

This thesis develops the study of a grid-connected photovoltaic system with a maximum power point controller. We presented a mathematical model of the PV system based on the theory of photovoltaic. Then, a photovoltaic system with a DC-DC boost converter, maximum power point controller with was designed. Simulink MATLAB has successfully simulated the system. First, the simulations of the PV panel showed that the simulated models were accurate to determine the characteristics of voltage and current. In addition, when the irradiance or temperature varies, the PV model's output voltage current changes too. Then, the simulation showed that the "Perturb and Observe" algorithm can track the maximum power point of the PV, it always runs at maximum power no matter what the operation condition is. The results showed that the algorithm delivered an efficiency close to 100% in steady state. In the final chapter a grid current based MPPT technique for q-ZSI grid connected PV system is proposed. The simulated results show that the proposed method tracks maximum power of the PV panel without the current sensor of PV panel. At the same time, the control system also satisfied the requirements of the grid, with an efficient algorithm for grid-connected PV power generation.

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