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Various PWM Techniques for Controlling Multi-Level Inverters in PV Systems

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Thanks

Thank God that was blessed to complete the study process and conclude it with this simple work. Thank God, thank you very much.

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Thank you all for what you have given us

Dedication

I dedicate this work to the two most important people in my life, my dear parents, and especially to them.

I also dedicate this work to my dear uncle **DOUABA NADJE**, who did not attend on this day, may Allah have mercy on you, my uncle, and make your resting place a paradise

And I dedicate this work to my brothers and sisters, here is one of the branches of our tree bearing fruit.

I also dedicate this work to those friends who were like sisters in the University residence, Hassani Mohammed bin Ibrahim.

I dedicate this work to everyone who smiled at me, I exchanged my work with your smile.

B. Houria

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To my dear parents, the candle of my life and the light of my path, I dedicate this fruit of my efforts, thank you for your unlimited support and your constant support. And to my brother DOUABA NADJE of my Lord, have mercy and forgive him,

I dedicate this humble work to my dear colleagues, thank you for your positive spirit and fruitful cooperation, you have been the best support to me during my research journey.to those who believed in me and supported me,

I dedicate this achievement to you, thank you for your trust and constant encouragement

DOUABA .M

List the Symbols

Symbol	Full name of the symbol
PV	Photovoltaic System is Necessary
AC	Alternating Current
DC	Direct Current
Isc	Short Circuit Current
Voc	Open Circuit Voltage
FF	Fill Factor
V	Temperature
MPP	Maximum Power Point
IC	Incremental Conductance
SCI	Self-Commutated Inverter
PWM	Pulse Width Modulation
LCI	Load Carrying Indicator
VSI	Voltage Source Inverter
VCM	Voltage Contral Mode
CCM	Current Control Mode
CSI	Current Surce Inverter
THD	Total Harmonic Distortion
CHB	Cascaded H-Bridge
NPC	National Power Corporation
FC	Flying Capacitor
ML	Multilevel
MLIs	Multilevel Inverter

List the tables

List the figure

Contents

General Introduction

A person who does not have a part of his body is called disabled, as well as the world today has become paralyzed without energy. The growing demand for energy, threatens the life of the environment because the world relies on fossil energy, which has caused many problems due to the production of toxic gases. It led to the phenomenon of global warming, which made the world look for solutions and other ways to produce energy without any environmental damage. This is what has made renewable energies evolve in the last 10 years from the absence to the basis of the current research.

Among the renewable energies that are leading the world today are wind and solar energy, but their production fluctuates due to the influence of climatic factors of temperature, wind, clouds, solar radiation ......Etc. Which has made it a new research challenge, the dependence on solar energy today. Despite its low efficiency and production compared to wind energy, A single turbine produces more energy than a solar panel, in less space than a solar panel consumes; because solar energy does not produce any annoying noise and is safer than wind turbines, which should not be in urban areas, and despite the advantages of the solar panel that it is safer than turbines, the current it produces is continuous and most of the energy use, AC current even in power transmission is transmitted in the sinusoidal form.

It is power electronics. The inverter is one of the most important energy devices used in a photovoltaic system. Because it converts the voltage of the ester current into an alternating current. An inverter for a classic is considered to have good efficiency in the case of a weak power voltage, but the power that we are dealing with in the network uses large voltage values. The research is back again to reduce energy losses. Multi-level inverters have emerged as an ideal solution for values for high voltage power. Three types of inverters have appeared, which are basically all modern technologies, and they have advantages and disadvantages for each type. what our study has shown is that one of the disadvantages of an inverter is the multiplicity of sources of input voltage, which applies to solar panels because they are considered independent sources by themselves. Our study was based on understanding the inverter and the pulse generation techniques it uses and comparing them.

Chapter 01
State of the art of Grid-Connected PV System

I.1 Introduction

Solar energy is one of the leading environmental and economic solutions in the modern era, as it relies on the use of sunlight to generate electricity in environmentally friendly ways. Thanks to the progress of modern technology, many devices are among them: panels, inverters, power electronics. Solar energy has become an essential role in meeting electricity needs. Where it contributes to the creation of new job opportunities in various fields.

The purpose of this chapter is to review the general grid-connected solar energy system, focusing on the development of an inverter element that plays a vital role in the process of converting solar energy into usable electrical energy in AC conditions. The definition of solar energy in the world in general and Algeria will be discussed in this chapter. Determine the components of a grid-connected solar power system. The types of inverters used in this type of system, their role in improving the efficiency of energy conversion and ensuring the stability of the output current. And the controllers used.

I.2 The characteristic of photovoltaic energy

I.2.1 The source of energy solar

Solar energy is a renewable, sustainable source that can provide energy security and independence for everyone. The general concept of solar energy is the consumption and use of light and thermal energy generated by the sun. Solar energy can be relied on as a natural and significant part of electricity generation in many countries to meet the energy requirements of the whole world if its harvesting and supply technologies are readily available. **[1, 2]** The average amount of solar energy received in the Earth's atmosphere is about 342W/m^2 annual effective solar radiation ranges from 60 to 250 W/m^2 **[1]** distributed as in the figure I.1. Solar energy is one of the best options to meet future energy demand because it is superior in terms of availability, efficiency, cost, accessibility, capacity and efficiency, although it is an unstable source, affected by climatic factors and is not available at night. **[3, 4]** Despite the fact that solar energy is the second most prominent source after wind energy **[5]** solar energy technology can be grouped into two types: solar photovoltaic and solar thermal. In recent years, solar photovoltaic energy has become the most desirable option for the use of semiconductors and the focus of research of many scientists **[3].** Photovoltaic systems are popularly configured as stand-alone, grid-connected and hybrid systems.

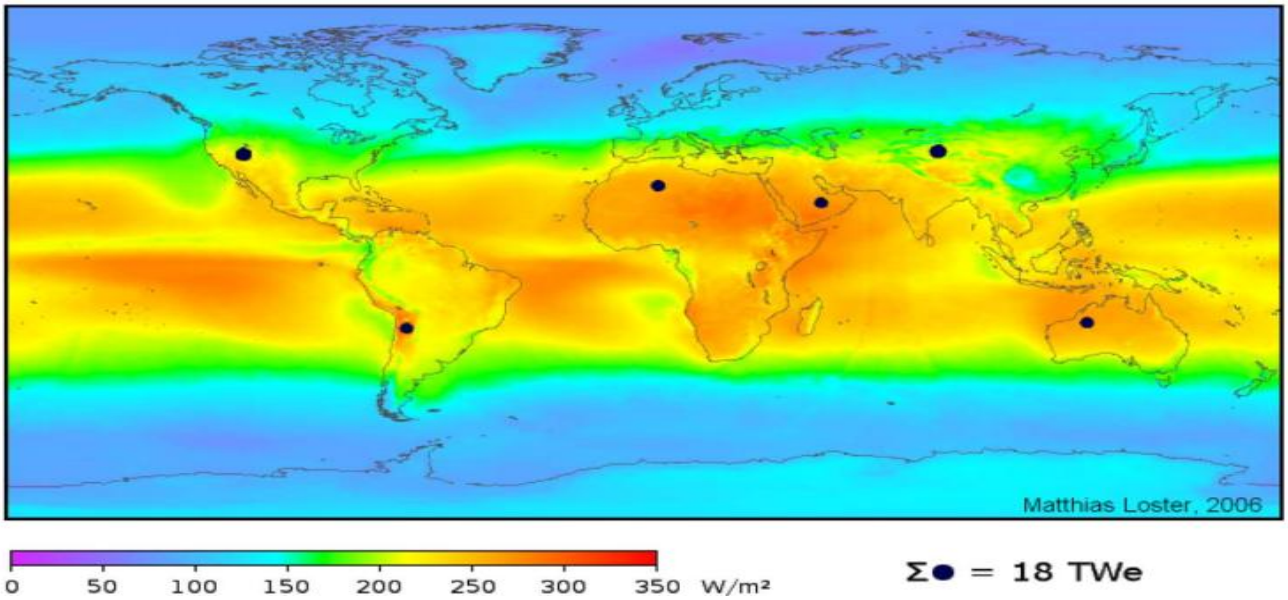


Fig I.1: Annual average solar irradiance distribution over the surface of the Earth **[4].**

I.2.2 Energy solar in Algerian

In recent years, Algeria has made important efforts to develop the renewable energy sector, through several measures such as the creation of a new ministry called the Ministry of Environment and renewable energies. Several programs have been adopted for the development of renewable energies see literature **[6, 7].** The Centre for the development of renewable energies in Algeria surveyed many types of renewable energies, and the data was collected in the renewable energy Guide report. He summarizes to the conclusion that the greatest potential of renewable energy in Algeria is solar energy. Algeria has a huge potential for solar electricity production, due to its vast area of 2,381,741 km^2, and its geographical location, because it is located in an area called The Sun Belt where Algeria ranks among the top 3 solar fields in the world, and this makes it an important solar mine. Where solar rays cover 90% of the country's area, the value of sunlight is estimated at 3000 hours per year. The daily power reaches 5 kW / m distributed as shown in the figure I.2, the table I.1 **[6] [8] [9] [10].**

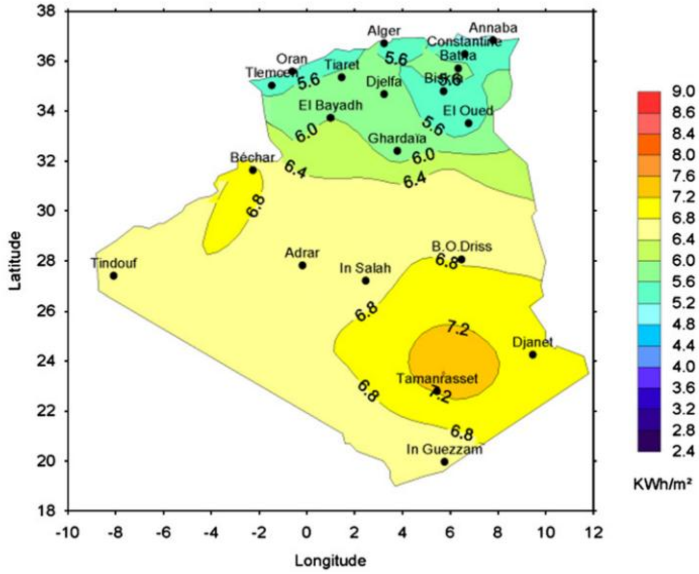


Fig: I.2: Potential sites for solar electricity supply in Algeria **[11].**

Table I.1: Solar energy capacity by region in Algeria **[11].**

Regions	Coastal areas	High Plateaus	The desert
Area%	4	10	86
Average sunshine duration (hours/year)	2650	3000	3500
Rated power (kWh/m²/year)	1700	1900	2650

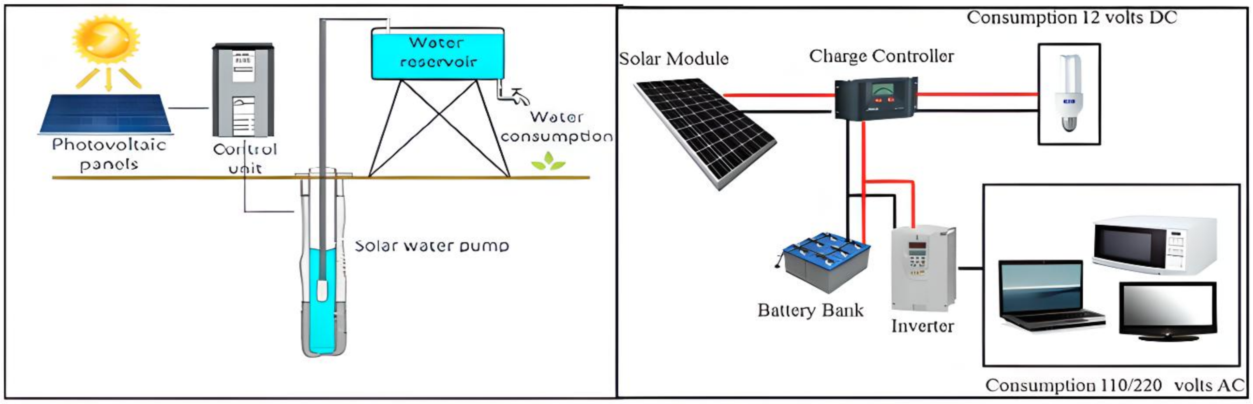
I.2.3 Concept structures of PV systems

I.2.3.1 Autonomous PV systems

According to the definition an autonomous system does not imply any interaction with the network. **[11]** Therefore, a grid-independent PV system is an excellent option for off-grid areas. **[12]** There are usually two types:

Without battery: it is in irrigation systems **[6].**

PV system with battery: as shown in Figure I.3, The mismatch of supply and demand poses a growing threat to the stability of the electricity system. This is what shows the importance of the system PV with a battery. **[13]** The energy produced during the day is supplied from the solar panel, they are stored in the battery. This energy stored can be used at night or during days with bad weather conditions (clouds, wind, rain......) **[14],[15].**



(a) Photovoltaic pumping system **(b) Photovoltaic system with storage**

Fig I.3: Autonomous PV systems: (a) without battery, (b): with storage system [16].

I.2.3.2 Grid connected PV systems

This system relies on solar energy as its primary source. There may be deficiencies in the energy produced, an excess of energy, or in the case of increased load. The system needs the grid to cover the shortage or surplus.

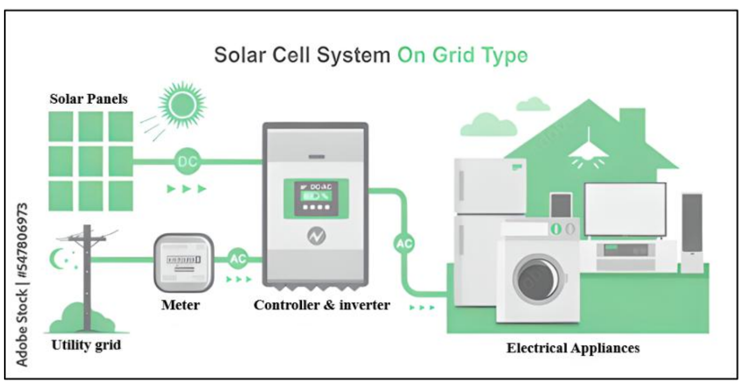


Fig I.4: Photovoltaic houses: On Grid Type.[17]

I.2.3.3 Hybrid PV systems

It is an electric power generation system, using a set of photovoltaic solar panels as the primary source of electricity generation, designed to work simultaneously or in parallel with the AC utility network and these systems include battery storage or other generation sources to supply loads during network outages and peak load hours**[17].**

Hybrid PV system with a battery connected to the grid as in figure I.5 is useful in eliminating the mismatch of renewable energy generation and relieving pressure on the power grid **[18]** as it helps to provide continuous power supply in locations facing problems due to power outages from the grid or in case of excessive power demand or non-linear loads, By which we mean changing the load requirements along the day **[19] [20].**

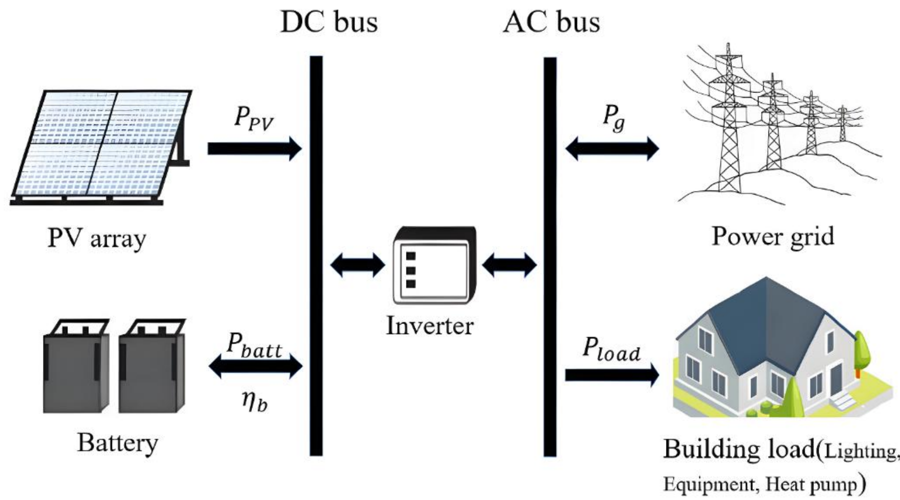


Fig I.5: Components of the grid-connected energy PV systems with battery **[13].**

I.3 Grid connected PV systems

I.3.1 Structure of the grid connected PV systems

The structure of the photovoltaic system and its connection to the grid depend on technical parameters of the network and special standards for photovoltaic systems as necessary, the optimization of power inverter services varies by different countries and international organizations **[21]** The grid-connected photovoltaic system is widely used in practical applications, as it mainly relies on the fast and accurate design of the control system. For proper operation. **[22]** The general system of grid-connected photovoltaic systems consists on a photovoltaic generator PV, Converters based on power electronics DC-DC and DC-AC and a simple filter-all these components are connected to the network as described in figure I.6.

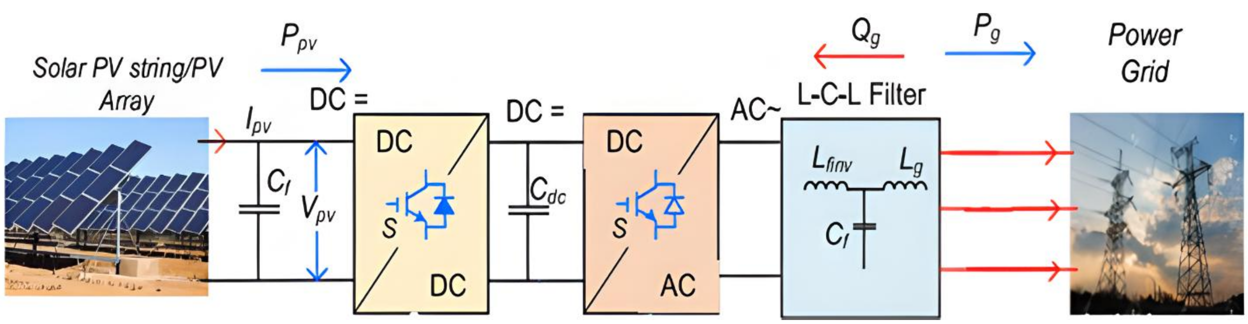


Fig I.6: General structure of Solar PV system integrated with grid **[12]**

The photo generally represents the devices of the photovoltaic system connected to the network.

Where the solar PV array represents the photovoltaic generator, the current conversion efficiency of commercial photovoltaic panels is usually less than 20%.

The DC-DC converter is used to improve the energy conversion efficiency, it is used to raise or lower the current produced by the solar PV array. The MPPT control technology uses the energy tracker to get the best energy produced by the solar panel **[23].**

DC-AC Inverters Transformers convert current from DC to alternating current. It is the most important part of a grid-connected photovoltaic system **[21].**

LCL-Filter optimizes the shape of the output alternating current from the inverter to the sinusoidal form

I.3.2 Solar PV system configuration

Grid-connected systems enable consumers to contribute unused, or excess electricity to the grid. It also enables them to consume electricity in case of failure of the photovoltaic system or lack of energy. There are several configurations of the solar power system determined by factors such as actors like power rating, voltage level, size, reliability, sustainability, cost, etc. decide the selection of a specific configuration for a particular plant. The intermittent nature of solar irradiation level is another primary criterion for selecting the specific configuration. **[21].** We will touch on the 2 most important power configurations as indicated in the figure I.7.

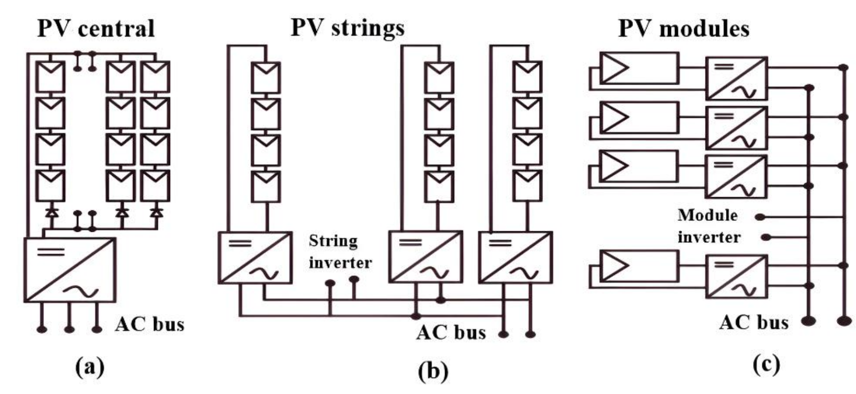


Fig I.7: Types of Configurations of grid-connected PV inverter **[8].**

I.3.2.1 Central PV solar inverter configuration

A group of solar panels is connected according to design calculations, the resulting energy is sent to one central inverter. As shown in figure I.7. (a) This configuration is considered productive from an economic point of view; however, it has disadvantages, among which are power losses between PV modules. Complexity of the MPPT algorithm **[24] [8] [25].**

I.3.2.2 String PV solar inverter configuration

At the moment it is more widespread, one series of the photovoltaic series is connected; as in figure I.7.(b) it is considered a low version of the central inverter; it is characterized by the ease of structure and the power is higher by about 1-3% compared to the central inverter; the disadvantages of this topology are harmonic distortion **[15] [8] [22, 25].**

I.3.2.3 Module PV solar inverter configuration

The inverter module is combined with a photovoltaic module, as in figure I.7. (c) in this topology the losses caused by the mismatch between the photovoltaic modules are removed. This leads to higher energy production. One of its minuses is an increase in cost for large-scale applications **[8, 22, 24, 26].**

I.4 The constituents of PV system connected to the grid

I.4.1 Generator solar panel

I.4.1.1 Solar cell structure and work

The cell consists of two layers. Silicon is usually used in its manufacture, The upper layer facing the sun is added to the element phosphorus, to give it the property of pumping electrons when light falls on it. this layer is called the N layer, while boron is added to the lower layer, giving it the property of absorption. Electrons This layer is called P, and when there is an electrical conductor between the two layers, the electrons move from the upper layer to the lower layer. here we form a P-N junction, and thus an electric current and electric voltage are formed. and silicon is very reflective, so they put an anti-reflective layer over the cell, a layer of glass is added to protect the cell.as in figure I.8.

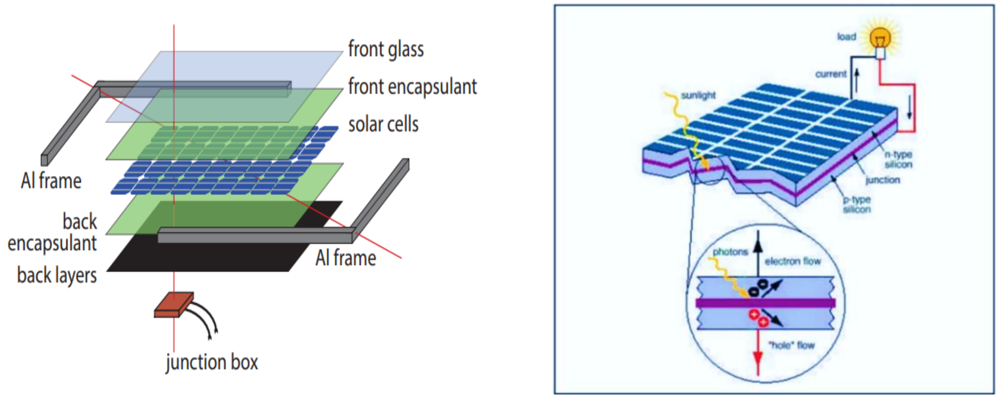


Fig I.8: Structure solar cell [10, 27]

I.4.2 Converter dc-dc

I.4.2.1 Concept

The converter is a device that acts as an intermediary between the load and the PV power system with load impedance to maintain high efficiency to avoid energy dissipation during conversion. It general performs Voltage regulation **[25] [28] [29].**

I.4.2.2 Types of the DC-DC converter

There are many types of DC-DC converters as represented in figure I.12.

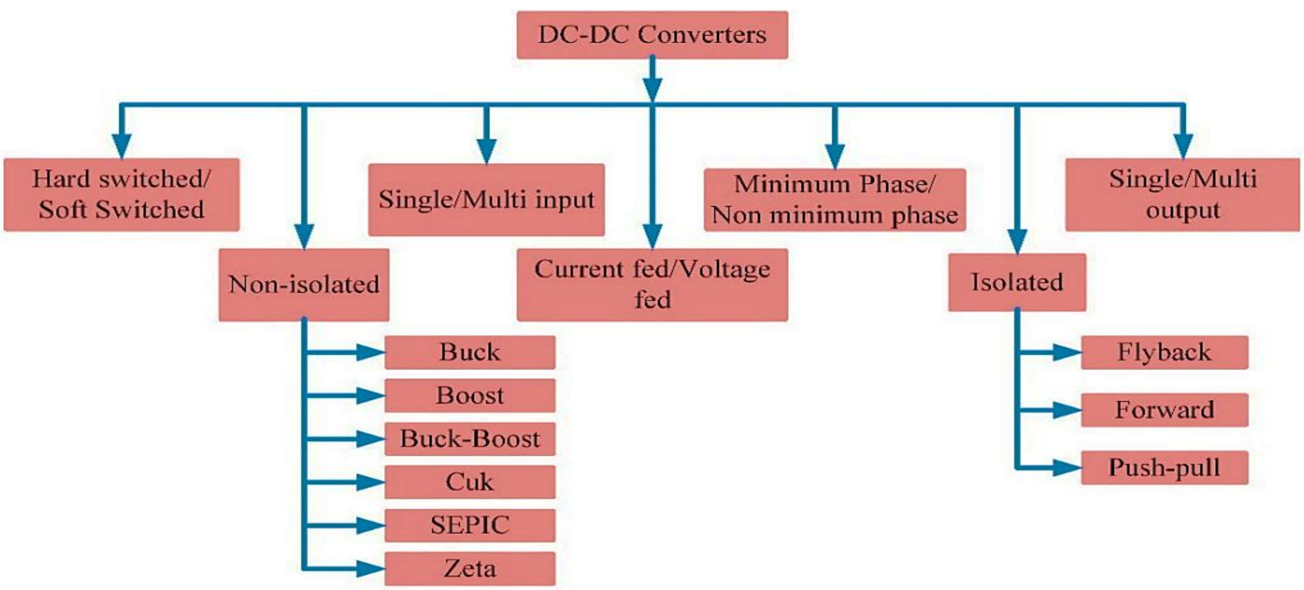


Fig I.12: Various types DC-DC converter[22]**.**

We will discuss the most important of these DC-DC converters

Buck

It is also called a step-down transformer. It is easy to control. It works in a simplified way by turning switches on and off to produce voltage **[29] [30].**

It is used when the required load voltage is less than the corresponding voltage $R_0 =< R_{MPP}$ **[30].**

Boost

It is used for network integration of direct current sources. It is also called a step-up converter. **[29]** It has an excellent property: it naturally generates an output voltage greater than the input voltage.**[30]** We can use this converter to amplify voltage as it offers superior reliability and versatility when contrasted with alternative options **[23].**

buck-boost

It is proportional to all values of load resistance. It is considered a hybrid between the two previous converter DC-DC. It is considered more accurate and reliable, but its drawback is that the output voltage is the opposite of the input voltage, in contrast to its arduous design **[29].**

I.4.3 Inverter DC-AC

I.4.3.1 Concept

Inverter is electric power electronics device, converting electrical energy from direct current to alternating current. It is one of the basic devices in many electrical and electronic applications. Used in many applications, and the operation of electrical and electronic devices powered by alternating current. **[22]** The inverter, like other devices, has a limited lifespan ranging from 10 to 15 years. **[28]**.. the DC-AC converters are generally classified according to the switching modes of their switches, two types of inverters are distinguished, as follows:

- **Non-autonomous inverter**

It is called an "assistant." It stands for SAI (Switched Auto-grid Inverter line), and the switching process is carried out through parameters from the utility network. Opening can be controlled, but closing cannot be controlled except through load **[22, 31, 32].**

- **Autonomous inverter**

It symbols SCI (Self-Commutated Inverter). It is a fully controlled electrical inverter. The capabilities located at the gate terminal control both the shutdown process and the operation of power switching devices. Its advantages are that it is very powerful for utility network disturbances, suppression of harmonics, and optimization of the network power factor. **[22, 31, 32].**

It is preferable to use SCI over LCI (Line commutated Inverters) for grid-connected PV systems due to the development of the control system and the development of switching devices, which are of two types **[22]:**

Voltage Source Inverter (VSI): is the preferred inverter for a grid-connected PV system is the VSI **[22, 31, 32].**

Current Source Inverter (CSI): it is used for auto PV system **[22, 31].**

I.4.3.2 Various Inverter topologies

Inverters can be classified into different categories. These division of categories is based on various factors, such as, number of power processing stages i.e. single stage and multi-stage, inverter and the inverter have fewer configurations as the presence or absence of Transformers. And the number of levels starting from two or more levels involved in the design and the type of user switching. Including **[8, 22].**

Two-levels inverter:

This type of inverter can be used in many photovoltaic applications, a single-phase inverter needs a minimum of 380 V DC from the input voltage of the photovoltaic array to produce a 220 as shown in Figure I.14. Its advantages are that it is simple and its investment cost is low. **[6, 33, 34].**

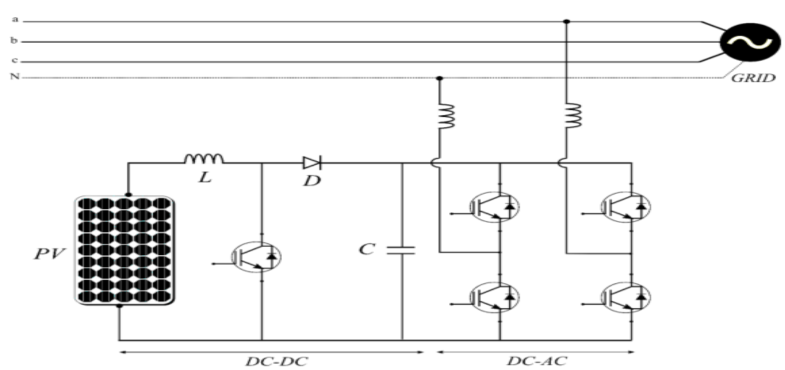


Fig I.14: Three -phase inverter connected to the network

There are also a three-phase inverter needs a minimum of 560 V DC from the input voltage of the photovoltaic array to produce a 380 v AC phase difference has been studied in many literatures. Its advantages lie in its energy production in a large amount compared to single-phase, as it is limited in production **[6, 33, 34]** figure I.15 represents an illustrative diagram of the method of connecting a three-phase inverter with the network.

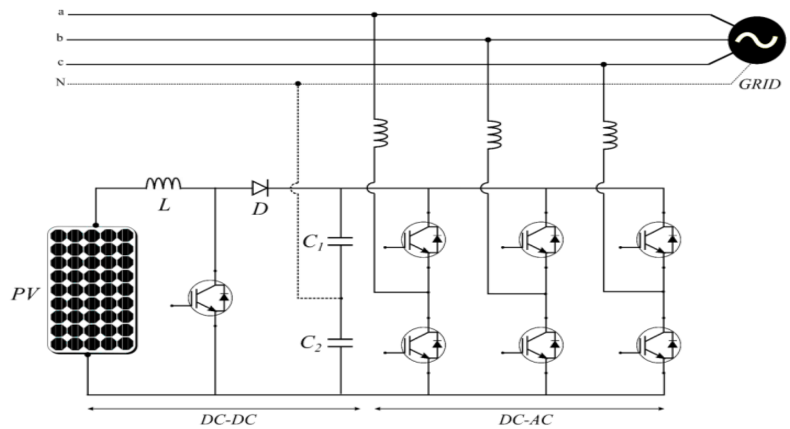


Fig I.15: Three-phase inverter connected to the network

They are also called conventional converters. It has some limitations for working at high frequency **[35]**. Where it operates high frequency with high conversion losses and rating limitations for high power and high voltage applications **[36]** it operates with a two-level output voltage it faces harmonic distortion, high pressure and high level of total harmonic distortion **[37]** as in the literatures **[12, 36-39].**

b Multi level inverters

It is called a multilevel for the multiplicity of the load abscess voltage. The output of the inverter voltage is characterized by several levels, at least 3 levels, as mentioned in the literature. The multiplicity of power switches allows the distribution of voltage pressure, resulting in excellent performance and better than conventional structures. as in the literature. Where the inverter has two characteristics **[40] [37] [38]:**

- First: that the greater the number of levels of the inverter necessarily decreases the total harmonic distortion THD of the output voltage.
- Second: the inverter structure plays a big role in improving the continuous conversion, especially for large and medium power applications **[41].**

As an increase in the number of output voltage levels forms waveforms with a better harmonic spectrum, as in Figure I.16

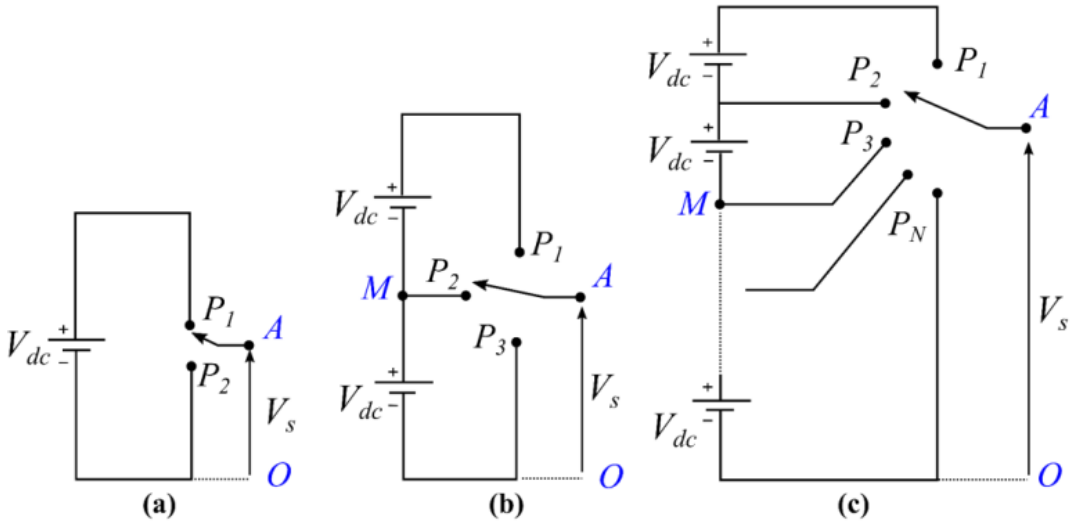


Fig I.16: Diagram of an inverter arm with two levels (a), three levels (b), N levels (c)

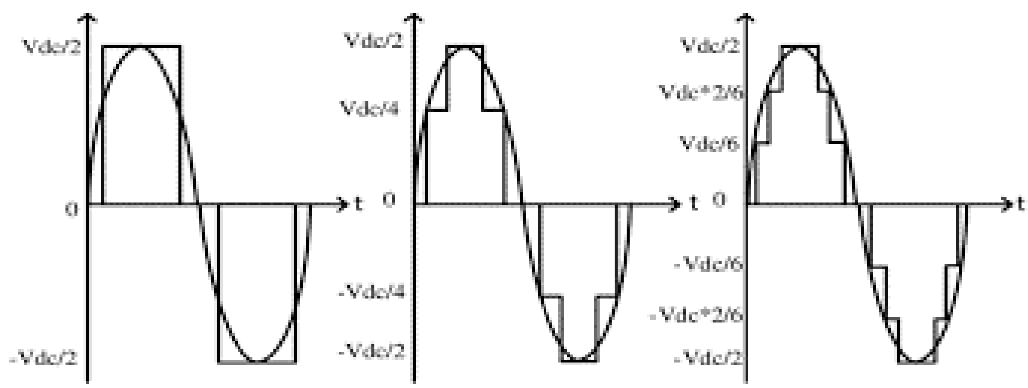


Fig I.17: Multilevel voltage output[42]

A comparison was made between a conventional reflector (two-level) and a multi-level reflector (three-level) the results are represented in the table I.2

Table 1.2: comparison between classical inverter and multi-level inverter [42]

	Conventional Inverter	Multilevel Inverter
1	THD is high in the output waveform	THD is Low in the output waveform
2	High switching stresses	Low switching stresses
3	Not used for high voltage applications	Used for high voltage applications
4	High voltage levels cannot be produced	High voltage levels can be produced

I.4.3.3 Various topology of multi-level inverter

The versatility of energy in various applications of variable speeds and power, led to the constant race for the development of energy semiconductors. Studies in the literature have proved that multi-level inverters are a viable solution for increasing power with low pressure. It has been recognized as a potential prospect for medium and high energy applications. Several topologies for a multilevel reflector have been developed over the past two centuries as in figure I.18

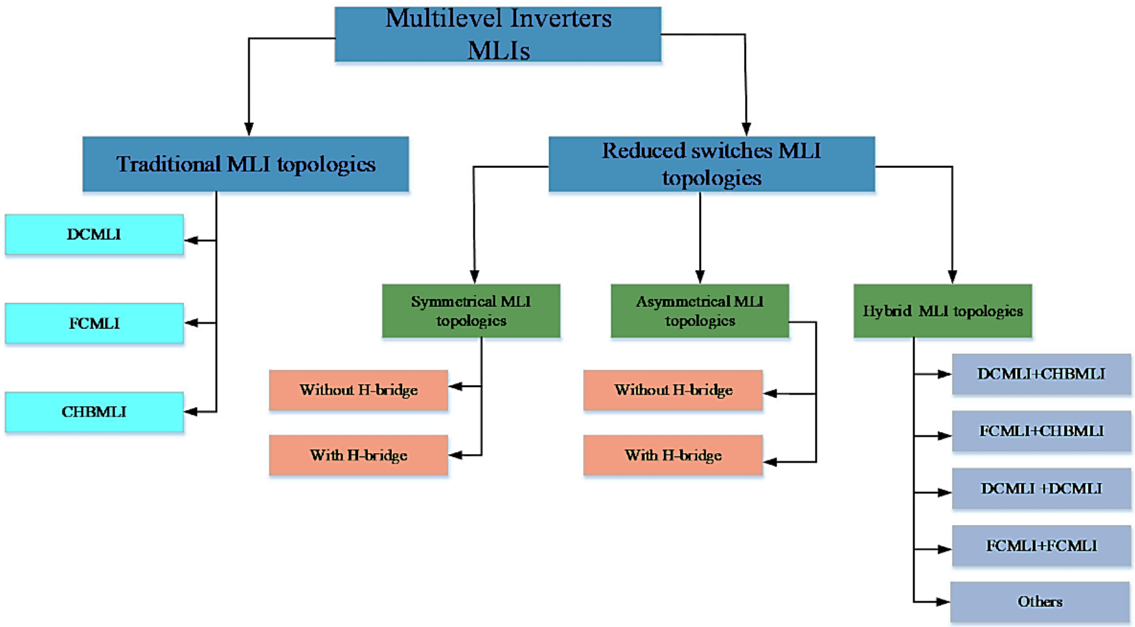


Fig I.18: Shows the different topologies of MLIs [43]

The basis of all these modern topologies are the types shown in Figure I.19, where they are considered the basic reference of only all multilevel reflector topologies that have been developed, changed in their keys, methods of control and integration .... Etc. as mentioned in the literatures

Figure I.19 represents the basic types of multi-level inverters classified according to the voltage source

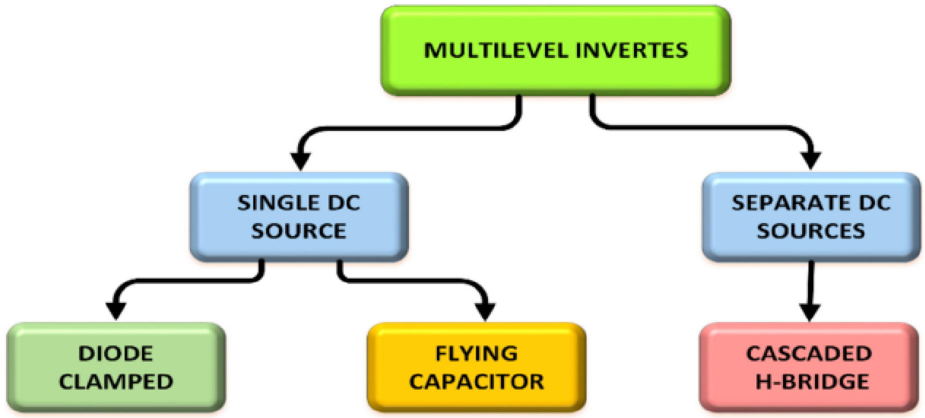


Fig I.19: Multilevel inverters (MLIs) and their classification [9]

I.4.4 Filter

I.4.4.1 Concept

The filter is considered one of the main parts of the renewable energy system. The output filter reduces the harmonics in the generated current generated by the inverters (semiconductor conversion) and improves the quality of the injected network current. High-order filters are becoming a more attractive solution for connecting the inverter to the grid, because the filter accurately compensates the voltage without phase delay at high-order harmonics. There are several types of filters, we will touch on the most widely used in the field of renewable energies **[12] [9] [8] [44].**

I.4.4.2 Types filter

There are several types of filters. The simplest variant is filter inductor connected to the inverter's output. But also, combinations with capacitors like LC or LCL can be used. These possible topologies are shown in figure I.23.

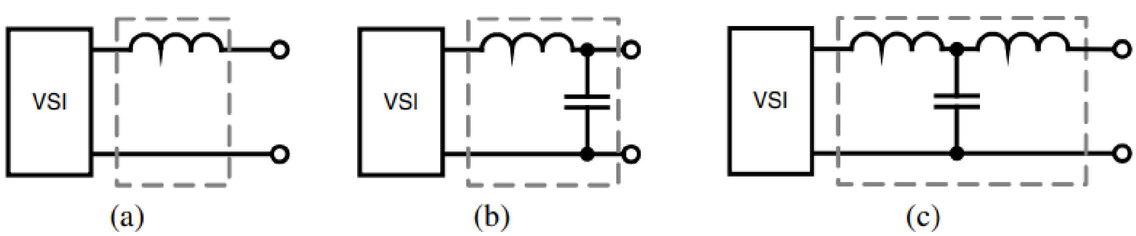


Fig I.23: types Basic filter topologies [26].

L - filter

L - filter (figure I.23 (a)) is the first-class filter, it is suitable for high-frequency inverters, where attenuation is sufficient on the other side. Inductance significantly reduces the dynamics of the system inverter filter. Despite its easy design and stable nature, its cost is high, dynamic response is slow and excessive voltage drop across the Updater. **[12].**

LC – filter

The LC-filter is second order filter and it has better damping behaviors than L-filter. This simple configuration is easy to design and it works mostly without problems. The second order filter provides 12 dB per octave of attenuation after the cut-off frequency f0, it has no gain before f0, but it presents a peaking at the resonant frequency f0 **[9]**.

The filter consists of an inductance in series with the inverter and a capacitance in parallel with the grid (Figure I.23 (b)). By using this parallel capacitance, the inductance can be reduced, thus reducing costs and losses compare with L filter. Its disadvantages include time delay and resonance frequency**[12].**

LCL-filter

the LCL-filter is a third-class candidate **[8]** that gives an attenuation of 60 dB/decade for frequencies above resonant frequency, therefore lower switching frequency for the converter can be used. It also provides better decoupling between the filter and the grid impedance and lower current ripple across the grid inductor **[6]** the design procedure to determine the parameter values of LCL filter is complicate to consider several constraints, such as filter size as well as reduced costs **[8].** Therefore, the filter must be designed precisely according to the parameters of the specific converter. In the technical literature we can find many articles on the design of the LCL filters **[10].**

Comparison between filter

Type	L-Filter	LC-Filter	LCL-Filter
Filter Type	First-order Filter	Second-order Filter	LCL Filter
Attenuation	20 dB/decade	12 dB/octave	60 dB/decade
Damping	Low	Better	Good
Design	Requires redesign	Easy to design	Requires precise design
Cut-off Frequency	Present	Peaks at resonant frequency	Peaks at resonant frequency
THD%	6.08	2.7	1.5

I.6 Conclusion

In this chapter, we learned about solar energy, which is the amount of insolation in the world in general and Algeria in particular. We also touched upon the equipment of the solar photovoltaic system connected to the grid, its types of components, its mode of operation. And we adopted the in-depth information of the inverter because it is considered a key part in a grid-connected photovoltaic system. The major issues with grid-connected photovoltaic systems are the disturbances caused by conventional inverters and their controls, as well as the limited voltage range of two-level inverters. This is why we aim to find a technical alternative to address this limitation in high-power PV installations. In our study, we propose multi-level inverters as a solution. In the next chapter, we will examine the mathematical modeling of a grid-connected PV system using multi-level inverters.

Chater 02: Modelling of grid-connected PV system with Multi-Level Inverter

II.1 Introduction

Grid-connected photovoltaic systems are a successful and reliable technology that can provide many advantages and benefits to homes and factories, as excess electricity produced can be exported to the grid or recovered, in case of cloudy weather or absence of sun. However, the low costs of photovoltaic system equipment, including: (inverter, GPV) and the continuous improvement of its efficiency, have made it an increasingly attractive option for those who are looking for ways to reduce energy costs and improve environmental sustainability.

In this chapter, we will delve deeper into the analysis of mathematical models that simulate the behavior of a grid-connected solar energy system that we will adopt in our study. We will start by reviewing the basic components of the system, and then we will derive the equations governing its behavior. We will also discuss the design and operation of this system with high efficiency to make the most of it.

II.2 Modelling of general system PV

Figure II.1 shows the photovoltaic system. Which consists of a photoelectric array, directly connected with a converter DC-DC to regulate the output voltage and an inverter DC-AC for powering AC loads. The system consists of two control structures:

1 tracking point of the great MPPT whose characteristic is to output the maximum power from the photovoltaic generator.

2 inverter control.

In the latter the inverter is connected with a filter to remove power impurities to clean up to the load

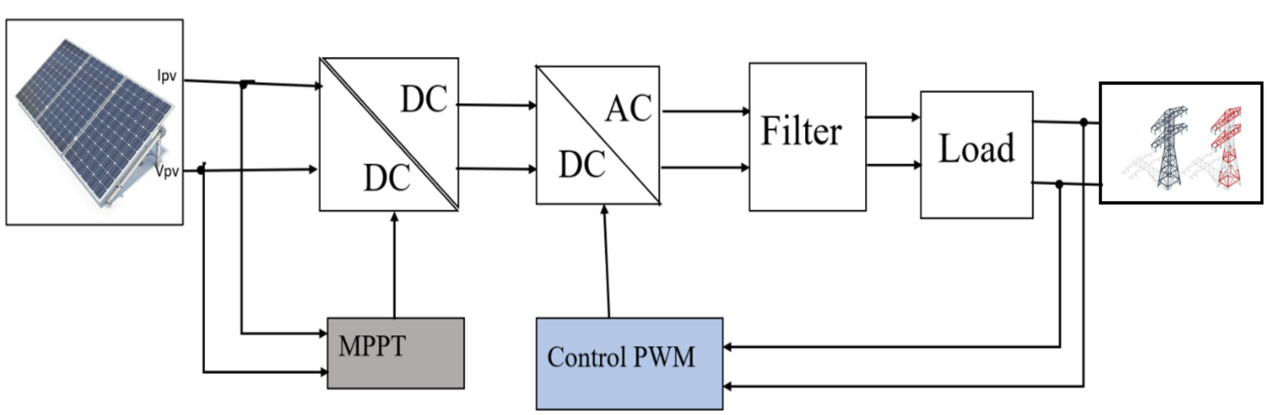


Fig II.1: Structure general system PV

II.3 Modeling system PV

II.3.1 Modelling of generator PV

In our study, we chose the polycrystalline plate type because it is temperature resistant and has good efficiency. Many mathematical models have been developed to represent the behavior of a photovoltaic cell, differing according to the procedures and number of parameters involved in calculating the final voltage and current. In our study, we used the general model that manufacturers rely on to give the technical characteristics of the solar panel **[6, 11, 35].**

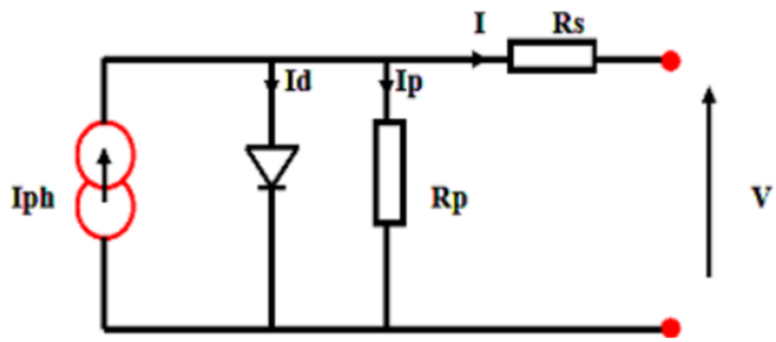


Fig II.2: Model of the actual photovoltaic cell

The generator is connected with a diode in parallel to protect the circuit from overcurrent. The diode parallel is connected in parallel with the current leakage resistor Rp. It is connected in series with the voltage leakage resistor Rs.

The expression for the electric current generated by the solar cell is written as follows

$$I_{PV} = I_{ph} - I_d - I_P \quad \textbf{II-1}$$

- I_{PV}: The generator output current PV.
- I_{ph}: The photo-generated current.
- I_d: the current passing through the diode.
- I_P: the current passing through the shunt resistor.

According to Shockley's diode equation, Id can be written:

II-2

And

II-3

So

II-4

Isa: The saturation current.

In general, for crystal cells, the parallel resistance of a cell of type

crystalline is very large and can be considered as an infinite value, therefore:

II-5

Then, the model is reduced to four parameters (Iph, Isa, Rs, Vth) whose thermal voltage Vth and the saturation current Isa are determined by these equations:

II-6

II-7

I_{SC} is the short circuit intensity.

V_{CO} is the open circuit voltage.

I_{OP} is the Optimal Power Point Current

V_{OP} is the optimal power point voltage.

Also, Iph the photo current generated represents the short circuit current Icc of the module

photovoltaic; this parameter is sensitive to irradiance.

On the other hand, the V_{CO} is the maximum value of the voltage that a solar cell can

reach zero current **[6].**

For a generator of NP modules in parallel and NS modules in series (Figure II.2) we have

$$\begin{cases} I_{cc} = N_p I_{cc(m)} \\ I_{op} = N_p I_{op(m)} \\ V_{co} = N_s V_{co(m)} \\ V_{op} = N_s V_{op(m)} \\ V_{th} = N_s V_{th(m)} \end{cases} \qquad \textbf{II-8}$$

The index m is indicated on the photovoltaic module.

Therefore, the current delivered by this generator is given by the following equation:

$$I_{pv} = N_p I_{ph} - N_p I_{sa}\left[e^{\left(\frac{V_{pv}+R_{sg}I_{pv}}{N_s V_{th}}\right)} - 1\right] - \frac{V_{pv} \pm R_{sg} I_{pv}}{R_{pg}} \qquad \textbf{II-9}$$

With

$$R_{sg} = \frac{N_s R_s}{N_p}$$

$$R_{pg} = \frac{N_p R_p}{N_s}$$

Also, the output current and voltage of a photovoltaic field are:

$$V_{PV} = \sum_{i=1}^{N_s} V_i = V_1 + V_2 + V_3 + \cdots + V_{Ns} \qquad \textbf{II-10}$$

$$I_{PV} = \sum_{i=1}^{N_p} I_i = I_1 + I_2 + I_3 + \cdots + I_{Np} \qquad \textbf{II-11}$$

The output power of the PV generator is given by:

$$P_{PV} = \sum_{i=1}^{N_p} V_i \sum_{i=1}^{N_p} I_i = \left(V_1 + V_2 + V_3 + \cdots .. + V_{N_s}\right)\left(I_1 + I_2 + I_3 + \cdots I_{Np}\right) \qquad \textbf{II-12}$$

II.3.2 Modelling of converter DC-DC

Boost is the best choice for our experience. Its form is presented in the Figure 3 which consists of a switch (S), an inductor (L), a diode (D), an output capacitor (C), and a load (RL). Figure II.3 presents the equivalent circuits of the boost converter during on-mode and off-mode. The switch position of the converter is controlled by a PWM of the time period (T) and duty cycle (d).**[6].**

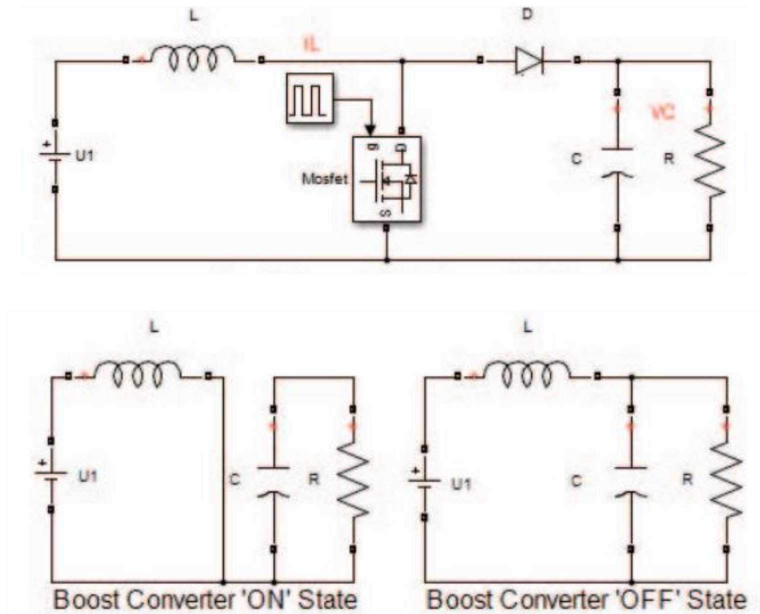


Fig.II.3: Boost converter fundamental[30]

During 'ON' state, the inductor is charge through V_{PV} defined in (8). There is no current flow to the capacitor and resistor in this state, where iL is zero as defined in (9).

$$V_{PV} = L * \frac{di_L}{dt} \quad \textbf{II-13}$$

$$0 = C\frac{dVc}{dt} + \frac{Vc}{R} \quad \textbf{II-14}$$

The state derivative of d_{iL} and d_{VC} in (10) and (11) can be obtained by rearranging (8) and (9). The state space matrix A and B in (12) for boost converter in 'ON' state can be formulated using (10) and (11).

$$\mathrm{di_L} = \frac{1}{\mathrm{L}} V_{PV} \quad \textbf{II-15}$$

$$dV_c = -\frac{V_c}{\mathrm{RC}} \quad \textbf{II-16}$$

$$\begin{bmatrix} di_L \\ dV_c \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 0 & -\frac{1}{\mathrm{RC}} \end{bmatrix} \begin{bmatrix} \mathrm{i_L} \\ \mathrm{V_c} \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} \mathrm{V_{PV}} \qquad \textbf{II-17}$$

When Boost converter enter 'OFF' state condition, where its equivalent circuit is similar to Buck converter in the 'ON' state. Therefore, state space matrix A and B for Boost converter 'OFF' are:

$$\begin{bmatrix} di_L \\ dV_c \end{bmatrix} = \begin{bmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & -\frac{1}{\mathrm{RC}} \end{bmatrix} \begin{bmatrix} \mathrm{i_L} \\ \mathrm{V_c} \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} \mathrm{V_{PV}} \qquad \textbf{II-18}$$

Similarly, the average of the boost converter state space A and B matrix for its 'ON' and 'OFF' state can be formulated with the account of switching duty cycle d. The average A and B matrix are shown (14) and (15) respectively

$$\bar{A} = \mathrm{A_{(ON)}d} + \mathrm{A_{(OFF)}}(1-d) \qquad \textbf{II-19}$$

$$\bar{A} = \begin{bmatrix} 0 & 0 \\ 0 & -\frac{1}{\mathrm{RC}} \end{bmatrix} \mathrm{d} + \begin{bmatrix} 0 & -\frac{1}{\mathrm{L}} \\ \frac{1}{\mathrm{C}} & -\frac{1}{\mathrm{RC}} \end{bmatrix} (1-\mathrm{d}) = \begin{bmatrix} 0 & -\frac{1-\mathrm{d}}{\mathrm{L}} \\ \frac{1-\mathrm{d}}{\mathrm{C}} & -\frac{1}{\mathrm{RC}} \end{bmatrix} \qquad \textbf{II-20}$$

$$\bar{B} = \mathrm{B_{(ON)}d} + \mathrm{B_{(OFF)}}(1-\mathrm{d}) \qquad \textbf{II-21}$$

$$\bar{B} = \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} d + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} (1-d) = \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} \qquad \textbf{II-22}$$

To complete the boost converter model, the average matrix of (14) and (15) are substitute into (1). The completed boost converter state space model is shown in (16).

$$\begin{bmatrix} di_L \\ dV_c \end{bmatrix} = \begin{bmatrix} 0 & -\frac{(1-\mathrm{d})}{\mathrm{L}} \\ \frac{(1-\mathrm{d})}{\mathrm{C}} & -\frac{1}{\mathrm{RC}} \end{bmatrix} \begin{bmatrix} i_L \\ V_c \end{bmatrix} + \begin{bmatrix} \frac{1}{\mathrm{L}} \\ 0 \end{bmatrix} \mathrm{V_{PV}} \qquad \textbf{II-23}$$

To obtain the output state of VC and iL, the output state space for C and D matrix is similar with (17).

$$\begin{bmatrix} Y_1 \\ Y_2 \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} \mathrm{i_L} \\ \mathrm{V_c} \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \end{bmatrix} \mathrm{V_{PV}} \qquad \textbf{II-24}$$

II.3.3 Algorithm MPPT

II.3.3.1 Brief overview on MPPT techniques

Maximum power point tracking (MPPT) is a technology that has been used to extract the maximum possible power from photovoltaic (PV)systems under any working conditions [35]. Many different MPPT methods and techniques have been proposed to improve static and dynamic performance. As represented in figure I.13.

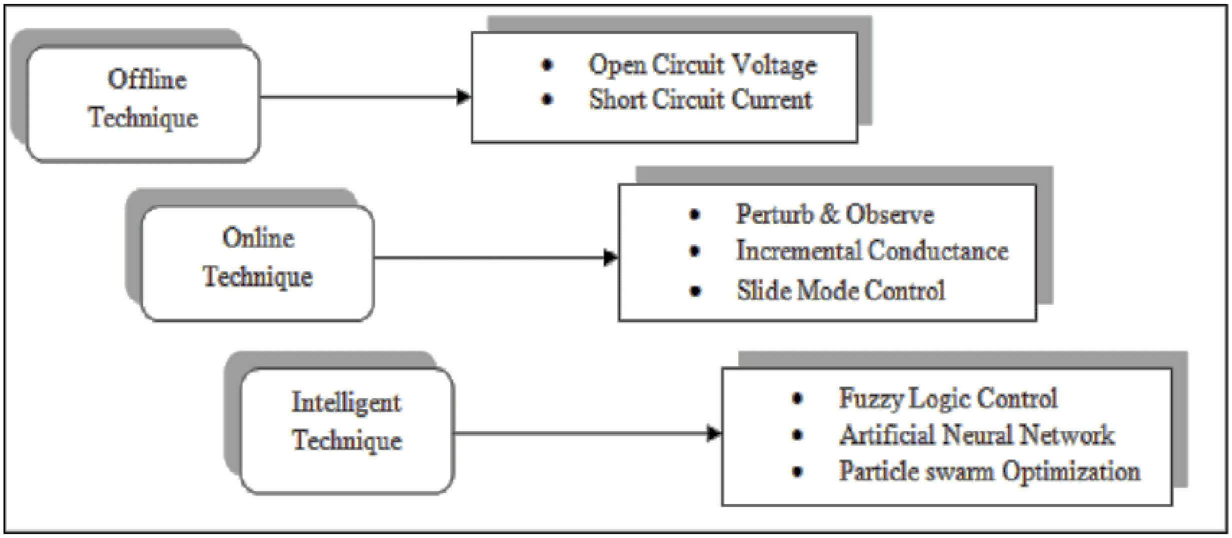


Fig I.13: Various types Algorithm MPPT

In our study, we will focus on P&O method due to its simplicity and ease of implementation.

Perturb and observe (P&O) method

The P&O method is widely used in commercial products and is the basis of the largest part of the most sophisticated algorithms. It is widely employed in practice, due to its low-cost, simplicity and ease of implementation **[12]**. The P&O method operates by periodically incrementing or decrementing the output terminal voltage of the PV cell and comparing the power obtained in the current cycle with the power of the previous one (performs dP/dV). **[45]** This is an excellent method to reach the MPP **[46].** The change in power ΔP and the change in voltage ΔV are used to determine the perturbation direction. If ΔP /ΔV is positive, the operating point is on the left-hand side of the maximum point (MPP), while the operating point is on the right-hand side of MPP when ΔP /ΔV is negative. **[23]** Once the direction for the change of current is known, the current is varied at a constant rate. the rate is a parameter that should be adjusted to allow the balance between faster response with less fluctuation in steady state. **[46]**The major disadvantages of the P&O technique are occasional deviation from the maximum operating point in case of rapidly changing atmospheric conditions, such as broken clouds. Furthermore, an appropriate perturbation size is important to ensure good performance in both dynamic and steady-state response **[12].**

We used the P&O technique due to the effectiveness of tracking and simplicity of implementation [47] as determining the appropriate step size is the key to the P&O method to achieve the desired effect [40] the value of the voltage increase for energy is determined by the following two relationships:

If $\frac{dP}{dV} > 0;\qquad Vref = Vref + dV$

If $\frac{dP}{dV} < 0;\qquad Vref = Vref - dV$

A suitable working role value is determined at the Switch gate of the isolated gate bipolar transistor (IGBT) used in the boost transformer, so that the maximum power can be extracted, the period is repeated to reach the maximum power point [48] the figure represents the flowchart of the MPPT algorithm

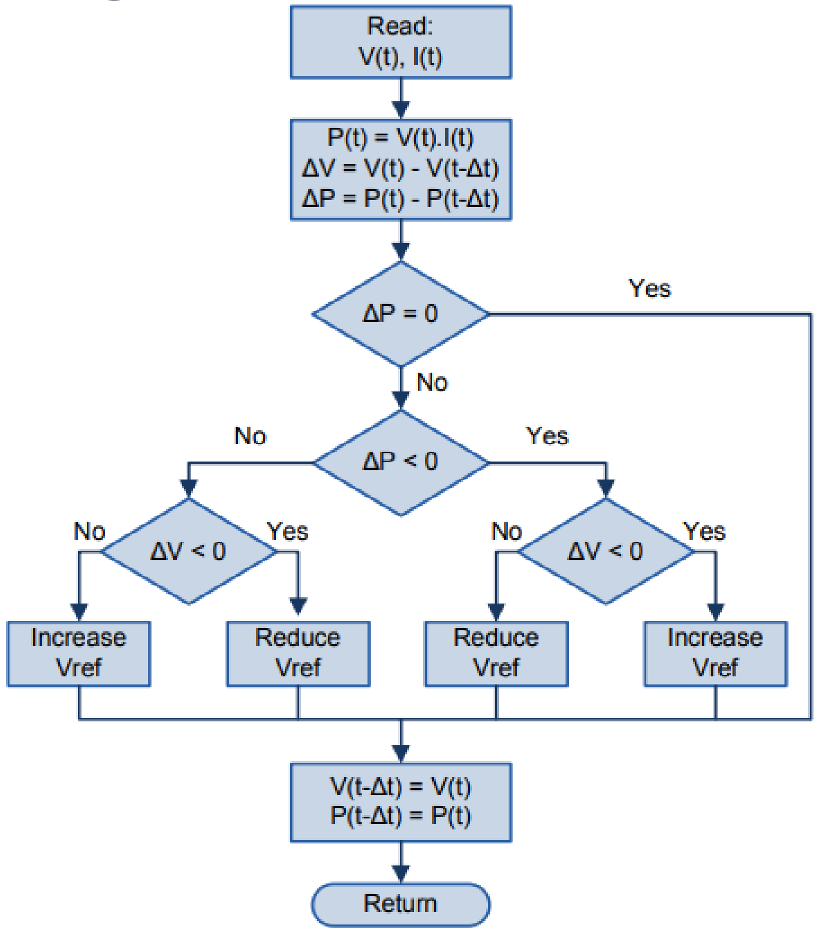


Fig II.4: Perturb & Observe MPPT algorithm flowchart [33]

II.3.4 Inverter DC-AC

We chose the Cascade for simple control and sustainability to handle high voltage from a few KV to MV. And the bearing is higher due to its modular structure that is free of capacitor balancing problems. However, it requires a number of DC voltage sources at multiple levels. **[49]** The multiplicity of voltage sources is calculated by the following relation:

$$P = 2n + 1 \quad \textbf{II-25}$$

P: Number of levels

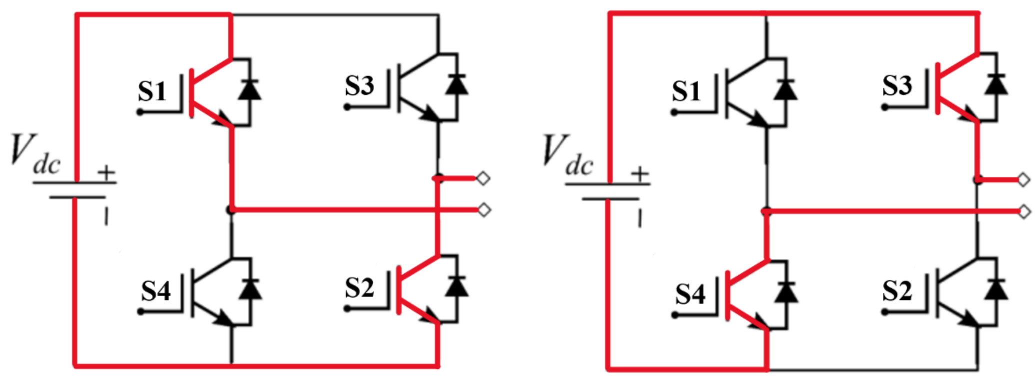
n: Number of sources. **[38]**

Where CHB is considered one of the most effective inverters because it uses IGBTs or MOSFITS to convert energy. As mentioned in the literature. The choice of switches is very important because it caused the loss or conservation of energy so that there are three types of energy loss.

- Conduction losses are dominant at a low switching frequency.
- Leakage losses: usually neglected in inverters.
- Switching losses are dominant in the case of large switching frequency. **[50]** And this is what we need in our considered study IGBTs and MOSFITs They are the best in all types of keys, but their use differs due to their features:

II.3.4.1 3 level inverters

Four switches are connected with a single DC current producing a three-level output voltage from H unit, Using PWM technology to control the working role of the switches with the aim of producing three output voltage levels as shown in the figure II.6. The work of the output module CHB is as in Figure II.5



a) The half-positive of the wave b) The negative half of the wave

Fig II.5: How the Cascade inverter works

When closing switches S1 and S2 a voltage is produced Vdc

When closing switches S3 and S4 a voltage is produced -Vdc

When closing all switches produces zero voltage

This is how we get the curve of Figure II.6, a voltage consisting of three levels, the number of levels is multiplied by adding HB units and they are connected sequentially **[51].**

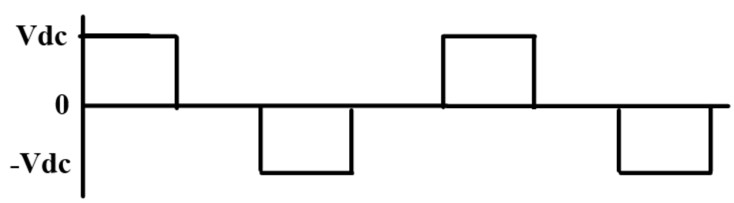


Fig II.6: Output voltage of 3 level inverter CHB

II.3.4.2 Cascade inverter 5 level:

And because our study relied on a 5-level inverter. Two HB modules are connected to obtain the desired 5levels This is what distinguishes the CHB inverter, if the number of units increases, the number of output voltage levels increases with the same previous relationship (Eq.7) the same previous control technology is used controlled in eight switches as in Table II.1.

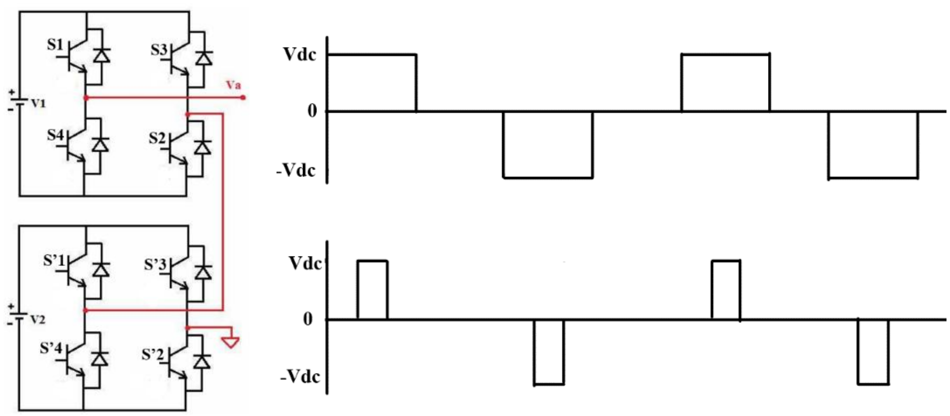


Fig II.7: CHB inverter 5-level a) structure b) curve

Table II.1: Open and closed switching and output voltage

Output voltage	Switching states				V_{H1}
	S1S2	S3S4	S'1S'2	S'3S'4	
2Vdc	1	0	1	0	V
Vdc	1	0	1	1	V
0	1	1	1	1	0
-Vdc	0	1	1	1	-V
-2Vdc	0	1	0	1	-V

II.3.4.3 Control of multilevel inverters

The power switches switch between tow modes ON and OFF modes **[52].**

While the performance of the multi-level inverter depends closely on the modulation technology (micro control) because it is responsible for the compilation of reference control signals, **[52] [36]** for this reason the technique used should be aimed at

Extension of the linear area of the reflector

Less switching loss

The overall harmonic distortion rate is lower in the wave switching spectrum

Easy execution, less calculation time **[32] [5]**

All these goals are in order to obtain a good quality of the output voltage so that the inverter can convert as much as possible of the maximum capacity and to synchronize the load.

fundamental switching frequency modulation

It is a method based on direct use. **[32]** Reduces common-mode voltages by avoiding inverter switching states that have a common offset voltage. **[53]**, it performs one or two switching of semiconductor power switches during each cycle of output voltages, producing a waveform and a low switching frequency compared to other modulation technologies. **[36]** Used in high voltage applications **[36]** They are divided into three basic types as in FigureII.8 **[40]**

High switching frequency modulation

Methods are used PWM The homeostatic wave is of high frequency compared to the sine wave. It does not need complexity or mathematical calculation unlike the previous Type. **[53]** simple charges are used, which are divided into four main types, as in Figure II.8. And we will pay attention to the last type (MC-PWM), which is divided into two types:

II.3.4.3.a.1 Phase shifted (PS) PWM

In this technique, several external carriers are used that have the same signals, the frequency and the same amplitude differ in phase by the following relation:

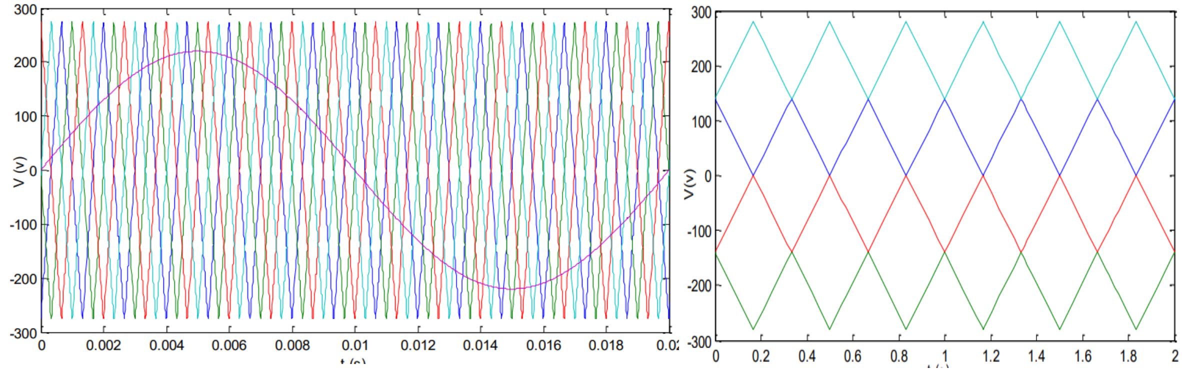
$$\frac{2\pi}{N-1} \qquad \textbf{II-26}$$

N: Number of levels

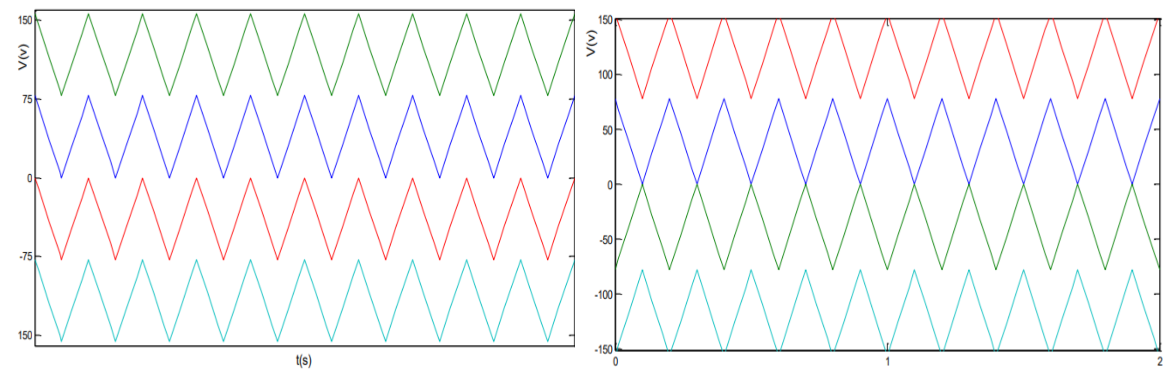
So that the phase difference depends on the number of cascading structures that are connected in series.

Modulation signals are generated with the waveguides the particular circuit is turned ON and OFF

In Figure II.9.(A) shows the PS technique.



(A)PS-PWM (B) ABOD-PWM



(C)PD-PWM (D) BOD-PWM

Fig II.9: Various types MC-PWM control[29]

II.3.4.3.a.2 Carrier Disposition Methods (level Shifted carrier)

This technique is based on a change in the amplitude of trigonometric waves. They are divided into three main types, which we will get acquainted with separately

a) Phase Disposition PWM (PD- PWM)

This topology is used in asymmetric multilevel with increasing voltage harmonics are reduced **[36]** it has the lowest distortion rate compared to other PWM methods. The values of the triangular waves vary from peak to peak as in Figure II.9.(C)**[32].**

b) Phase Opposition and Disposition PWM (POD-PWM)

this technique has carrier signals of the same magnitude as well as the same frequency, but the DC offset of carrier signals has differences, as shown in Figure II.9.(D) tire is a 180° phase angle difference between carrier signals that are above zero references and carrier.

signals that are below zero references. Similar to the PD-PWM technique.

it reduces from the lateral harmonics **[40, 54].**

c) Alternative Phase Opposition and Disposition PWM (APOD-PWM)

This technique focuses on harmonic energy in the form of lateral harmonics. **[54]** The form of this technique is shown in FigureII.9.(B), so that the alternative carrier waveforms have the same frequency and voltage but differ in Phase opposite to them, they are opposite to each other. **[41, 55]** .

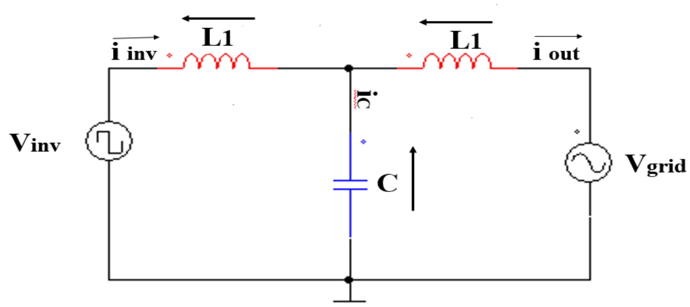
II.3.5 Modelling LCL-Filter

The main goal of connecting the inverter with the grid is to provide a stable flow between loads, generators, and the grid. **[34]** The filter is designed to meet several points, including working in the mode of Correction and checking the waves generated by the cascade inverter, and reducing harmonics.

The LCL filter is characterized by low costs and dynamism, unlike the filter L or CL. **[37]** The LCL filter is a third-order system with three components **[20, 56]** as in Figure II.10

It is used in network-connected Inverters due to its high attenuation of high-frequency signals **[57].** The candidate is determined via specific criteria as mentioned in the literature. It is also designed and its parameters are determined by criteria mentioned in the literature, including **[8, 58].**

His mathematical statement of the same form is specified in the following statements.



FigII.10: The equivalent circuit of the LCL filter

Applying KRETSCHOFF'S law and MAY'S law we find

$$i_{inv} = i_C + i_{out} \quad \textbf{II-27}$$

$$V_{inv} = i_L * L * S + i_C * \frac{1}{C} * S \quad \textbf{II-28}$$

$$V_{out} = -i_L * L * S + i_C * \frac{1}{C} * S \quad \textbf{II-29}$$

Assuming the candidate is perfect. And that in the case of an open circle: V = 0 we find:

$$i_C = \frac{1}{C} * V_C \qquad \text{II-30}$$

The last statement represents the dynamic behavior of the LCL filter.

$$\frac{1}{S^3 * L_1 L_2 C + S(L_1 + L_2)} \qquad \text{II-31}$$

The capacitive modulation of the LCL filter is displayed in the phrase +1 and the filter resonance frequency is defined in the phrase *1

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{L_1 + L_2}{L_1 * L_2 * C}} \qquad \text{II-32}$$

$$X_c = \frac{1}{w * C} \qquad \text{II-33}$$

C: Capacitor capacity

L1: inductance capacity of the first seducer

L2: inductance capacity of the second seducer

II.3.6 Modelling of grid

The connection of the grid to the photovoltaic system is based on the external control system PLL, which is a control loop for quadratic direct currents connecting the grid and the inverter

The PLL control system is a system based mainly on the PID system. It adjusts the frequency of the internal oscillator to maintain the zero difference between the input and output phases to adjust the rotation frequency. It can also quickly detect the useful phase angle in the grid-connected inverter. Figure II.11 represents the network [59-62]

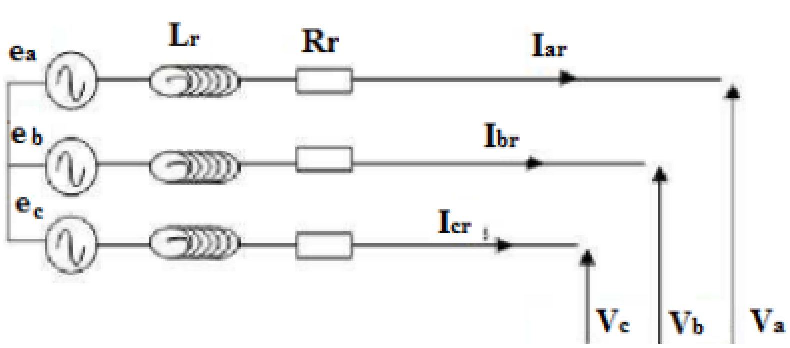


Fig II.11: Symbolic diagram of a three-phase network

The power grid can be represented by a sinusoidal voltage source in series with a resistance, called a short-circuit resistance, and since the network is defined as three-phase, we repeat the circuit as in Figure 11. The network voltage is determined by the following equations:

$$\begin{cases} Va = V_m sin(wt) \\ V_b = V_m\, sin(\,wt - \dfrac{2\pi}{3}) \\ V_c = V_m\, sin(\,wt - \dfrac{4\pi}{3}) \end{cases} \quad \textbf{II-34}$$

Assuming that the system is associated with a stellar form, we have:

$$\begin{cases} V_a + V_b + V_c = 0 \\ I_a + I_b + I_c = 0 \end{cases} \quad \textbf{II-35}$$

To model the grid power the system is converted from triple to binary using park. So, we get:

$$\begin{cases} V_{rd} = V_d - R_f \times i_d - L_f \dfrac{d}{dt} i_d + L_f w_{iq} \\ V_{rq} = V_q - R_f \times i_q - L_f \dfrac{d}{dt} i_q - L_f w_{id} \end{cases} \quad \textbf{II-36}$$

It is in the latter that the reference voltages necessary to generate a two-phase synchronous system are obtained:

$$\begin{cases} V_{invd} = R_f \times i_d + L_f \dfrac{d}{dt} i_d - L_f w_{iq} + V_{rd} \\ V_{invq} = R_f \times i_q + L_f \dfrac{d}{dt} i_q + L_f w_{id} + V_{rq} \end{cases} \quad \textbf{II-37}$$

- Lf: presents the inductance of the filter.
- RF: shows the resistance of the filter.
- Ωr is the angular velocity of the network voltage.
- Vod, Voq are the inverter voltages,
- Ird, Irq the currents in the rotating frame (d-q).
- Vrd, Vrq are the voltages of the network on the axes d and q, respectively.

The terms active and reactive energy can be represented by two phrases. After using the park adapter:

$$\begin{cases} P = \frac{3}{2}(V_{gd}i_{gd} + V_{gq}i_{gq}) \\ Q = \frac{3}{2}(V_{gq}i_{gq} - V_{gd}i_{gq}) \end{cases} \quad \text{II-38}$$

We see that the reactive power is directly controllable by the current iq. To get a unit power factor, the reference reactive power must be zero (Qref = 0)

So, the component on the q axis of the current is zero which means that the current has just one component which is on the d axis. The expression of the active and reactive powers becomes

$$\begin{cases} P = \frac{3}{2}V_{gd}i_{gd} \\ Q = 0 \end{cases} \quad \text{II-39}$$

II.3.7 Control of the grid

The regulation of the grid feeder current is of great importance in the active energy exchange between the photovoltaic array and the grid, in grid-connected photovoltaic systems, to ensure efficient operation and stability, using an appropriate controller. The more improvements the controller makes, the more stable the system becomes and the dynamic response of the system improves. Usually, the control consists of three main modules:

II.3.7.1 DC bus voltage regulator

that regulates the output voltage of the photovoltaic array. DC bus voltage regulator after MPPT algorithm and before multilevel inverter.

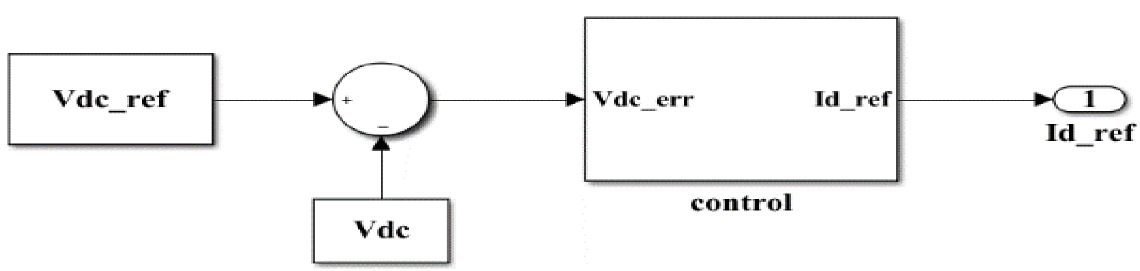


Figure II.12: Block diagram of the VDC voltage regulator

The voltage error statement is written in the following form:

$$V_{dc}(err) = V_{dc}(ref) - V_{dc}$$

Applying KRETSCHOFFS law, we find the term of the DC vector current as follows:

$$I_{dc} = C_{dc}\frac{dV_{dc}}{dt} = I_{PV} - I_{inv}$$

- I_{PV}: The output current of the chopper.

- I_{inv}: The input current of the inverter Iinv=Ir+Ic
- C_{dc}: The DC bus capacitor.

The schematic of the DC bus model is shown in the following figure:

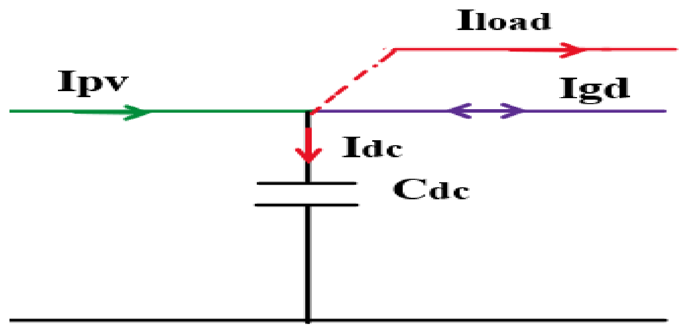


Fig II.13: The continuous bus model of our system

The final continuous carrier term is obtained as follows:

$$\frac{dV_{dc}}{dt} = \frac{I_{pv} - I_{gd} - I_{load}}{C_{dc}}$$

II.3.7.2 Closed PLL loop

The inverter output voltage coincides with the network voltage, that is, it determines the amount of the inverter output voltage angle. Shows the classical form of a three-phase PLL.

II.3.7.3 Current controller

used to determine the value of the current Fed to the network.

PWM techniques are usually used to generate pulses for semiconductor switches of the CHB inverter.

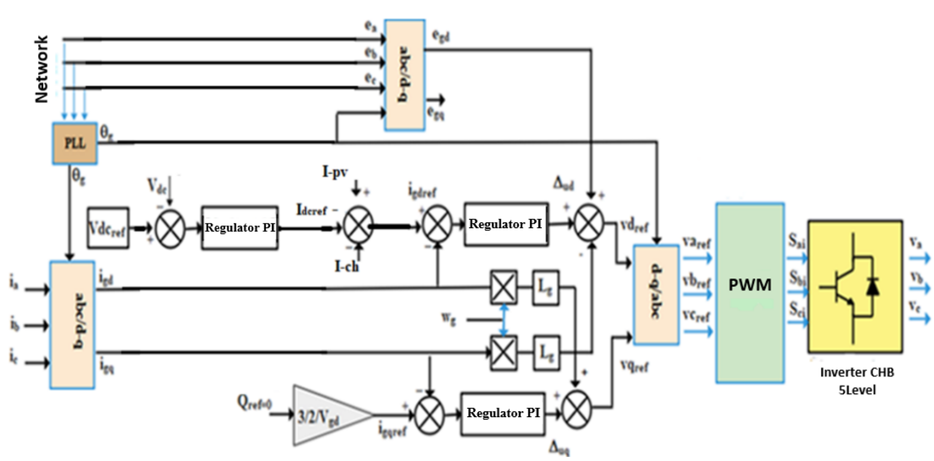


Fig II.14: The control structure of CHB inverter.

II.4 Conclusion

In this chapter we got acquainted with the mathematical equations of the components of our photovoltaic platform connected to the network, which, in turn, determine the behavior of each device and the factors affecting it. In the third chapter, we will try to apply these equations in one of the programs to learn more about the system and how it works.

Chapter 03: Simulation and results

III.1 Introduction

MATLAB as a powerful tool is valuable and effective for various scientific and engineering fields. It is used in detecting and analyzing electrical errors, finding the necessary solutions, solving equations and correcting them, as well as analyzing the electrical behavior of the circuit and searching for errors. In this chapter, we present the results of the simulation of our photovoltaic system connected to the grid using the equations that we adopted in the previous chapter. The simulation results that we obtained were using the MATLAB program because it is considered easy to use, and it depends on most programming languages. And taking into account various factors that affect the performance of the system, including: solar radiation, inverter parameters and solar panels. Characteristics and Axis of the rectifier current, alternating current.

III.2 Sizing of our system

Sizing of photovoltaic systems is an important part of system design. Take into account the relationship between the sizes of the photovoltaic array, the grid and the rest of the equipment

Knowing the dimensions of the system is a very important step to simulate and operate the system. And to know the obstacles that it may face, such as weather fluctuations and technical errors when applied on the ground

In our study, we adopted the use of the parameters of an existing solar panel we have (we adopted the photovoltaic panel located in the laboratory of our department) we used it and we considered the presence of four panels to obtain the photovoltaic array and we used a public network as used in the paper the rest of the system parameters are shown in the table

Table III.1: Proposed system parameters

GPV	Nominal Peak Power	Pmpp	300W
	Open-Circuit Voltage	Voc	45V
	Short-Circuit Current	Isc	8.60A
	Maximum power Voltage	Vmpp	37.65V
	Maximum Power Current	Impp	8.08A
BOOST	Condensate	C_B	4000uF
	Inductance	L	200mH
Inverter CHB	Source Tension DC	Vdc	100
Filter LCL	inductance capacity	L1	2e-6 H
	Capacitor capacity	C	0.2C
	Inductance capacity	L2	2e-6H
Load RL	Resistive	R	10
	Inductance	L	0.3
Grid	Single phase tension	Va	311

The results of the simulation of the photovoltaic system obtained by us in the metlab program are shown in Figure III.1:

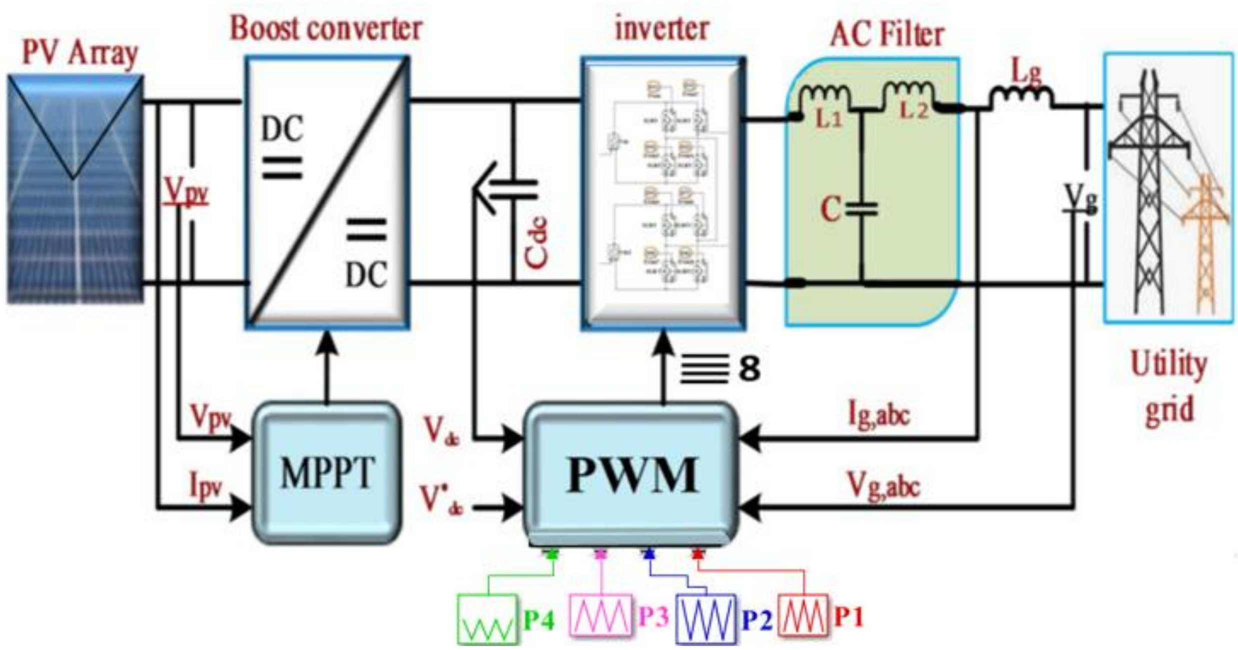


Fig III.1: simulation diagram of PV system connected with the network

III.3 Results of global system

III.3.1 Results of the solar radiation

We have selected these values for the intensity of solar radiation in order to adjust and coordinate them to match the degree of brightness of the sun during daylight hours with approximate values.as shown in the figure III.1.

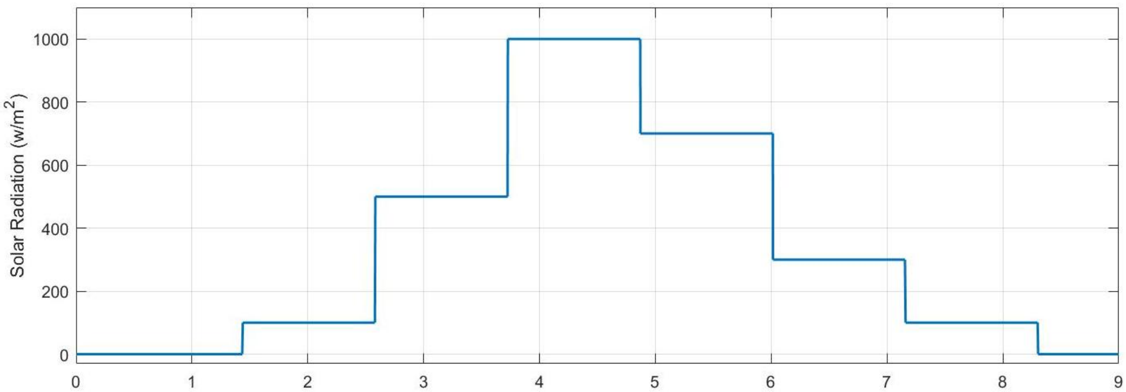


Fig III.1: A random example of solar radiation variation

III.3.2 Results of load

We adopted a change in the load values as shown in Figure III.2 in order to understand the impact of control and network behavior on the acquisition of energy from the solar panel and charging the load in case of solar power failure.

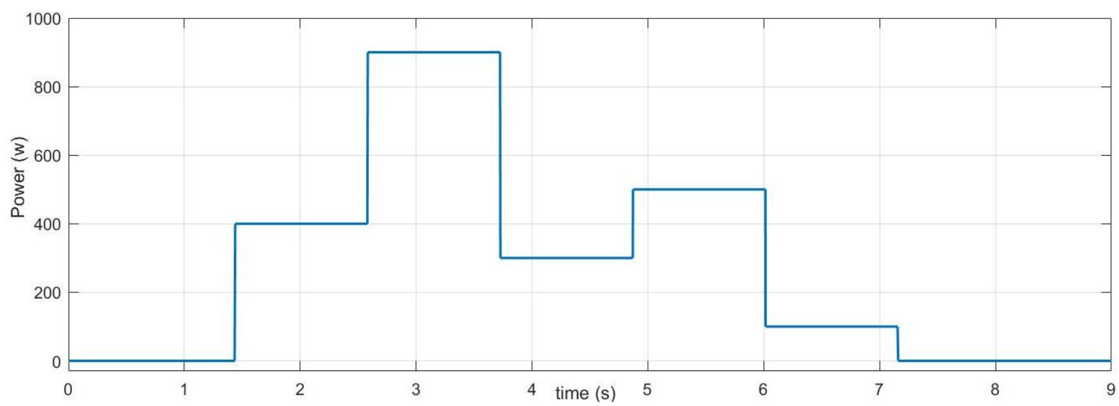


Fig III.2: Variation in load values

III.3.3 Results of PV generator

The results of the photoelectric array simulation are presented in Figure 12. We assumed a constant temperature and adopted a change in the intensity of solar radiation as previously assumed. The results are shown in the attached forms

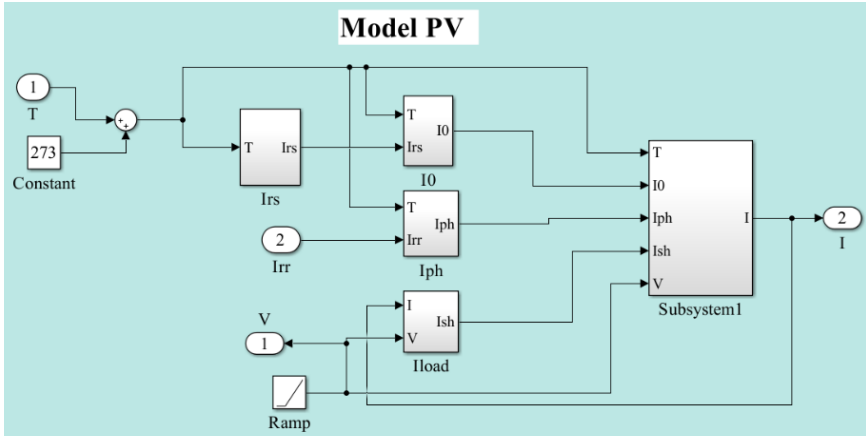


Fig III.3: Simulation diagram of the PV

The figure III.3 is expressed on the general Modal of the photovoltaic panel where we used constant values to find out the validity of the modal results.

In our study, we used four solar panels with the same characteristics, we combined two in sequence and combined them by branching, as in the figure III.4

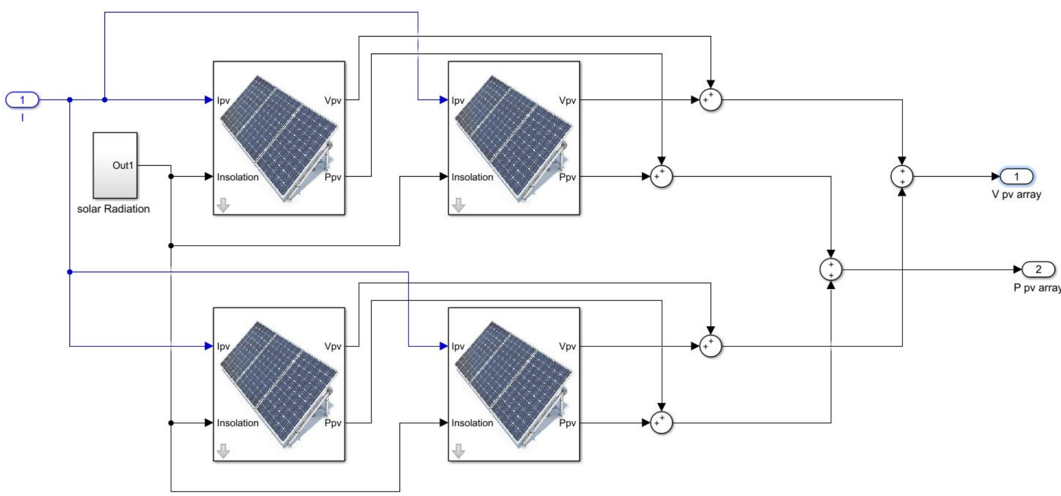


Fig III.3: Simulation diagram of the PV array

The results obtained are as follows

III.3.3.1 the current

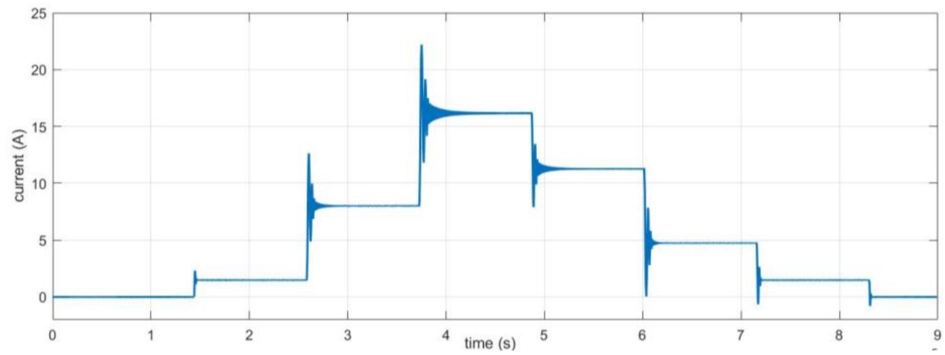


Fig III.4: Output current of solar array

We note that the current values change with a change in the intensity of solar radiation, at the same rate as the solar radiation changes, but there is uncertainty at the beginning of any change to move from a current level to a new current level, after which the current is constant.

III.3.3.2 The voltage

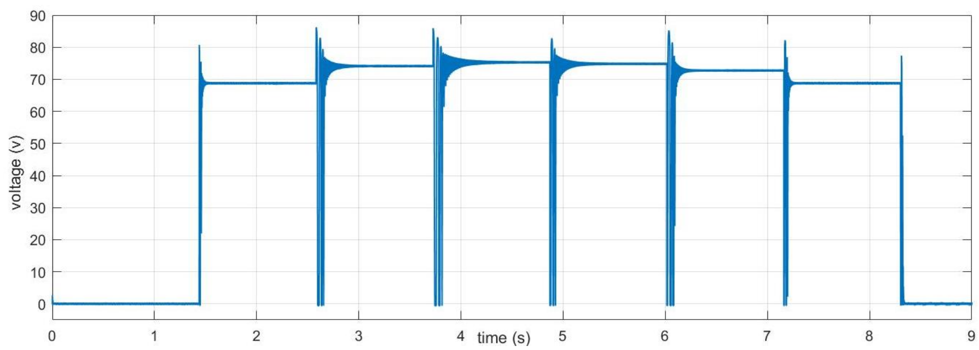


Fig III.5: Output voltage of solar array

In the tension curve, we notice that the tension value was zero when the radiation was zero, but then it became almost constant at approximately the same value of 75V. There is a change in the value of the tension with the change of radiation, but it is slight.

III.3.3.3 The power

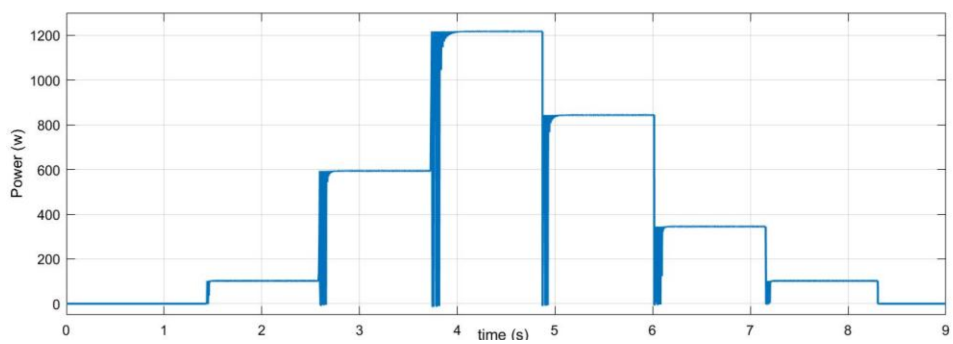


Fig III.6: Power of solar array

The energy of the plate is the product of the multiplication of the current in tension and this explains the result of the power curve of the photovoltaic array so that when the solar radiation intensity was ideally 1000 the energy output was at the peak. At the moments when the intensity of the radiation changes, there was a disturbance in the change of the energy value, as was the case in the current and tension.

III.3.4 Results of command bus DC

DC bus voltage regulation is essential for a photovoltaic system to function stably and correctly. Because the photovoltaic system is known to be suspicious of energy production due to its influence on weather factors. The control is very important in grid-connected photovoltaic systems because the Vdc will be one of the inputs of the inverter. In our study we used a cascading reflector known as a multi-source. We used a reference value of 100 because we adopted the boost converter because it has an output voltage value greater than the input value with MPPT technology suitable as PO as the system simulation is shown in Figure III.7

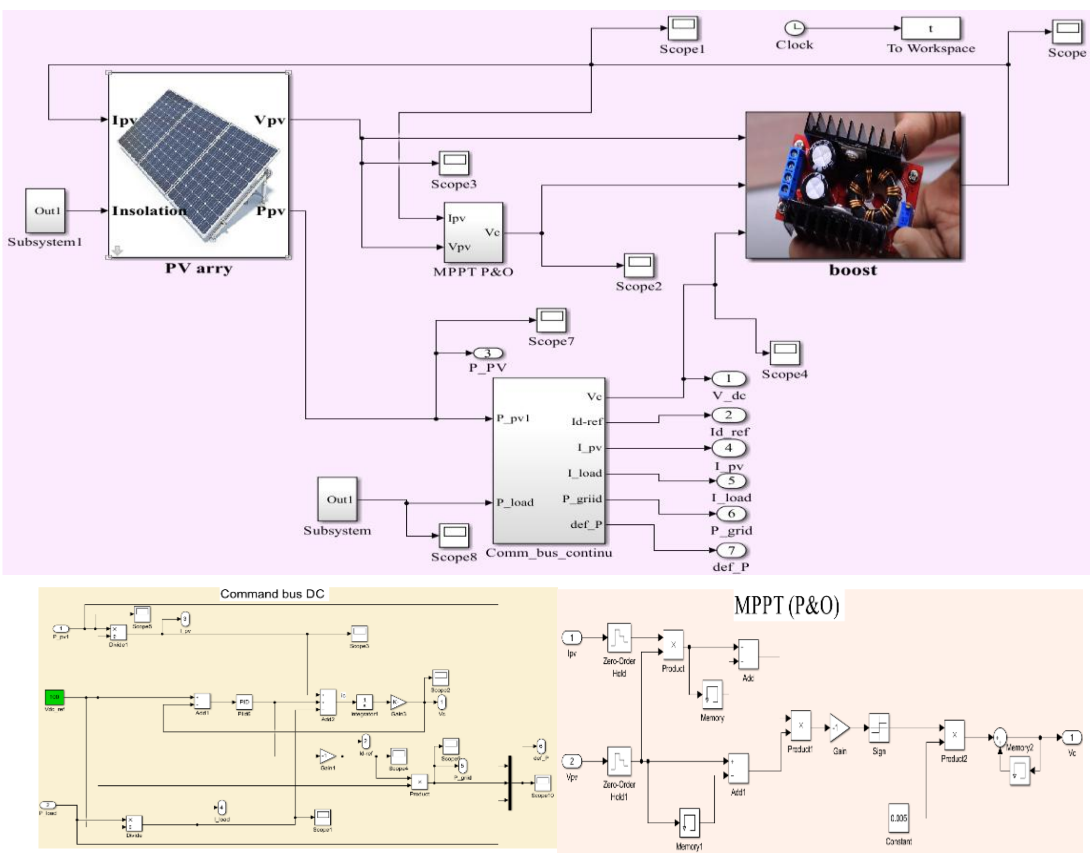


Fig III.7: Simulation of a solar array system with boost and MPPT technology

III.3.4.1 Different voltages

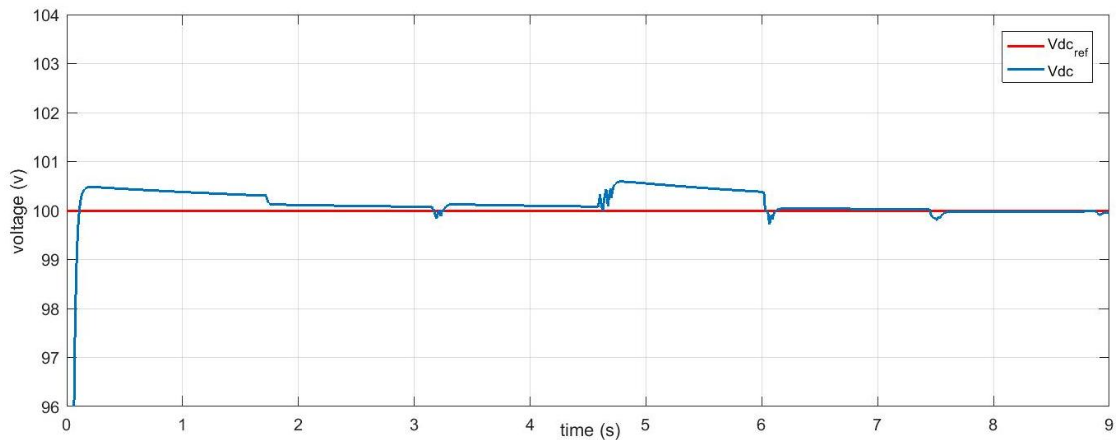


Fig III.8: The DC bus voltage of the input of the five-level DC inverter

We note that the control unit was able to track its reference value despite changing conditions such as solar radiation or a change in the load and the uncertainty value did not exceed 0.6%. Finally, we summarize that the controller provides convenient linear control and fast dynamic response to the DC connection voltage.

III.3.4.2 Power of system

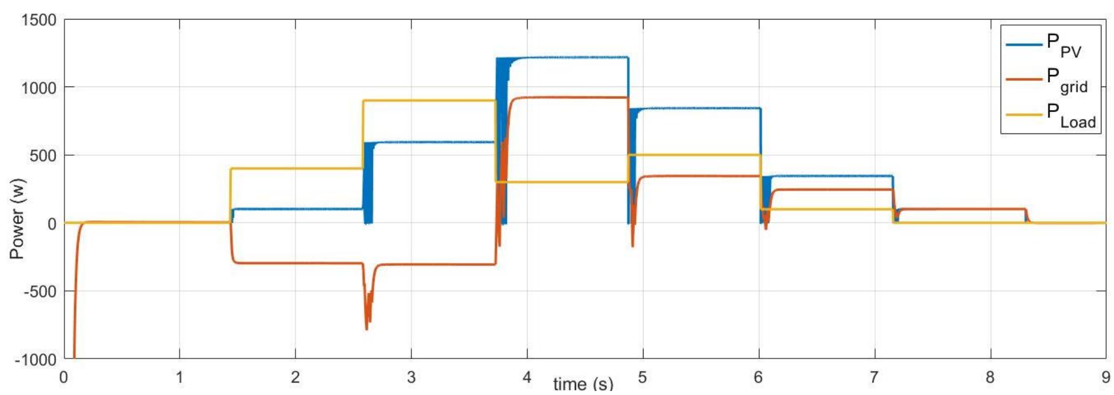


Fig III.9: The evolution of the various power of our system

Represents the negative value of the grid, that the grid is fed into the load with the photovoltaic array.

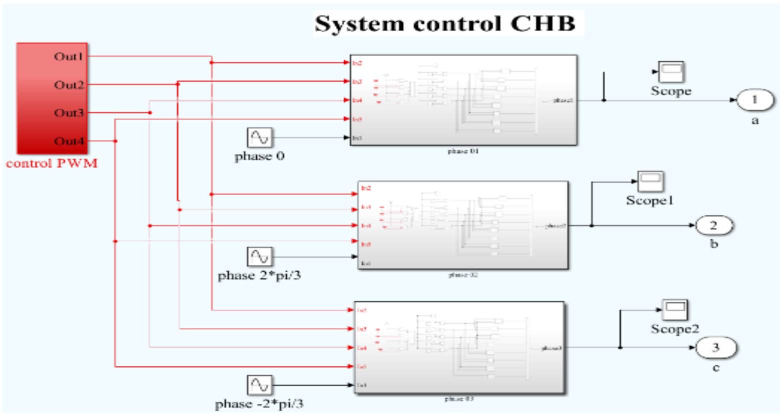
The positive value of the grid indicates that the grid consumes the excess energy produced by the photovoltaic array.

Where we observe in the figure III.9 that there is an integration between the load power and the grid power, so that if the load power exceeds the value of the photovoltaic array output, the power decreases, that is, the grid gives power to the load to cover the lack of PV. This explains the excellent performance of the controller, its role and carrier.

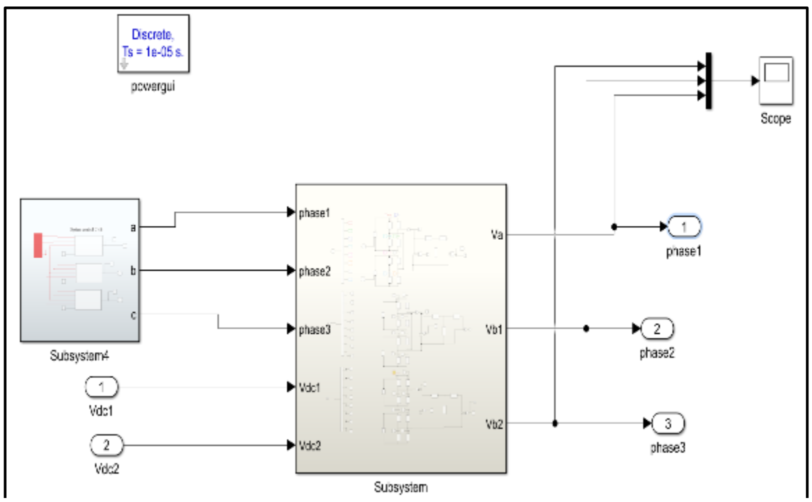
III.3.5 Results of the 5-level inverter CHB

Now we have come to the focus of our study, the five-level CHB inverter, which is the basis of the photovoltaic system, where it is the basic part of the connection between the PV generator and the grid or any AC load.

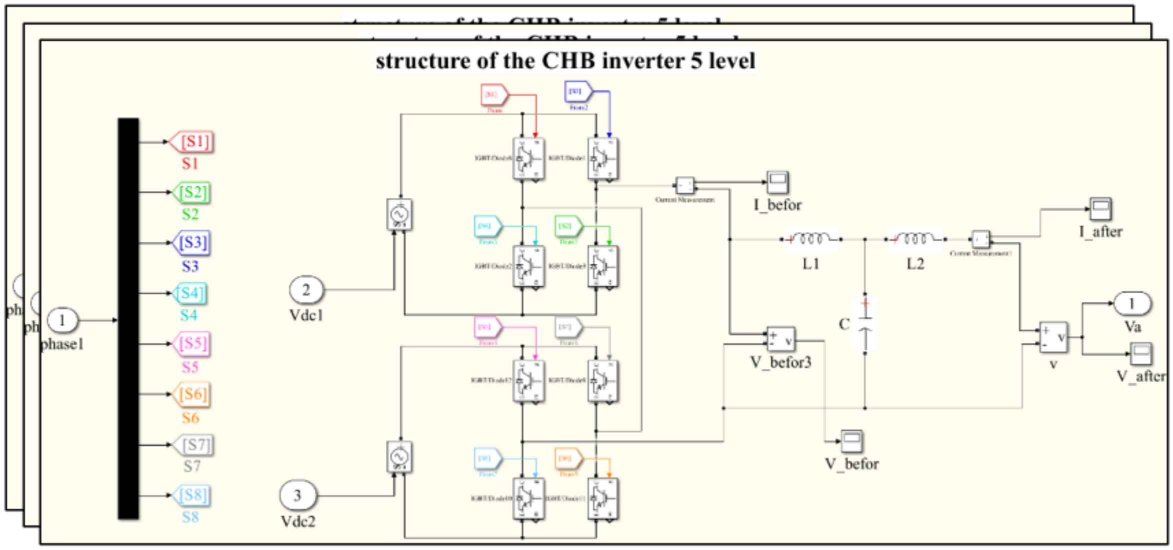
The results of the CHB inverter simulation are shown in FigIII.10. And the results of the output voltage and current in the figure III.11 and figure III.12



(a)



(b)



(c)

Fig III.10: Simulation of inverter CHB (a) System control (b) connected System control with inverter (c) structure of CHB inverter 5-level

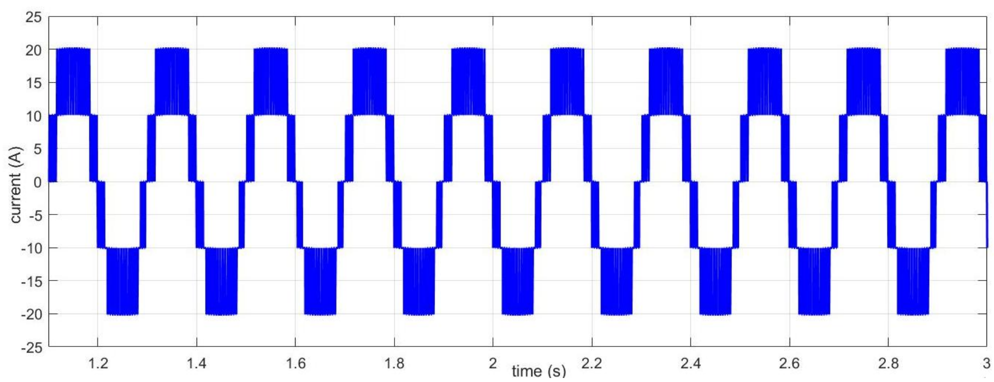


Fig III.11: output current of inverter

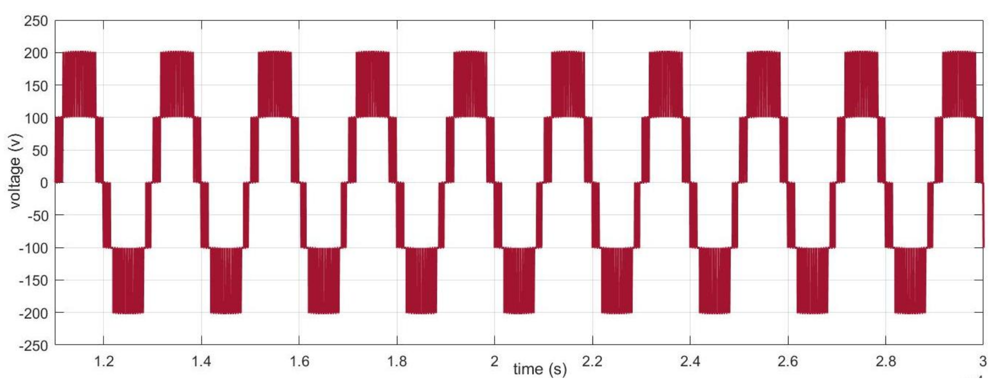


Fig III.12: output voltage of inverter

We note in Figures III.11 and III.12 the results of the output of the CHB inverter, where we notice that the figure is a current and voltage curve of five levels that are similar in role and amplitude. And very close to the sinusoidal shape. The same comment applies to the three-phase CHB 5-level inverter, as described in two figure III.13 III.14.

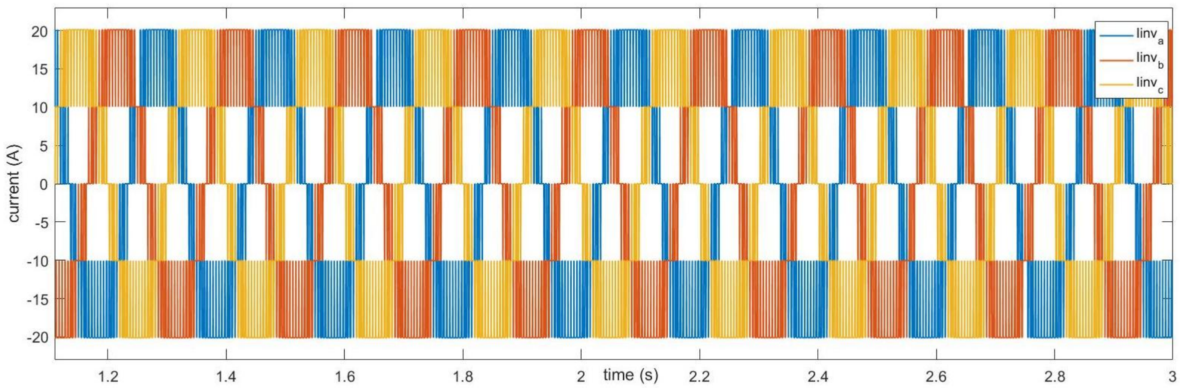


Fig III.13: output current of three-phase inverter

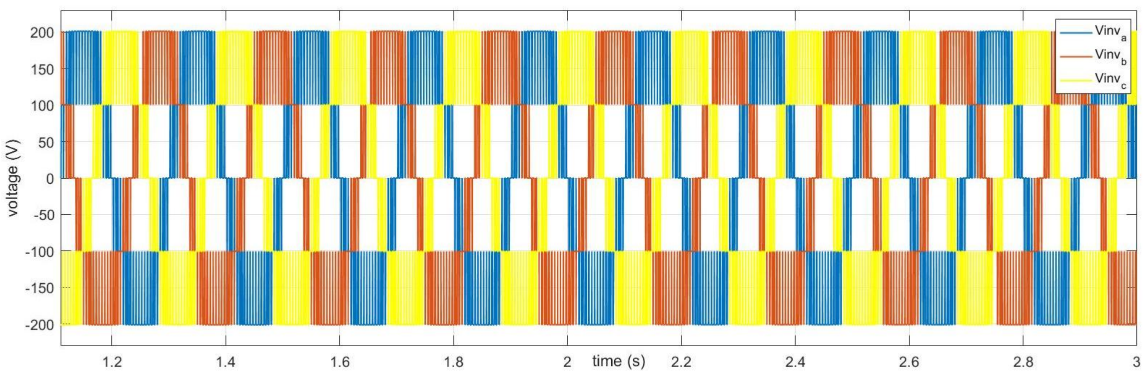


Fig III.14: output voltage of three-phase inverter

In the same simulation we changed the modulation techniques and studied the THD ratio obtained from the different CM-PWM techniques that we touched on in the second chapter the results are as follows:

III.3.5.1 Results of Phase shifted (PS) PWM

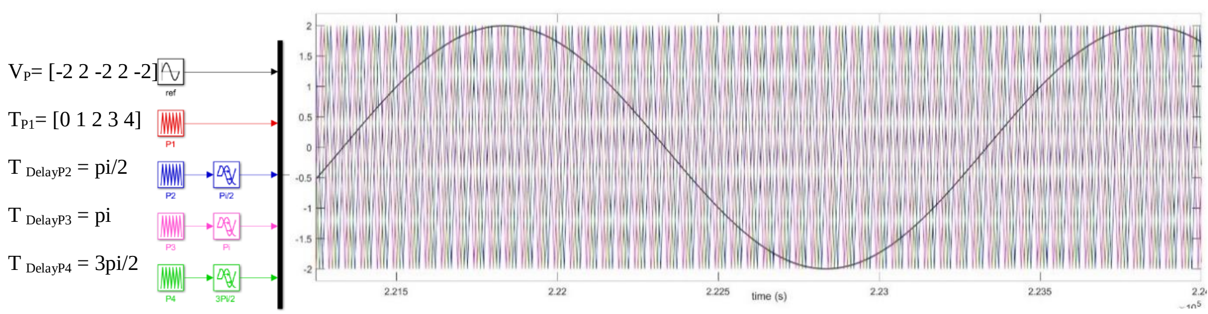


Fig III.12: Structure Phase shifted (PS) PWM

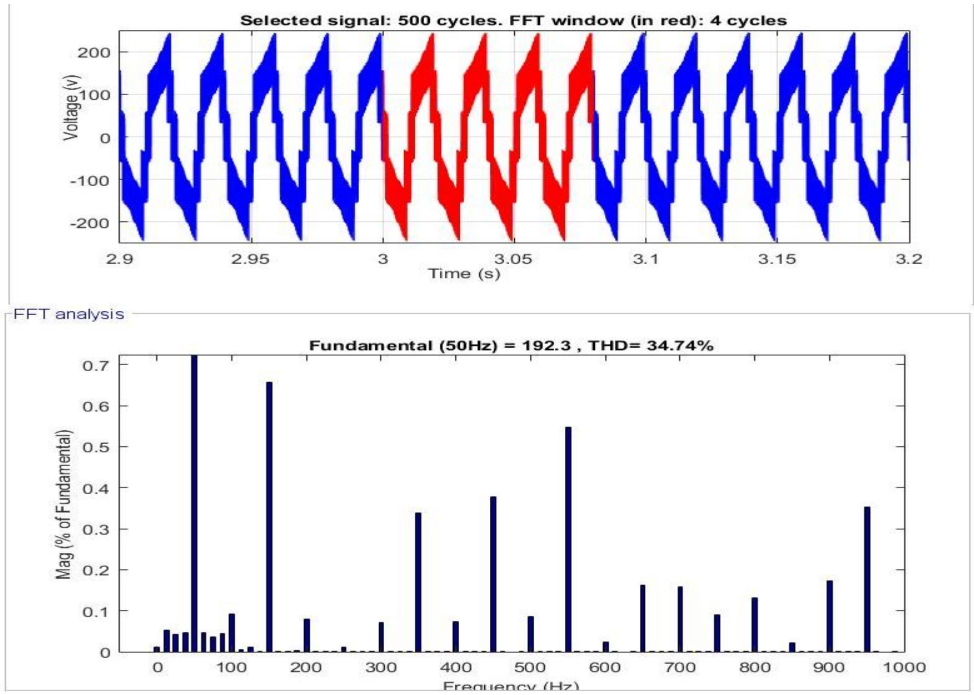


Fig III.13: Harmonic spectra of load voltage with PS-PWM

III.3.5.2 Results of Phase Disposition PWM (PD- PWM)

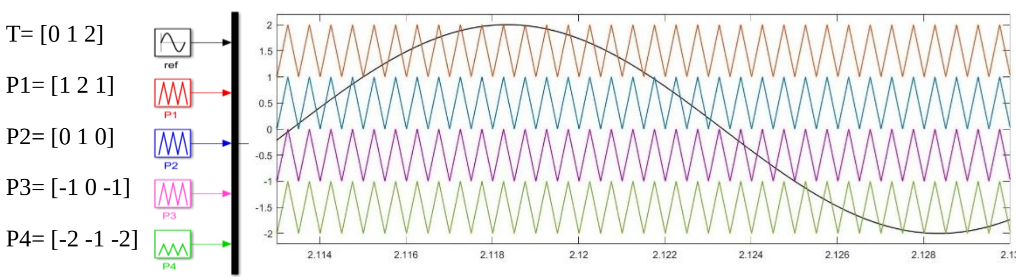


Fig III.14: Structure Phase Disposition PWM (PD- PWM)

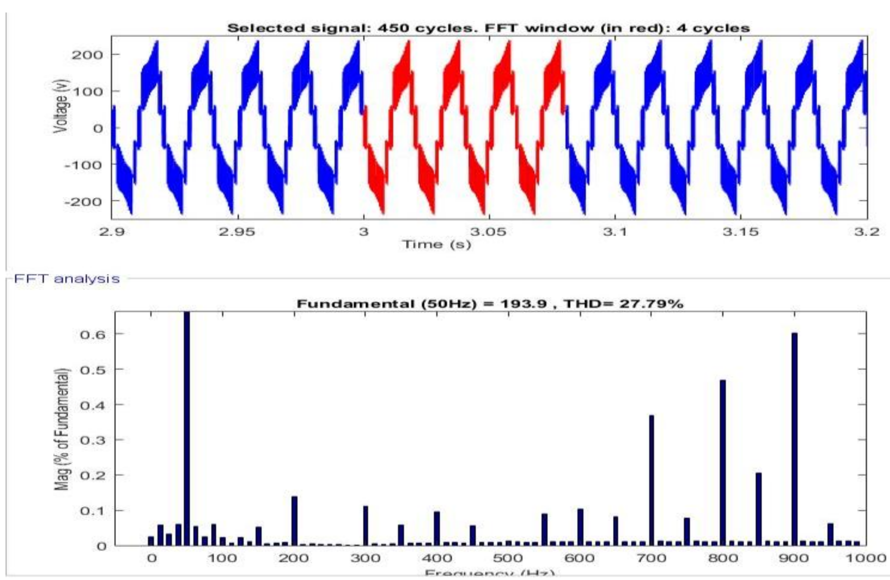


Fig III.15: Harmonic spectra of load voltage with PD-PWM

III.3.5.3 Results of Phase Opposition and Disposition PWM (POD-PWM)

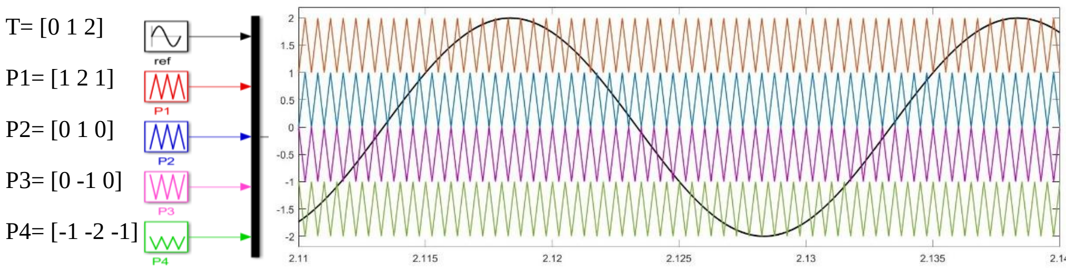


Fig III.16: Structure Phase Opposition and Disposition PWM (POD-PWM

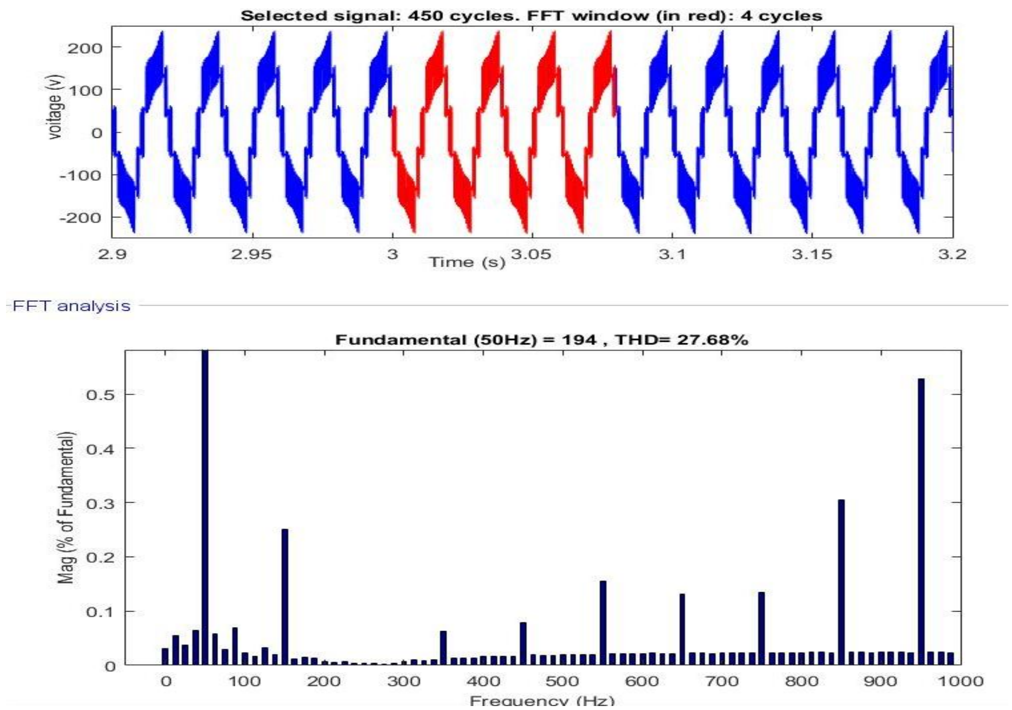


Fig III.17: Harmonic spectra of load voltage with POD-PWM

III.3.5.4 Results of Alternative Phase Opposition and Disposition PWM (APOD-PWM)

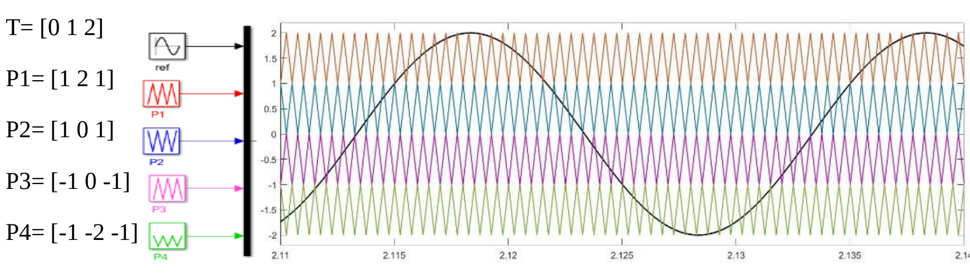


Fig III.18: Structure Alternative Phase Opposition and Disposition PWM (APOD-PWM)

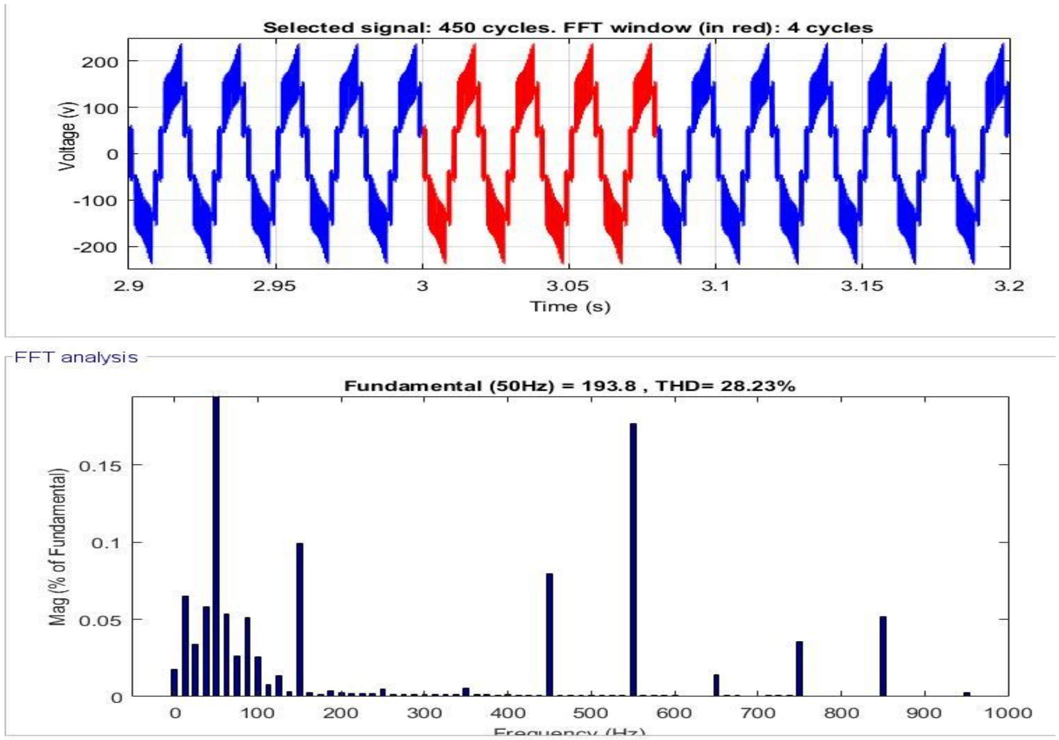


Fig III.19: Harmonic spectra of load voltage with APOD-PWM

III.3.6 Analysis of results

The diagrams (Fig III.12–Fig III.14–Fig III.16–Fig III.18) represent the results of the structures of PWM technologies applied to a five-level CHB reflector the THD results of the powergui block were obtained from the FFT analysis. Explained in the figures (Fig III.13–Fig III.15–Fig III.17–Fig III.19).

As the THD results obtained by our were similar for CMD techniques, while for SP technology, the THD value exceeded the ratio of 1%.

The increase in the percentage of THD continues to reduce the efficiency of the technology and increase energy losses.

For CD technologies, the results of THD were under 1%, that is, they are good technologies compared to SP technology.

We note from the results we obtained that the best technology is APOD technology because it had a THD percentage lower than the rest of the technologies by THD=0.44%. Then followed by POD technology with a ratio of THD=0.55%. Then the PD technique, which is considered the last technique in cm techniques and the penultimate technique in our study by THD=0.61%, and the last technique in the order of less THD is the sp technique, which is considered a bad technique compared to the rest of the studied techniques because the percentage of THD in it exceeded 1% by THD =1.26%.

III.3.7 Comparison pervious study

We have compared the results obtained from the simulation of the system and now we will compare them with the results obtained in a previous study.

The previous study that they approved was conducted a year under 2024 the title cascaded H-Bridge Multilevel Inverter: Review of topologies and pulse width modulation.

III.3.7.1 General summary of approved study information

This study reviewed the topology of the PWM pulse width switching approach on a five-level cascading bridge inverter.

At the beginning of his article, after the introduction, he mentioned a general definition of the cascading bridge reflector, and then he singled out a 5-level reflector and its mode of operation, then he mentioned the types MLI, which relied on CHB, he mentioned 6 types, including H5 Inverter (SMA)–Improved H6.

Then he singled out the title of the types of modification techniques, mentioned 5 types with a brief definition, mentioned the characteristics of each type, including (CHEPWM–MCPWM–SPWM), then explained in the table the results that you get in the five-level CHB reflector, then mentioned the MLI services, mentioned the use of the three basic types CHB–FC–NPC, then a summary of his work, then concluded his work with thanks and appreciation before the list of references.

Table III.2: Comparison between our study and pervious study

	THD Fr = 50 Hz (our study)	THD Fr = 50 Hz (previous study 2024)
SP-PWM	34.74%	39.60%
PD-PWM	27.79%	39.60%
POD-PWM	27.68%	39.30%
APOD-PWM	28.23%	39.46%

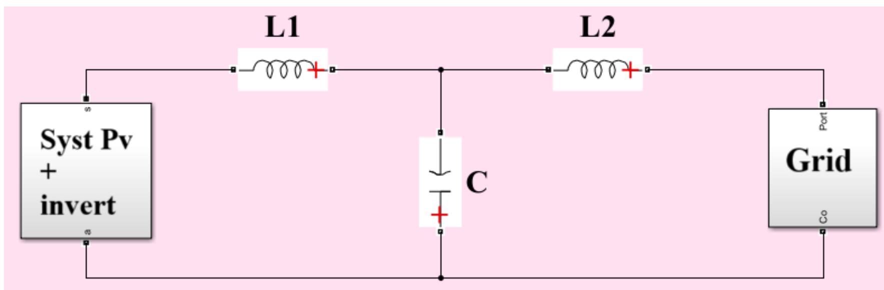
The table represents a comparison of the values of the results of our experiment with the results of a previous experiment.

We note that the values of the experiment were very large compared to the results of our experiment. Because it did not adopt the same VDC input voltage for the CHB inverter, although it is the same inverter and the same number of levels, but the results were approximate compared with the techniques.

From it we note that if the value of the input voltage of the inverter CHB changes, it is advisable to change the adjustment techniques because each technique has advantages and is at its peak at specific parameters

III.3.8 Results of the filter

The filter is used to filter the current of impurities simulating the LCL filter for study shown in Figure III.20. The results of the filter we used in the experiment are represented in the two forms III.21–III.22



FigIII.20: Simulation of LCL filter

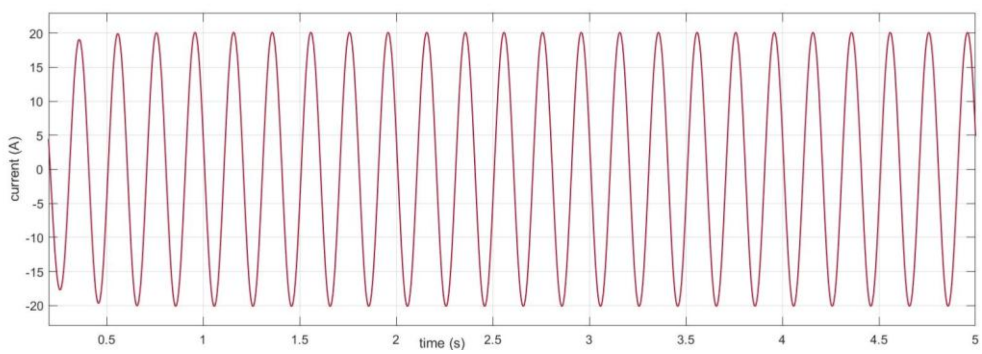


Fig III.21: Results of current after filter LCL

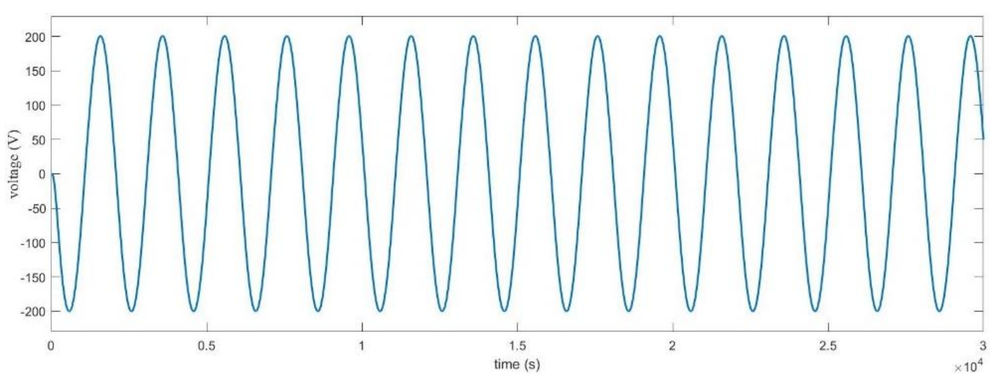


Fig III.22: Results of voltage after filter LCL

Figures III.21 and III.22 represent the current and output voltage of the generator after the LCL filter, respectively. Where we notice that The Shape of the current and Voltage has changed from a five-level shape to sinusoidal shape.

It is from it that the filter is necessary to adjust the shape of the output of the inverter.

III.3.9 Results of the load RL

In our study, we used to choose the RL load in general because most of the loads used in homes and others behave like the RL load. The simulation of the system is shown in figure12 and the results are in the figure

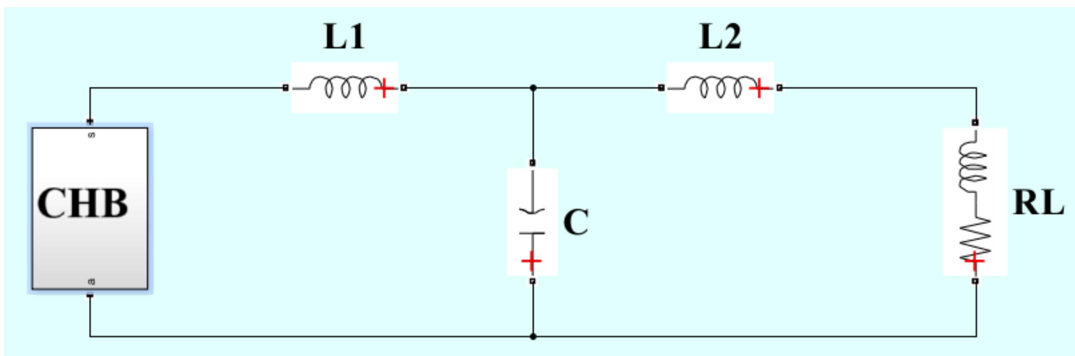


Fig III.22: Simulation of LCL filter With load RL

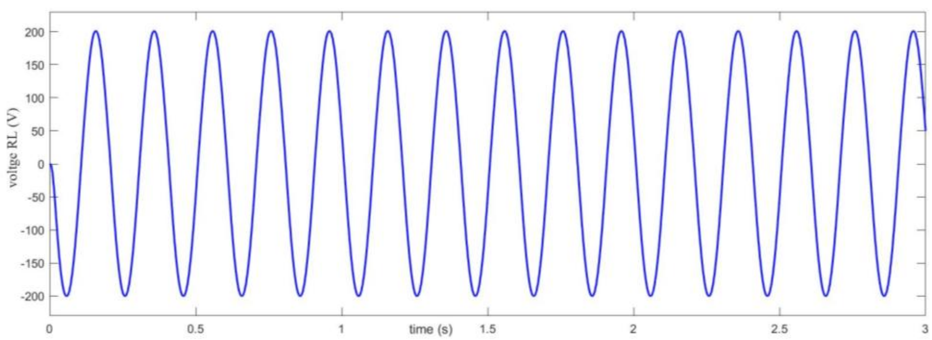


Fig III.23: output voltage of RL load

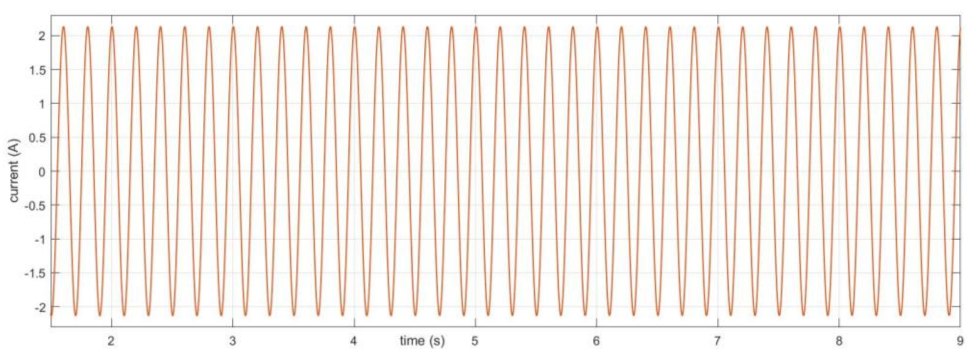


Fig III.24: output current of RL load

III.3.10 Results control of current the grid

The results of the direct and quadratic currents of the network (Id, Iq) are presented in two figures respectively

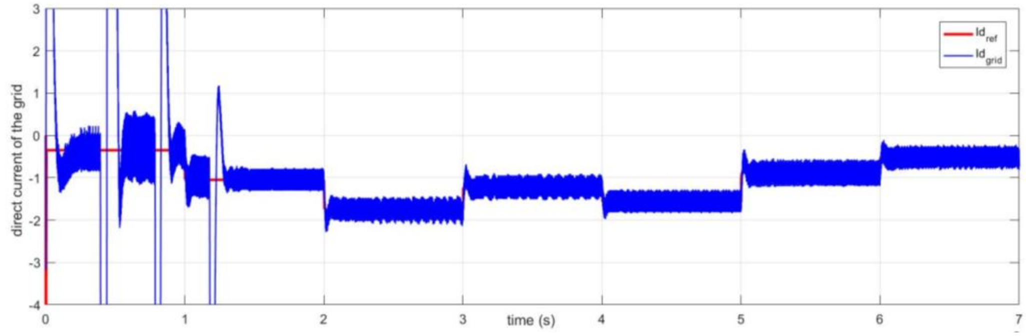


Fig III.24: The direct current of network Id.

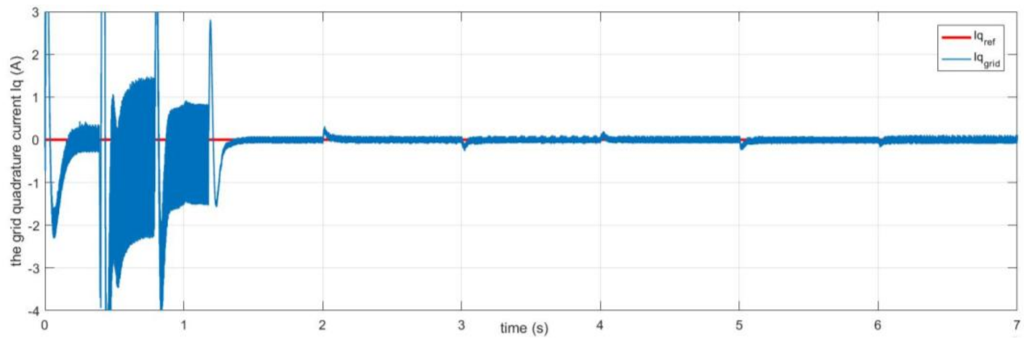


Fig III.25: The quadrature current of network Iq.

We note that the forward and quadratic current is trying to reach the reference values, but the change in the intensity of solar radiation is suspicious, but it returns to the reference value in less than a fraction of a second. From it we conclude that good control improves power quality and network stability. The resulting current distribution optimizes the output of a five-level inverter current by converting the DC current from the GPV to the load and the network according to the load needs.

III.4 Discussion of the results

Note that stream control is an essential part of the system, as the VDC value was tracked in its reference value and changes by changing its reference in a fraction of a second, using PID controllers. This is what makes DC highly efficient, as shown by the results of Figures III.8and III.9.

As for Figures III.11, III.12, III.13 and III.14, we find that the inverter is of great importance in the solar energy sector, especially the CHB series inverter, as it changes the current form from continuous to alternating without significant losses, similar to a classic inverter.

The results did not highlight the work of the inverter because it works at a high voltage and this is due to our use of the parameters of a photovoltaic panel located in the laboratory of our department. The reason to use it in order for our study to be clearer and more logical is because it is something concrete. However, they were satisfactory results.

With regard to the pulse generation techniques shown in figures III.12, III.13, III.14, III.15, III.16, III.17, III.18 and III.19 the THD value was very small due to the same reason as the previous one. However, the study we used in the comparison proved the validity of our results, although the difference in values was very large. The THD results we compared were almost 30% unlike our results did not exceed .1. 5%, but it was the same difference in values, and this is proved by the results of Table 2, and we come to the conclusion that The Uses of PWM techniques differ by the use of the inverter, as mentioned by the literatures.

The filter is an essential element to make the output of the sine inverter more and near the desired as shown by the results of the two figures III.21 and III.22

The results in figures III.23 were a confirmation of our study as correct.

The last part was the results of the network control of the output results of the inverter to connect it to the network. Figures III.24 and III.25 showed that the value of Iq and I'd changes as the value of solar radiation changes. And we say again that control is an important part of any system to proceed with continuity and higher efficiency by going beyond the first part of the results, which it interprets as in. The transitional regime.

III.5 Conclusion

In this last part of the thesis, we started with a description of the final simulation model with the parameters table. Furthermore, we presented the simulation results for both the DC side and the AC side of the system with emphasis to the quality of the voltage and current wave forms injected into the distribution network by running the FFT analysis for the currents on the grid side.

General Conclusion

In the first part of this thesis, we laid the groundwork by detailing the general system architecture of grid-connected photovoltaic (PV) systems, highlighting their various structures and configurations. A critical aspect of our discussion was the overview of the fundamental components that constitute a grid-connected photovoltaic system. We delved into the physics behind solar cells, exploring their operation principles, efficiencies, and the materials used in their construction. Furthermore, we examined the different topologies of stationary converters, placing particular emphasis on the multi-level concept. This section included a historical overview of multi-level conversion technology, outlining its evolution and the driving forces behind its development. We systematically analyzed the advantages and disadvantages of each converter topology, providing insights into their performance metrics, cost implications, and practical applications.

To conclude this chapter, we presented a comprehensive overview of passive filters, an essential component designed to mitigate high-frequency harmonics generated by the inverter. We discussed the significance of these filters in ensuring that our system adheres to established standards for harmonic compatibility with the electrical grid. By effectively reducing harmonic distortion, passive filters play a crucial role in maintaining the integrity and stability of the power delivered to the network.

In the second part of the thesis, we focused on the design and implementation of a three-phase sports inverter model, specifically utilizing a High-Tech Design (HTD) chassis. We moved on to introduce advanced control modulation techniques for the multi-level main inverter, such as pulse width modulation (PWM), selective harmonic elimination, and sinusoidal PWM. Each of these modulation techniques was analyzed in terms of their operational efficiency and their impact on power quality.

Moreover, we highlighted the challenges posed by improper LCL filter design, which can result in significant voltage attenuation at the inverter's output. This inadequacy can exacerbate resonance and oscillation issues, leading to increased total harmonic distortion (THD), instability within the power system, and a sluggish dynamic response to load changes. We detailed how an appropriately designed LCL filter mitigates these issues by reducing ripple current and voltage, thereby enabling our system to fulfill stringent power quality standards. The implementation of the LCL filter also facilitates the seamless integration of the inverter with the grid, ultimately enhancing the overall performance and reliability of the power system.

In the third part of our research, we concentrated on the modulation techniques applicable to multi-level inverters. We provided a thorough explanation of pulse generation, elucidating the process of comparing the reference waveform with the carrier waveform to derive the control signals required for switching the inverter. Additionally, we discussed widely adopted modulation strategies, such as Alternate Phase Opposition Disposition (APOD), Phase Opposition Disposition (POD), Phase Disposition (PD), and Variable Frequency Control (VFC). Each strategy was elaborated upon, highlighting its strengths and typical use cases.

Next, we explored the application of a DC-DC converter, specifically a Pak converter, which works in tandem with an integrated circuit (IC)-based maximum power point tracking (MPPT) algorithm. This section focused on the effectiveness of the IC-based MPPT in consistently identifying and harnessing the maximum power output from solar panels under varying conditions. We conducted rigorous testing across a spectrum of scenarios, including constant and fluctuating radiation levels, as well as situations where MPP tracking was not employed. The results indicated that the step-by-step conduction algorithm demonstrated robust performance across all testing conditions, even amidst load variations, confirming its reliability and efficiency.

To wrap up this segment, we introduced a distinct power quality (PQ) control method tailored for the alternating current (AC) side of the photovoltaic system. This method aims to optimize the interaction between the system and the grid, ensuring that power quality standards are met and maintained throughout operation.

In the final part of the thesis, we presented an in-depth analysis of the simulation results derived from a photovoltaic system connected to a 100 kV electrical network. The outcomes, gathered following extensive simulation tests conducted using MATLAB, provided compelling evidence of the effectiveness of the PWM sinusoidal control algorithm in enhancing the system's performance. Furthermore, we observed significant benefits from employing the additional MPP conduction strategies developed for user-specific needs, underscoring the practical applications and advantages of our research findings.

In this research, we have explored the Pulse Width Modulation (PWM) techniques used for controlling multi-level inverters in photovoltaic (PV) systems. The study focused on analyzing and evaluating the effectiveness of these techniques in improving power quality and operational efficiency.

Future Aspirations and Solutions: As solar energy technologies continue to evolve and reliance on them increases, our ambition is to enhance the capabilities of multi-level inverter systems. We aim to continue research into innovative and advanced methods for automating the control of these systems through the integration of artificial intelligence technologies. These solutions could significantly improve the dynamic performance of inverters, allowing for quicker responses to fluctuating electrical loads and changes in lighting conditions.

Moreover, we face significant challenges regarding system reliability and stability. Therefore, we emphasize the importance of developing advanced strategies for power quality control, such as employing smart monitoring of inverters and implementing sophisticated algorithms to protect against excessive disturbances. This would ensure system stability and enhance its overall performance.

The annex

Parameters of solar panel

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ملخص:

إن الطلب المتزايد على الطاقة والتلوث البيئي الذي تنتجه الطاقة التقليدية جعلها السبب في ظهور الطاقة المتجددة مثل الطاقة الشمسية واعتماد العالم عليها اليوم. ومع ذلك، فإن فعاليتها وتنوعها جعلتها تحديًا جديدًا وموضوعًا للبحث.

سنناقش في هذه الأطروحة أهمية استخدام العاكس متعدد المستويات في النظام الكهروضوئي المتصل بالشبكة، ومساهمته في تحسين الطاقة الموجهة للشبكة. سوف نتعرف على أنواع المحولات متعددة المستويات. ولكننا سوف نهتم بالعاكس المتتالي لأنه يتميز بتعدد مصادره

إجمالي جهد الإدخال. وهذا يجعله اختيارًا مناسبًا للنظام الكهروضوئي المتصل بالشبكة. سوف نبني على تطور تقنيات التحكم في التبديل العاكس باستخدام تقنيات التبديل المعروفة مثل PWM. ونبين تأثيرها على عمل العاكس باستخدام برنامج MATLAB وقيمة THDلكل تقنية

الكلمات الرئيسية:.CHB العاكس المتتالي. PWM تقنيات تبديل. THD .التشويه التوافقي

Summary:

The increasing demand for energy and environmental pollution produced by conventional energy has made it the reason for the emergence of renewable energy such as solar energy and the world depends on it today. However, its effectiveness and variability have made it a new challenge and subject of research.

In this thesis, we will discuss the importance of using a multi-level inverter in a grid-connected photovoltaic system, and its contribution to improving the directed energy of the grid. We will become familiar with the types of multi-level inverters. But we will pay attention to the cascade inverter because it is characterized by multiple sources

Total input voltage. This makes it a suitable choice for a grid-connected photovoltaic system. We will build on the evolution of inverter switch control technologies using well-known switching technologies such as PWM. And we show their effect on the work of the inverter using the MATLAB program and the THD value of each technique

Keywords: CHB cascade inverter. PWM switching techniques. THD Harmonic distortion

Résumé :

La demande croissante d'énergie et la pollution de l'environnement produite par les énergies conventionnelles en ont fait la raison de l'émergence d'énergies renouvelables telles que l'énergie Solaire et le monde en dépend aujourd'hui. Cependant, son efficacité et sa variabilité en ont fait un nouveau défi et un sujet de recherche

Dans cette thèse, nous discuterons de l'importance de l'utilisation d'un onduleur multi-niveaux dans un système photovoltaïque connecté au réseau, et de sa contribution à l'amélioration de l’énergie dirigée du réseau. Nous nous familiariserons avec les types d'onduleurs multi-niveaux. Mais nous ferons attention à l’onduleur en cascade car il se caractérise par de multiples sources

Total de tension d’entrée. Cela en fait un choix approprié pour un système photovoltaïque connecté au réseau. Nous nous baserons sur l'évolution des technologies de contrôle des commutateurs d'onduleurs en utilisant des technologies de commutation bien connues telles que PWM. Et nous montrons leur effet sur le travail de l'onduleur en utilisant le programme MATLAB et la valeur THD de chaque technique

Mots-clés : Onduleur cascade CHB. Techniques de commutation PWM. THD Distorsion harmonique