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Theme:

MPPT based on fuzzy logic controller applied to a Photovoltaic System

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DEDICATION

☆I DEDICATE ALL MY GRATITUDE AND VIRTUES TO MY DEAR PARENTS WHO HELPED ME AND WHO SPARED NO EFFORT TO TEACH ME BY THEIR SACRIFICE THAT THEY FIND HERE THE TESTIMONY OF DEEP RESPECT AND MY INFINITE GRATITUDE.

☆TO MY BROTHERS:

☆TO THE PERSON WHO ALWAYS RELIES ON ME MAMA

☆TO MY AUNTS AND UNCLES,

☆TO MY DEAR COUSINS , AND TO MY WHOLE FAMILY.

☆TO MY DEAR FRIENDS

☆TO ALL MY FRIENDS AND COLLEAGUES IN THIS PROMOTION

☆TO ALL THOSE WHO PARTICIPATED DIRECTLY OR INDIRECTLY FOR THE REALIZATION OF THIS WORK AND THOSE WHO HOPE FOR SUCCESS.

MOHAMED TAYEB BENYAZA

DEDICATION

☆First of all, I thank Allah the Almighty for giving me the courage and the will to do this modest work; which I dedicate:

☆My mother and father; without them I would not have reached this stage of study, may God help me to honor, serve and fill them.

☆To those I love and adore: my brothers Foad, Badre Eldine ,Yahya ,Abdel salam and Aissam

☆To my teachers

☆To all my friends

☆To those I spent with unforgettable moments.

And to the all those whom loved me.

☆Without forgetting my friend and my partner Mohammed Tayeb Benyaza and all his family.

Zakaria Khelfaoui

GRATITUDE

ABOVE ALL, WE THANK ALLAH FOR GIVING US COURAGE, PATIENCE AND STRENGTH DURING ALL THESE YEARS OF STUDY AND THAT THANKS TO HIM THIS WORK HAS BEEN ACCOMPLISHED.

WE WOULD LIKE TO EXPRESS OUR THANKS AND GRATITUDE TO OUR SUPERVISOR: MR. BOHAFS ALI FOR THE TRUST HE HAS GIVEN US FOR THE DIRECTION OF THIS WORK, WITHOUT CEASING TO ENCOURAGE US AND PUSH US TOWARDS THE HORIZONS OF SCIENTIFIC RESEARCH

OUR THANKS TO THE DEPARTMENT OF ELECTRICAL ENGINEERING OF THE UNIVERSITY OF OUARGLA AND TO ALL THE TEACHERS WHO TAUGHT US DURING THE YEARS OF THE CURRICULUM.

OUR THANKS ARE ALSO ADDRESSED TO THE JURY MEMBERS WHO AGREED TO JUDGE THIS WORK

. FINALLY WE ALSO THANK ALL OUR FAMILIES AGAIN AND PEOPLE WHO HELPED US DIRECTLY OR INDIRECTLY IN THE WRITING OF THIS WORK

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Glossary

AC: Alternative Current

C1: Input Capacitor

C2: DC link Capacitor

D: Duty Cycle

DC: Direct Current

F: Maximum Switching Frequency

FLC: Fuzzy Logic Control

G: Solar irradiance

GCPS: Grid Connected Photovoltaic System

Gm: Gain Margin

GPV: Photovoltaic Generator

Ic: Capacitor Current

IPM: Current at Maximum Power

Ig: Grid Current

IPV: Solar Cell Output Current

Ipv: Panel reference current

Is: Incident Solar Intensity

Isc: Short Circuit Current

I0: Dark Saturation Current

k: Boltzmann's constant

Ki: Integral gain of PI regulator

Kp: Proportional gain of PI regulator

L: Inductor

MPC: Model Predictive Control

MPPT: Maximum Power Point Tracking

N: Diode Quality Factor

NP, Ns: Number of Cells in Parallel, Number of Cells in Series

PI: Proportional Integral controller

Pm: Phase Margin

Pmax: Maximum Power

Ppv: Solar Cell Output Power

PV: Photovoltaic

P&O: Perturb and Observe

Q: Elementary Charge

Rg, Lg: Resistance and Inductance per phase of the Grid filter

RS, RSH: Series Resistance, Parallel Resistance

SAPS: Stand Alone Photovoltaic System

T: p − n Junction Temperature in Kelvin

Ts: Sampling Time

Vg: Grid Voltage

Voc: Open Circuit Voltage

VPM: Voltage at Maximum Power

VPV: Solar Cell Output Voltage

Vt: Solar Cell Thermal Voltage

VSI: Voltage Source Inverters

η: Conversion Efficiency

Résumé :
Le travail présenté dans cette thèse a pour but de faire transférer l'énergie solaire au réseau électrique en utilisant différents algorithmes de commande et de recherche du point de puissance maximale (MPPT). Parmi ces algorithmes, le ''P&O'' et ''l'IncCond'' qui sont considérés comme des commandes classiques, le troisième algorithme utilisé est une technique intelligente ''MPPT basé sur la Logique Floue''. En comparant ces trois techniques, la Logique Floue présente un meilleur comportement de point de vue rapidité de recherche du PPM et de précision au régime permanent et aussi s'avère être très performante lors d'un changement des conditions climatiques.
Pour un deuxième but de ce travail, un émulateur PV a été étudié, désigné et réalisé ce qui nous a permis de tester l'efficacité des techniques de commandes étudiées par simulation sur MATLAB/SIMULINK avec la possibilité de changer les conditions climatiques telles que la température et l'éclairement solaire en temps réel.

Abstract:
The work presented in this thesis aims to transfer solar energy to the power grid using different maximum power point control and search (MPPT) algorithms. Among these algorithms, the "P*O" and "IncCond" which are considered classic commands, the third algorithm used is an intelligent technique "MPPT based on Fuzzy Logic". By comparing these three techniques, Fuzzy Logic exhibits a better behavior from the point of view of speed of search for ppm and precision at steady state and also proves to be very efficient during a change in climatic conditions.
For a second purpose of this work, a PV emulator was studied, designated and realized which allowed us to test the effectiveness of the control techniques studied by simulation on MATLAB/SIMULINK with the possibility of changing climatic conditions such as temperature and solar illuminance in time

General introduction

Energy has always played a vital role in the daily activities of human life and its development. With development energy production became indispensable to all activities and an increased need for energy is felt in developed and developing countries and much more in recent years, a growing need that encourages an increasingly strong energy production, this production has tripled since the 60s to the present day. Essentially the energy produced came from fossil sources such as coal, oil and gas.

The consumption of energy from these sources gives rise to greenhouse gas emissions that generate increasing pollution in parallel with the growth in energy consumption. Excessive consumption of these resources would lead to a premature depletion of available reserves, which is a danger for future generations, by putting them in front of an energy crisis like the one that hit the world in the 70s, but of greater magnitude, given the daily dependence on electrical energy that the world is experiencing today. All these reasons push us to look for other alternatives to these sickle energies, and to be more interested in renewable energies such as water, wind, sun, biomass and geothermal energy. By their advantages over fossil fuels, renewable energies are a promising solution to the inconveniences of other energy sources. The latter would allow man to meet his energy needs while protecting his environment with its high solar exposure throughout the year, Algeria has all the assets to develop solar energy and make it one of its major assets for its development and to get out of its dependence on oil and gas. As a result, solar energy has experienced a strong craze and exponential growth in recent years in our country, which has led to the creation and specialization of several companies in the field. In the same context, this thesis focuses on the study of an autonomous photovoltaic system that ensures the conversion of solar energy into electrical energy. Consisting of a multi-cell photovoltaic generator, a power interface that is a simple DC/DC converter circuit and resistive load. The model of our system was developed using the Matlab /Simulink simulation software, it will allow us to study the static and dynamic behavior of our system with or without MPPT control fuzzy, which is implemented to improve the performance of the controller which is the subject of our studies in this dissertation

This work is subdivided into 3 chapters:

In the first we present and explain the principle of operation of a photovoltaic system and a photovoltaic cell as well as its mathematical model. We will also be interested in the DC/DC converter and its principle operation.

The second chapter will be devoted to the MPPT command, where we present the origins as well as the different types of MPPT command that exist .As for the second chapter, it will be entirely devoted to fuzzy logic and MPPT controller, in which we will present and explain its principle. Then we will present the MPPT command based on fuzzy logic.

Finally in the third chapter we will expose and discuss the results of simulation obtained.then we end our work with a general conclusion.

<u>Chapter I:</u>

General information in photovoltaic systems

I.1. Introduction:

The demand for solar energy electricity generation system has been continuously increasing due to the improvement of solar panel and power conversion technology, particularly with growing demand for renewable energy across the world. Large amounts of PV electricity are now injected into utility systems through distribution networks. A solar electricity generation system often comprises many PV arrays and PV inverters. A PV generation system could be formed by many parallel and serial connected PV panels to provide sufficient voltage and currents. A PV inverter that is constructed using power semiconductor devices and microcomputer-based control circuit is used in controlling the PV system operation so that it can always operate at its maximum power point (MPP) to capture the maximum possible power under any given solar irradiance. On the other hand, the PV inverters also convert the dc power generated by PV panel to 50 Hz ac power at an appropriate voltage suitable for grid connection. PV panels are usually designed with a lifetime of 25 years; however, the PV inverter’s lifetime is usually less than that due to the failure of its components. Great attention has been paid to the development of advanced PV inverters to achieve higher efficiency, higher reliability, lower cost and advanced control algorithms. Advanced power semiconductor devices, high-quality capacitors, inductors and advanced inverter circuit topologies and control strategies are the keys for high-quality PV inverters. It is imperative to adequately evaluate the inverter’s efficiency, reliability and performance to reduce the development period. For the development and experiment test of photovoltaic converters, repeatable test conditions are very often required to justify their control algorithms [1]. It would be very difficult to carry out repeatable tests by using outdoor installed PV panels as the unpredictable atmospheric conditions affect the repeatability of the test conditions and the high system installation and maintenance cost. Today various PV simulators have been developed to replace actual outdoor PV panels for testing PV inverters and control algorithms, some of them have already being commercially available.

This energy respects our environment by reducing greenhouse gas emissions (it does not emit any during its use). The prices are constantly decreasing due to the increase in production volumes, as the market is strongly stimulated by the buy-back of electricity by the electricity companies, and it has been growing at a rate of 40% per year worldwide for the last few years. Few economic sectors can achieve such results [4].

I.2. The Sun, a great source of energy

The Sun is a fantastic fireball that has been burning for 4.55 billion years. It is so big and so warm that even though we are very far from it, we still benefit from its warmth and light. Imagine instead: the Sun is 1,300,000 times bigger than the Earth, and the heat in its core can reach 15 million degrees! Fortunately, 150 million kilometers separate us and our atmosphere protects us from the power of its rays

I.2.1. Solar energy

The Sun is the basis of all energies. Sunlight can be used to produce electricity. This is done by using panels made of electronic cells that react to the sun's rays. This is called photovoltaic solar energy. These installations are becoming more and more widespread throughout the world [6].

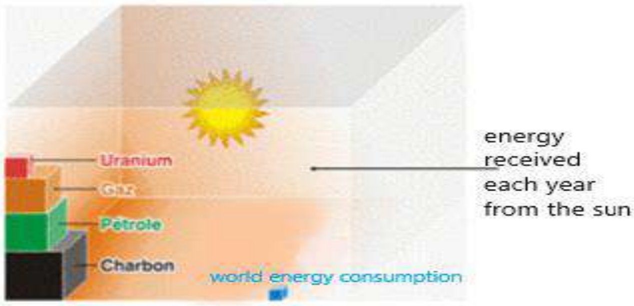

Figure I.1: received Energy per year

The solar radiation can be direct or verbose. Direct radiance is a right beam which they can concentrate by using a magnifier or a mirror. Verbose radiance is the radiance reflected by the atmosphere and by clouds, the mist and dust (fig. I.6) clouds and dust absorb and return the radiance, reducing the part which attains the terrestrial surface. When the sun shines, the bulk of radiance reaching the soil is direct; when there are clouds, 100 % of radiance are verbose. Direct radiance and verbose radiance constitute total radiance. And, by cloudy time, this total radiance cannot exceed 10 % of that accepted by sunny time [2].

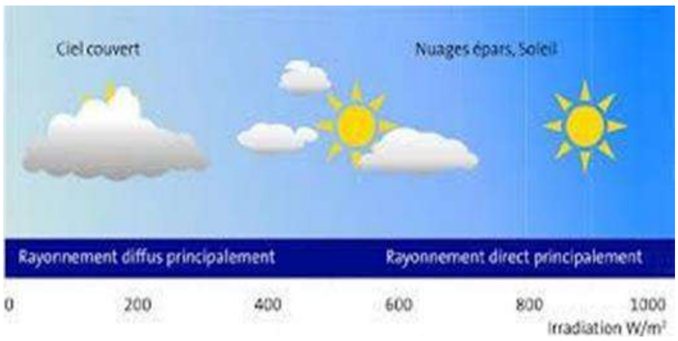

Figure I.2: Directed and diffused radiance [2]

Long cloudy periods reduce in a significant way the quantity of available solar energy. Humidity absorbs and reduces radiance .The presence of smokes, of mist or of dusts cubbyhole also the penetration of the solar radiation. This being, if the complete quantity of solar energy accepted in a given point can vary from season to the other one, it does not vary from one year to the next. [2] Under medium degrees of latitude, total radiance can attain 1 000 W/m ² at the level of the sea, at midday and by (cloudless) clear sky [1].

Besides the composition of the atmosphere, the thickness of atmosphere that radiance must cross also plays a role mattering on the valuation of the quantity of the solar radiation which attains the surface of the Earth. When the bright rays are perpendicular in the surface, the thickness of crossed atmosphere is the weakest; light is less absorbed and fewer broadcasts by the atmosphere and the surface accepts more solar energy [1].

The thickness of the atmosphere is characterized by the number of mass of air (AM). It corresponds to the report between the thickness of the atmosphere crossed by radiance (OM) and thickness crossed in the vertical of the site (OA) (fig. I.3). this relation is function of the angled height of the sun h, that is to say the angle which makes the direction of the sun with horizontal plan [1].

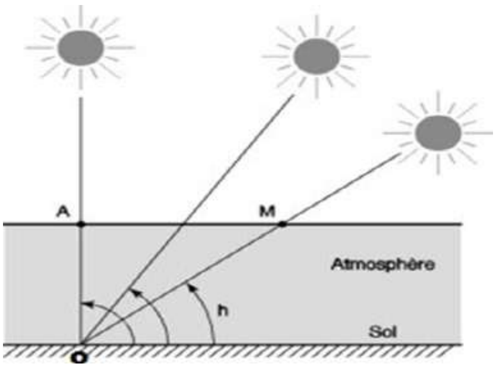

Figure I.3: Relation between the mass of air and the thickness of the atmosphere [2].

The solar radiation is not divided in a uniform way on the whole planet, as well in the space (degree of latitude) as in time (season). The unequal sharing out according to degrees of latitude is linked to the sphericity of the globe (fig. I.8), which leads to a reduction of the angle of impact as they get closer to poles. The angle of impact of solar ray is maximum in the Equator (90 °) and diminishes towards poles. It is for this reason that the zones of low degrees of latitude (consisted of between 40°N and 40°S) accept more energy than the zones of high degrees of latitude for instance in the arid zones close to the Equator, the annual hours of sunshine are 2 300 kW / m ² instead of 1 100 kW / m ² in central Europe .In a perspective restricted to regions populated by the man, this variation remains however not very important (with a mailman from 1 to 3.5) [1].

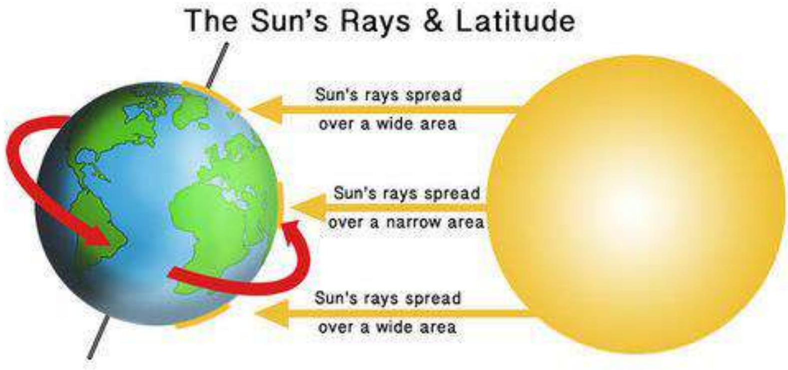

Figure I.4: Relation between the sphericity of the globe and the sharing out of radiance on the planet [1].

Under the same degree of latitude, hours of sunshine also vary in the course of the year according to seasons (fig. I.9) this variation of the solar flux in the course of time is a consequence of the rotation of the Earth around an axle tipped up by 23°27 ' in comparison with the plan of revolution around the sun (plan of the orbit of the Earth). The axle of incline being constant in the course of rotation around the sun, the angle of impact of the solar rays, for the same degree of latitude, varies in the course of the revolution of the Earth [1].

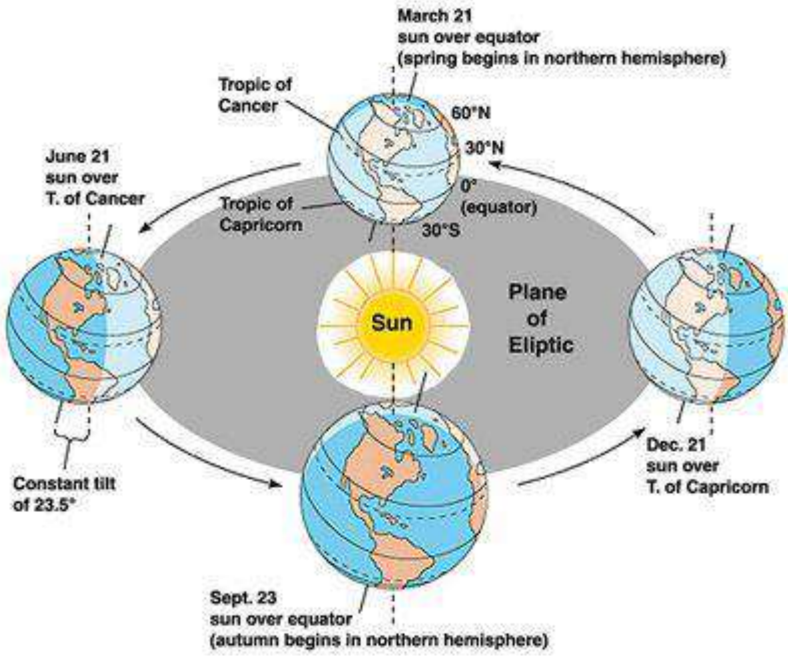

Figure I.5: Influence of seasons on hours of sunshine [1].

I.2.2. Principles of the solar radiation

The sun issues radiance composed of million particles with high energy called photons. Every photon transports a fixed quantity of energy. According to transported quantity, radiance is infrared (warmth), visible (visible radiance) or ultraviolet ray (radiance with very high energy) [2].

The solar ghost represents the various groups of achieving radiance the Earth and classifies them by length of wave. Different modules and collectors exploit length of wave different from the solar ghost [2].

Earth's atmosphere receives about 1,350 watts of solar energy per square meter. This constant value is called the "solar constant". All of this energy does not reach the Earth's surface. The atmosphere absorbs and reflects a significant part of it and the part actually reaching the surface of the Earth does not exceed about 1,000 KW/H. In fact, the sun's illumination only reaches this value when the sun is at its zenith on a cloudless day. [2]

I.2.3. Solar radiation

Solar radiation is the quantity of radiative energy of the sun really attaining a surface or the quantity of solar energy accepted by unit of surface. It measures in watts by square meter (W/m ²) or kilowatts by square meter (kW / m ²). If a solar module directly faces up sun (if it is perpendicular in solar radiations) radiation is stronger than if module makes an angle with solar radiations. During sunny day, the quantity of accepted energy is lesser in the morning and late in the afternoon, for two reasons: the angle between the surface glides and solar radiations am not optimum, on one hand, and solar radiations transport less than energy, on the other hand. At midday, accepted energy is in its maximum. Quantity really accepted at some point depends on the quantity of cloud and of the quantity of dust in the atmosphere [2]. The angle between the solar radiation and the surface is said angle of impact of the solar rays. The more it gets closer to 90 ° and the more the quantity of energy accepted by the surface is important (fig. I.6). If a photovoltaic solar module is permanently turned towards sun, it produces advantage of energy. They acquire this result by using a technology said of« chase of the sun » [2].

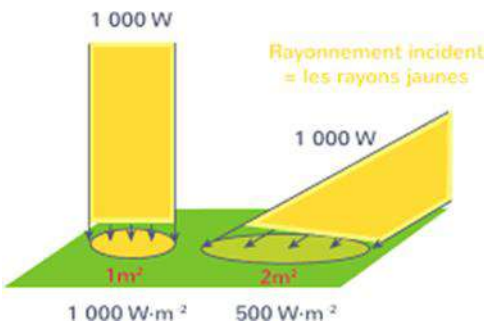

Figure I.6: Angle of impact of solar radiations [2]

I.3. The photovoltaic cell

Photovoltaic effect (or photoelectric) consists in converting light into electricity. It was discovered by the French physicist Edmund Becquerel in 1839 and accepted an industrial application from 1954. Principle of which is to thrill the peripheral electrons of certain atoms of semiconducting elements, what is going to create an electric current [7].

In practice, a photovoltaic cell accepts solar light and transforms it into electricity by means of a semiconductor, most often by some silicon. Several cells constitute a photovoltaic module producing a direct current, then transformed into alternating current by an The photovoltaic cell

The basic material most used nowadays for the manufacture of the photovoltaic cells is silicon (90 % of worldwide production). This one is in very big quantity on our planet since it constitutes about 28 % of the earth's crust. In fact they find it especially in form of dioxide of silicon (SiO2), named also silica which is the main constituent of sand. It is therefore very abounding and not very costly [1, [3].

Some of his caracterstic are given in this table I.1.

Table I.1.a basic material caractistic

Symbole	proprty	Value
Si	nuclear number	14
	nuclear mass	28.086
	assemble volumique	2330 kg/m^3
	Fusion temrature	1683 K
	Boiling temerature	2628 K

However, to be usable in electronics, silicon must be very pure [3] and it must first undergo a series of treatments (fig. I.7) [1]. Manufacturing a module requires energy. This amount of energy corresponds to that which a module must produce over a period between 2.6 and 4.6 years (energy return of the module). It generates 5 to 15 times more energy than that required for its manufacture for an estimated lifespan of 20 years (fig. I.8). Silicon is used in its crystalline form (mono- or multi-crystalline) or in its amorphous form [1].

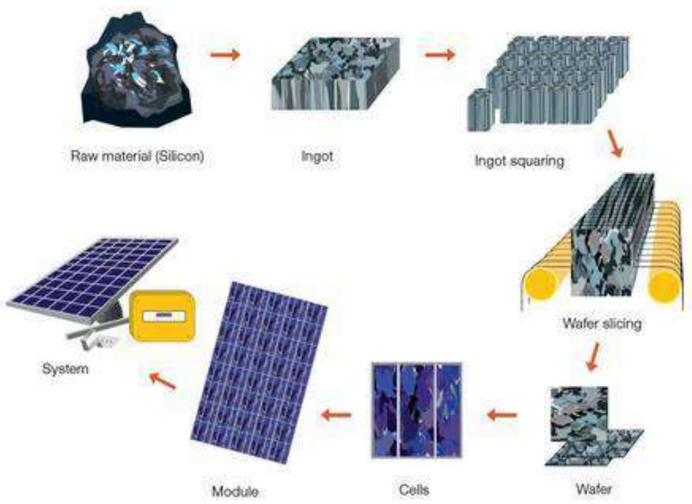

Figure I.7 Manufacture of a crystalline silicon cell

I.3.1. Different Types of PV Cells

Many new styles of PV cells are being developed today but mainly two distinct material:

I.3.1.1. Crystalline Silicon PV Cells (Monocrystalline)

These Solar Cells are manufactured from crystalline silicon. Many of you must be knowing that silicon is the second most common material on Earth and is abundantly found in sand. To make solar cells out of silicon, manufactured silicon crystals are sliced to about 300 micrometers thick and coated to work as a semiconductor to capture solar energy.

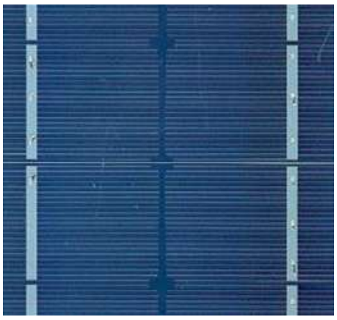

Figure I.8. Monocrystaline pv cell

I.3.1.2. Thin-film or Polycrystalline PV Cells

Thin-film PV cells use amorphous silicon or an alternative to silicon as a semiconductor. These solar cells are relatively flexible and can be directly installed with building materials. They work great even during clouds when there is low sun light. Here, the disadvantage is that thin-film PV Cells comparatively generate less electricity than crystalline silicon cells.

Figure I.9. polycrystaline pv cell

In both cases (mono or multi crystalline), the silicon is then sliced by wire saws. On these wafers, the incorporation of dopants is then carried out by diffusion or vacuum implantation techniques. Then, the silicon is covered with an anti-reflection layer on the front side, which reduces to less than 5% the losses by reflection of the incident light, and which gives it a dark blue color, characteristic of crystalline silicon photogenerators. The top and bottom of the wafer must then be covered with metal contacts to collect the generated electricity. To let the light through, the front electrode is deposited in the form of a grid, the back being simply covered with a continuous metal layer (fig. I.20) [4].

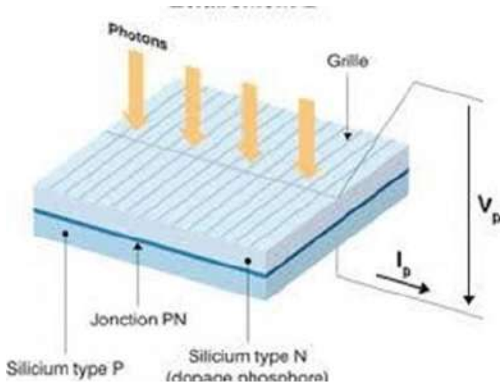

Figure I.10 silcium crystalin cell

I.3.2. PV Cell or Solar Cell Characteristics

Do you know that the sunlight we receive on Earth particles of solar energy called photons. When these particles hit the semiconductor material (Silicon) of a solar cell, the free electrons get loose and move toward the treated front surface of the cell thereby creating holes. This mechanism happens again and again and more and more electrons (Negative Charge) flows towards toward the front surface of the cell and creates an imbalance of electrons. Now, when the front (–) and back (+) surface of the photovoltaic cell are joined by a conductor such as a copper wire then electricity is generated.

I.3.3. PV Cell Working Principle to Generate Electricity

Solar cells convert the energy in sunlight to electrical energy. Solar cells contain a material such as silicon that absorbs light energy. The energy knocks electrons loose so they can flow freely and produce a difference in electric potential energy, or voltage.

The flow of electrons or negative charge creates electric current. Solar cells have positive and negative contacts, like the terminals in a Battery. If the contacts are connected with a conductive wire, current flows from the negative to positive contact. The Figure below shows how a PV cell works to generate electricity.

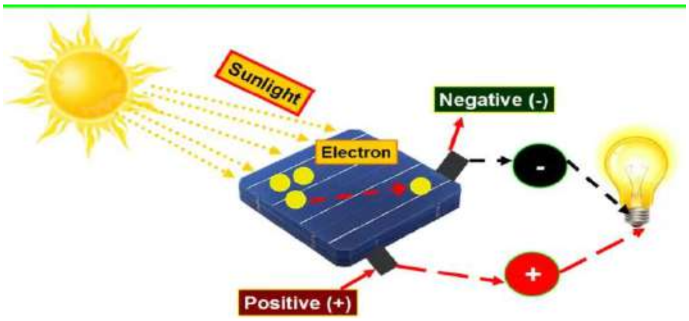

Figure I.11 how cell works

I.3.4. How much Electricity can a PV Cell Generate

A single photovoltaic cell can produce about 1 to 2 watts of electricity. This energy is too less for use in any household or for a commercial purpose.

In order to increase the output of electricity, several photovoltaic cells are electrically connected together to form a photovoltaic module and these modules are further electrically connected to form a photovoltaic panel / photovoltaic array. The number of modules connected to form an array depends on the amount of solar electrical energy needed.

I.3.5.Connecting of PV cells

I.3.5.1. Series of photovoltaic cells

The low operating voltage of a cell (around 0.6 V under 1,000 W/m²) makes it little usable in practice, and it is necessary to mount several in series to increase this voltage (fig. I.12).

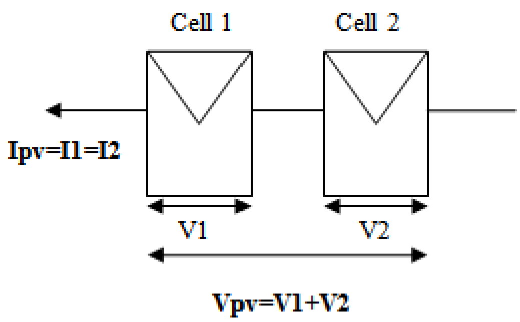

Figure I.12 series photovoltaic cell

The voltage in solar cells mounted in series is cumulative, it means that the voltage obtained by the series of N cells is N times the voltage of a cell. The cells are crossed by the same current, and the resulting characteristic of the series grouping is illustrated in Figure I.13. [06]

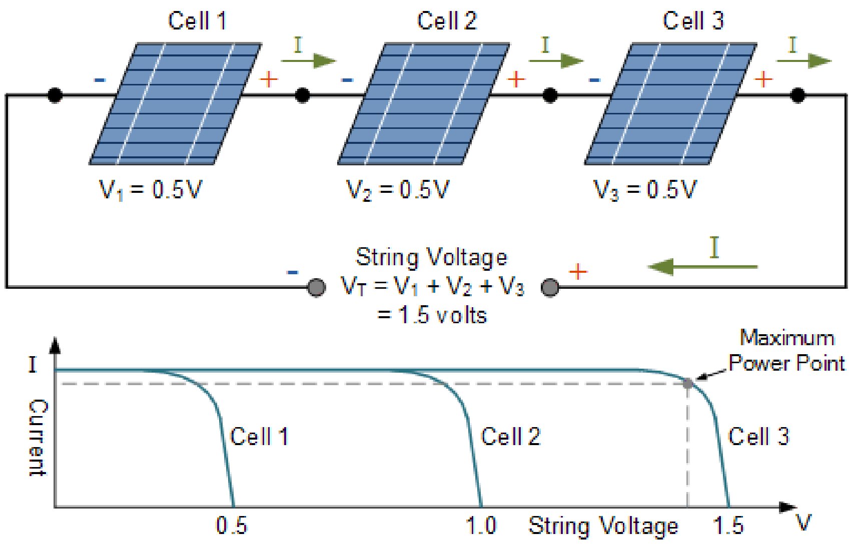

Figure I.13 Series Connected PV model

I.3.5.2. Photovoltaic Cell Shading

Now let's assume that Solar Cell No2 in the string has become either partially or fully shaded while the remaining two cells in the series connected string have not, that is they remain in full sun. When this occurs, the output of the series connected string will reduce dramatically as shown. [06]

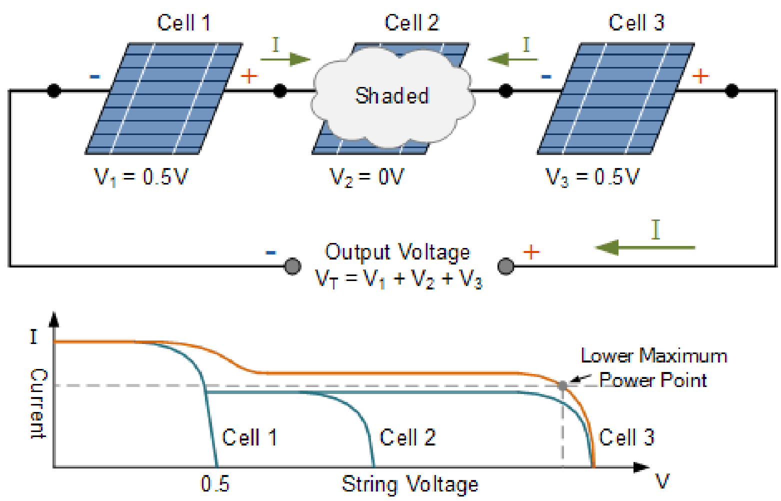

Figure I.14 Series Connected PV Cells

I.3.5.3. Parallel Photovoltaic model

Currents are added and voltage is equivalent to that of a single cell, so parallel connectionsincrease the current output of the GPV

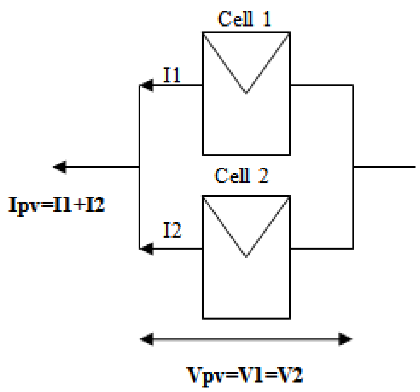

Figure I.15 a parallal photvoltaiic cell

I.4. Converting DC to AC Electricity

The PV cells generate DC or direct current. This DC electricity has to be converted to AC or alternating current so that it can be used in a home lighting system or running appliances. An inverter is used to convert DC to AC. This is same as converting DC from a battery to AC.

I.5. Generating AC electricity by solar panel photovoltaic system

Array of Solar Photovoltaic Panel System generates DC Electricity. This DC Electricity is Cnverted to AC using a System called "Solar PV Balance-of-System" (BOS).

The BOS System uses some equipment to convert DC to AC. Such Equipment include:

- Solar Panels to Generate DC from Sunlight.
- An inverter to convert DC to AC.
- Solar Battery to Store the electricity.
- Few other electrical wiring accessories for installation of the system to work.

I.6. DC-DC Converters

Due to nonlinearity of PV system the output power is changeable according to the change of Atmosphere conditions. Therefore, the best device can play the role of regulating the voltage and current output of PV source is called dc-dc converter [8]. Figure 1-10 illustrates a schematic diagram for a DC-DC converter. The converter changes DC input voltage Z[(\) into DC output voltage ZE(\), but at a different voltage level than that of the input. Preferably, this change is done with low losses to the converter, so the transistor functions as a switch, applying the control signal d(t). As illustrated in Figure 1-11, the control remains at high for a designated period \E] and at low for a designated period [8].

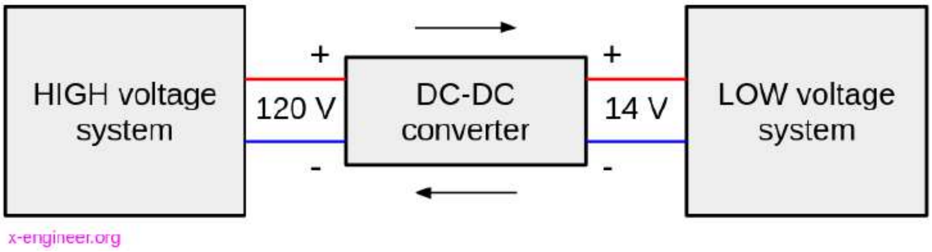

Figure I.16 Structure of a DC-DC converter

I.7. THE INVERTER:

Inverters are like the brains of the solar energy system. Their main function is to take D.C. current from the Solar panels or the batteries and convert them to AC current that can be used by our appliance; this is to say that we can’t use our solar system without an Inverter.

Inverter does not supply Electric Energy (Power) on it’s own, it merely converts from one form to another (From D.C. to A.C.). The Inverter must be connected to an energy source (Battery) for it to function. If it is not connected to a battery bank it simply cannot be used.[06]

I.7.1. There are Inverters and there are Inverter/chargers.

Inverters: All they can do is to convert D.C. energy from the batteries to A.C. Energy that can be used by our appliances and devices, they do not have inbuilt charges in them to charge the battery bank from an A.C power source.

Inverters/charges: They convert D.C. Energy from the batteries to A.C. Energy that can be used by our appliances and devices, they also come with in-built chargers. The chargers enable them to charge the batteries from an A.C. power source (Utility power supply or maybe Generators).

Inverter/chargers are particularly very useful for solar systems that are also connected to the grid. What this means is that you have the option of charging your batteries with your solar panels and you also have the option of charging your panels with either the utility or your generators.

I.7.2. Inverter ratings:

Inverters are rated in this format 1.5kw 12V, 2.5kw 24 V, 6kw 24V,48v and so on

Let me explain in terms of power and voltage.

- Power(Kw)

1.5kw 12V. This means that the maximum power that your system can take is 1.5kw (Please note 1.5Kw is equal to 1500 watts, 1kw =1000watts; kw=Kilo watts). If your system supplies a higher power than your Inverter capacity, let’s assume 2kw, not only would the extra 500watts of energy be wasted, the higher power could damage your Inverter if care is not taken.

- Voltage(V)

2.5KW 24V.This mean your Inverter works with a 24 Volt system. The voltage rating of the Inverter you buy is depended on the system voltage of your solar system. It is very important that you do not purchase an Inverter with a different voltage rating from your system.

You determine your system voltage from the voltage of your batteries and Solar panels in your solar system.

Some modern Inverters can work with two or more voltage systems for example 7KW 24V, 48V

Now there are three different types of Inverters used in solar installation.

I.7.3. INVERTER (TYPES):

I.7.3.1. Enteral inverter

This type of inerter is also called string Inverter. This is the most common Inverter type being used.

It is a single (central) Inverter that has all the solar panels connected to it. All the DC Power from all the solar panels are fed into the central Inverter and the Inverter converts it to AC power for use by the system.

I.7.3.2. MICRO INVERTERS

This is a relatively new technology and a lot more efficient then the central Inverter. This type of Inverter is installed on all the panels involved in the system. They are a lot smaller than the central Inverters; they convert the DC power produced by the panels to AC and pass it directly to the system

I.7.3.3. POWER INVERTERS

This type is a compromise between the central Inverter and micro Inverter. The Power Inverters are placed on the panels but they do not completely convert the power from DC to AC, they condition the output from the panels and then send it to the Inverter. The Inverter does the final job of converting to AC.

I.8. charge Controller

A charge controller is a device that controls the charging of the batteries in the battery bank. It is placed between the battery and the solar panel. The main purpose of a charge controller is to prevent the batteries from getting overcharged**.** It regulates the current flowing in and out of the batter, this is done to ensure your batteries last long and more importantly this is done for users safety. Charge controllers come in different shapes sizes and color.[06]

I.8.1. Features of a charge controller

Below are some of the features of a charge controller, some charge controllers have more features than the other.

I.8.1.1. Preventing overcharging battery :

This is the main function of a charge controller; batteries are very sensitive components, so care must be taken not to overcharge them. The charge controller regulates the voltage and current coming into the battery.

I.8.1.2. Blocking reverse current.

At night when the solar panels are not producing anything, the battery has a higher voltage than the panels because of this higher voltage, current from the battery would try to find its way back to the solar panels and if this is allowed, it could damage our solar panels. The charge controller prevents current from flowing from the battery to the solar panel. (newer models of solar panels also come with a way of blocking reverse current in built as a precaution)

I.8.1.3. Preventing deep discharging.

Discharging your battery below 50% significantly reduces the lifespan of your batteries, the charge controller monitors battery usage and alerts you, when your battery is about to be discharged below the recommended level.

I.8.1.4. Data logging

Some charge controllers record the values from your solar systems such as the maximum power generated from your solar panels, current , voltage, battery levels and the likes, this is done on a daily basis and it stores this data in the memory of the charge controller .This helps you to monitor your solar system and detect any fault that may arise early enough. It also enables you to have a record and keep track of the performance of your system.

I.8.2. Two types of inverters

- Pulse width modulator (PWM) charge controller
- Maximum power point tracking (MPPT) charge controller

I.8.2.1. PWM (Pulse width controller) charge Controller

This type of charge controller charges the batteries by sending out short pulses of current to the batteries, hence the name.

It monitors the battery state and varies the nature of the pulse it sends accordingly, during the bulk stage when the battery is low, it sends long and continuous pulses and it sends it out rapidly. It monitors the battery and as the battery starts getting fully charged, the frequency of the pulse decreases, It doesn't send it as rapidly as before anymore and the pulses become shorter and shorter, this is done so that the battery is not overcharged.

I.8.2.1.1. Advantages

- PWM charge controller is cheaper than the MPPT charge controller, it is easily affordable. It can be used for small scale solar projects.

I.8.2.1.2. Disadvantages

- It is not as efficient as the MPPT charge controller.
- It can't be used for large scale projects 60amps and above.
- It can't convert the excess voltage to current.

I.8.2.2. MPPT (Maximum Power Point tracking) charge controller

This is actually a much more recent type of charge controller. The MPPT charges the battery by sending out the maximum power possible to the battery hence the name. It monitors your PV module and your battery and determines the most appropriate power to send.

One of its most distinguishing features is its ability to convert excess voltage from the panel to current for your systems.

I.8.2.2.1. Advantages

- It has a higher efficiency compared to the PWM.
- It converts excess voltage to current for the system.
- It can be used for large scale projects

I.8.2.2.2. Disadvantages

- t has a higher cost compared to PWM.

Table I.2 Categorizing use cases of inverter devices and circuits by voltage and frequency

Type	Elements to change	Inverter usage
VVVF	Voltage/ frequency	Industrial motors, pumps, air conditioners, refrigerators, etc.
CVVF	Frequency only	Electromagnetic cooker, rice cooker, fluorescent lights, etc.
CVCF	Constant voltage and frequency	Computer power supply, UPS (uninterruptible power supply), etc.

I.9. Chopper:

In electronics, a chopper circuit is any of numerous types of electronic switching devices and circuits used in power control and signal applications. A chopper is a device that converts fixed DC input to a variable DC output voltage directly. Essentially, a chopper is an electronic switch that is used to interrupt one signal under the control of another.

In power electronics applications, since the switching element is either fully on or fully off, its losses are low and the circuit can provide high efficiency. However, the current supplied to the load is discontinuous and may require smoothing or a high switching frequency to avoid undesirable effects. In signal processing circuits, use of a chopper stabilizes a system against drift of electronic components; the original signal can be recovered after amplification or other processing by a synchronous demodulator that essentially un-does the "chopping" process.

Some Application of a chopper electronics:

- Switched power mode supplies including DC to DC converters
- Speed controller for DC Motors
- D.C. voltage boosting
- Battery-operated electric cars
- Battery chargers

I.10. Batteries

Batteries are very important in a solar system set up, they simply store energy for use in the Night when the sun is down. There are various kinds of batteries as we will soon out; some batteries are also more suited for some specific situations than the others. In general batteries cover up for the Solar Panel's inherent inability to produce energy when there is no sunlight by reserving energy for later use.[06]

When dealing with batteries we have to be extremely careful when working with it because of a lot of reasons like:

- They can cause electric shock.
- Some of them when faulty can release gases that can prove fatal**.**
- In some cases batteries can blow up.

I.11. Mathematical Model of Solar Panels

The equivalent lumped circuit model of solar cells has been widely used for the performance simulation and prediction for designing, manufacturing and evaluation of PV systems. There are two main models for PV cells, the first one is a single-diode model based on the modified shocked diode equation incorporating a diode quality factor to account for the effect of recombination in space-charge region [2]. Figure 17 shows a single-diode solar cell model. It is represented by a current source in parallel with a diode and a parallel resistor, as well as a series connected resistor at the output terminal.

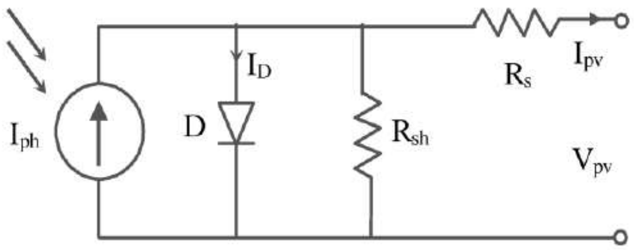

Figure I.17 Equivalent circuit of a single-diode solar cell model.

For a solar panel with a number of series-connected PV cells, it is a common practice to assume that the characteristics of the series cells inside the solar panel are nearly identical [3,4,5]. A PV panel model therefore, is considered as a single cell with some multipliers dependent on the number of series-connected cells in the PV panel. Based on the single-diode model, the I-V characteristic of a PV panel is given by (1):

$$Ipv = Iph - Is\left(e^{\frac{Vpv+Ipv*Rs}{n*Ns*Vt}} - 1\right) - \frac{Vpv+Ipv*Rs}{Rsh} \qquad \textbf{(I.1)}$$

where, Ipv and Vpv are the terminal current and voltage of the PV panel, Iph is the photo current, Is is the dark saturation current, Rs and Rsh are the series and shunt resistances of the solar panel, n is the diode quality factor, Ns is the number of series-connected PV cells in the PV panel, Vt is the solar cell thermal voltage defined as Vt=kT/q, where k is Boltzmann’s constant (1.38 × 10 – 23 J/K), q is the elementary charge (1.6 × 10 − 19 C), and T is p − n junction temperature in Kelvin.

The second one is the double-diode model, which can simulate the space-charge recombination effect by incorporating a separate current component with its own exponential voltage dependence [2,6].

Figure I.18 shows a double-diode solar cell model. It is represented by a current source in parallel with a diode and a parallel resistor, as well as a series connected resistor at the output terminal.

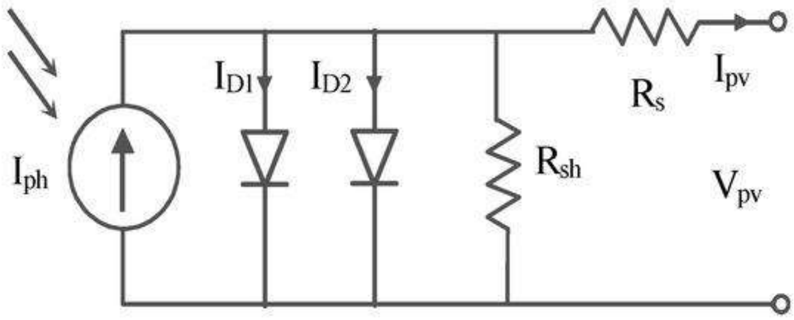

Figure I.18 Equivalent circuit of a double-diode solar cell model.

For a solar panel with a number of series-connected PV cells, the I-V characteristic based on the double-diode model is given by (**I.2**):

$$Ipv = Iph - Is1\left(e^{\frac{Vpv+Ipv*Rs}{n1*Ns*Vt}} - 1\right) - Is2\left(e^{\frac{Vpv+Ipv*Rs}{n2*Ns*Vt}} - 1\right) - \frac{Vpv+Ipv*Rs}{Rsh} \quad \textbf{(I.2)}$$

where, Is1 is the dark saturation current due to diffusion mechanism, Is2 is the dark saturation current due to carrier recombination in space-charge region, n1 is the diode quality factor for diffusion current, n2 is the diode quality factor for generation-recombination current, the other parameters are the same as in Equation (1) [4].

In practice, the double-diode model can be further simplified by approximating n1=1 and n2=2 based on Shockley's diffusion theory [2,6]. The simplified I-V characteristics for the double-diode model is given in Equation (3):

$$Ipv = Iph - Is1\left(e^{\frac{Vpv+Ipv*Rs}{Ns*Vt}} - 1\right) - Is2\left(e^{\frac{Vpv+Ipv*Rs}{2Ns*Vt}} - 1\right) - \frac{Vpv+Ipv*Rs}{Rsh} \quad \textbf{(I.3)}$$

The single-diode model was found not very accurate in describing cell behavior under low illumination conditions [2,4,6]. Research shows that estimated series resistance values could be negative using solar module characteristics collected at low solar illuminations [6]. It has been shown that the double-diode model is a more accurate model in presenting the solar panel behavior as compared with the single-diode models particularly at low irradiation levels, as it is able to simulate the space-charge recombination effect by incorporating a separate current component with its own exponential voltage dependence [2,4].

Comparing Equation (3) with Equation (2), there are only five unknown parameters (Rs, Rsh, Is1, Is2, and Iph) in Equation (3) which need to be determined based on the available data provided from PV panel's datasheets. Details of the determination of the five parameters were described in [4].

The short circuit current of the solar panel can be calculated by setting Vpv=0 and neglecting the current through the diode: as expressed in Equation (**I.3**):

$$Isc = \frac{Iph}{\frac{Rs}{Rsh}+1} \approx Iph \qquad (\mathbf{I.4})$$

The short-circuit current is approximately equal to the photo- generated current. To achieve the maximum possible output power of a solar panel, the solar panel should be operated at a suitable voltage level at which it can generate its maximum output power. The voltage and current at the MPP can be solved based on Equation (5):

$$\left.\frac{dP}{dV}\right|_{Vmpp.Impp} = \left.\frac{d(Vpv*Ipv}{dV}\right|_{Vmpp.Impp} = 0 \qquad (\mathbf{I.5})$$

where, VMPP, IMPP represents the output voltage and output current of the solar panel respectively [7].

I.12. The photovoltaic system

Photovoltaic is a renewable energy from the sun. It directly uses solar radiation to transform light into electric current through the photovoltaic effect (fig. I.28). Electricity is produced from daylight.

The light is transformed into electricity by means of photovoltaic modules composed of several solar cells connected to each other. The electricity produced corresponds to a direct current (DC). To use it in mains power or to power devices operating with alternating current, it must be converted to alternating current using a DC/AC converter also called an inverter. This is the case for photovoltaic installations connected to the building and/or distributor grid, which today represent nearly 90% of the world market.

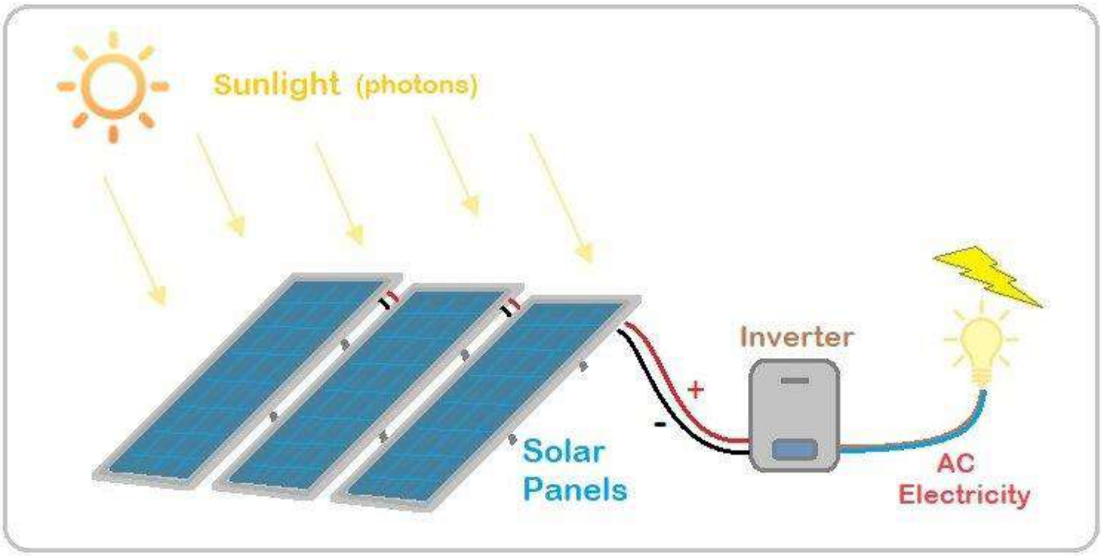

Figure I.19 PV systeme

Photovoltaic modules must be combined with other components to ensure a reliable power supply: the whole constitutes a photovoltaic system (Figure I.**20**).

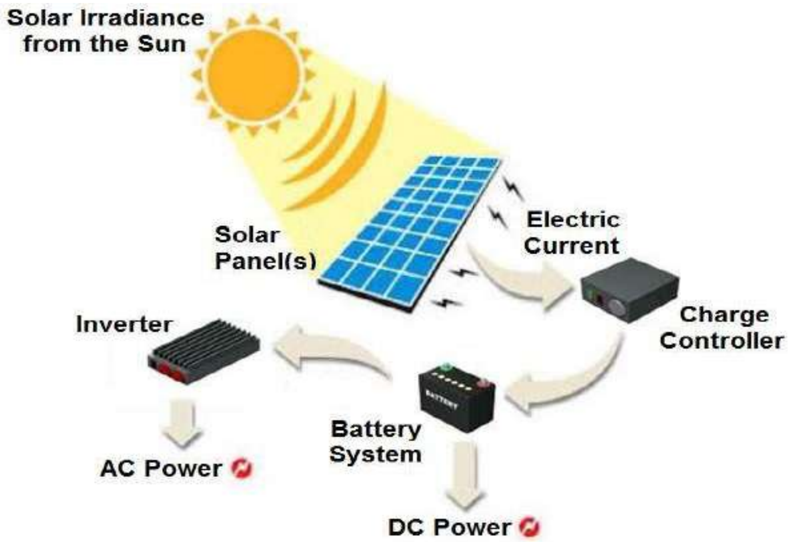

Figure I.20 constitutes of a photovolaic system

The impact of this technology on the environment is minimal. It does not generate any nuisance: no greenhouse gases or waste. Most of this impact is due to energy consumption and the use of toxic chemicals during the panel manufacturing phase, such as cadmium [1].

I.12.1. Types of Solar Photovoltaic System

According to the method of utilization, there can be two configurations:

- Stand-alone system
- Grid-connected system

I.12.1.1. Stand-alone System

In this system, power is supplied to a load without the use of any common grid or connection to any other system and operates autonomously and independently. It is used for backup power where connecting to the grid is very costly. It can be used to power DC loads, also the AC loads using an inverter.

There are different types of standalone systems. But the hybrid stand-alone system is most commonly used

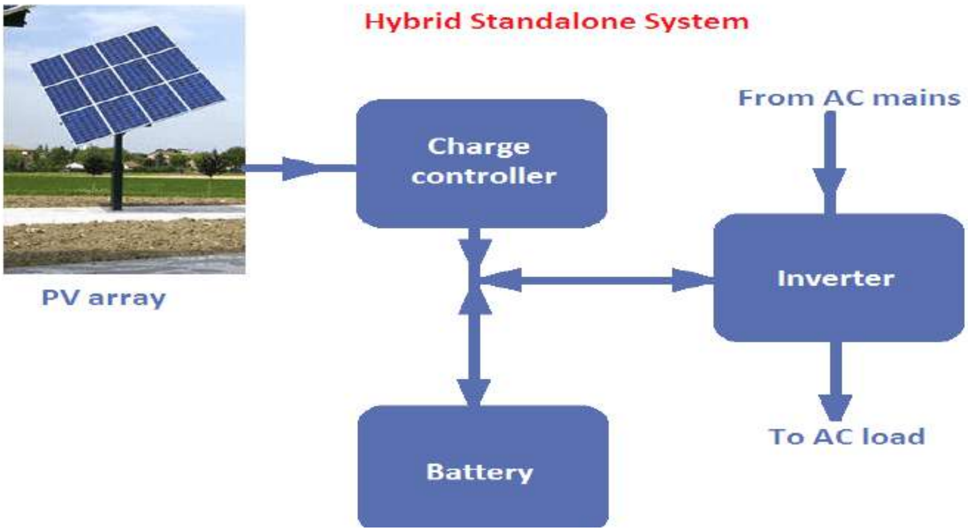

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Figure I.21 hybrid stand-alone systeme

In a hybrid standalone system, one or more sources in addition to the PV panels are used. Sources like generators, fuel cells, AC mains etc. may be used in conjunction with PV arrays. Thus dependence on any single source is reduced. This also reduces battery storage capacity and size of PV arrays.

The stand-alone photovoltaic installation produces electricity for a building or other consumer that is not connected to the grid. The autonomous application of photovoltaics concerns several very diverse fields [1].

- Space domain (space stations, satellites, etc.)
- Professional field (communications, transport, street furniture, etc.)
- Domestic or agricultural estate (rural dwellings, agricultural activities, health centers, islands, etc.)
- Field of electronics (watches, electronic labels, calculators, etc.)

I.12.1.2. Grid-connected System

In this system, the power generated by the PV array is given to grid or to the AC loads directly. When power generation exceeds the requirement of the loads, it is supplied to a commercial grid. Thus the system becomes a part of a large network. In this system, when power produced by the PV array exceeds the local load requirement, is supplied to the grid. An energy meter is used to monitor the supplied energy.

I.13. Advantages and disadvantages of photovoltaics

When choosing the system, the advantages and disadvantages must be weighed in the light of the constraints, needs and specifications of the project

I.13.1. Benefits

- ✓ Direct conversion of free and inexhaustible solar energy into electricity.
- ✓ Absence of noise, pollution and emissions.
- ✓ Reduced maintenance (no moving parts; module life = 20 years).
- ✓ Possibility of adapting the size of the installation to existing needs, with the possibility of extension on demand, as the energy need increases.
- ✓ Absolute safety if the installation is compliant. The risk of electric shock is reduced to 12 or 24 V_{dc} and the risk of fire is lower than with generators powered by kerosene or oil.
- ✓ Silicon used most often as a base material, it is the second most abundant element of the Earth's crust on earth.
- ✓ Energy return time is significantly longer than the operating time.

I.13.2. Disadvantages

- ✓ The initial cost of PV systems is high, even if long-term profitability is assured. They are therefore sometimes out of reach of low-income people.
- ✓ In most installations, electricity must be stored in batteries. However, batteries: (i) require regular maintenance, (ii) need to be replaced periodically, and (iii) can impact system performance (when local products are of poor quality or cannot be replaced).
- ✓ Random and periodic electricity production, depending on the level of sunshine (for example, depending on the density of cloud cover) and becoming zero and at night.
- ✓ Low-power PV systems often require DC equipment that is more energy efficient than AC equipment, but often costs more.

I.9. Conclusion

In this chapter, we presented the important notions about solar energy and the different types of radiation (direct, diffuse and global). We have also defined some basic concepts that help us study the photovoltaic system such as the principle of operation of a PV cell and the principle of the photo-current, then the modeling of a cell. Finally we finished by showing the different technologies of PV cells that exist and their field of application and thus their advantages and disadvantages.

Chapter II :

Fuzzy logic with the maximum power point tracker (MPPT)

II. Fuzzy logic with MPPT controller

II.1.1. Introduction

Photovoltaic cells are used to provide electrical energy in various applications, and who says various applications says various operating conditions.

A photovoltaic panel must provide the maximum of its power at any time and under any operating conditions, and to achieve this the panel cannot be connected directly to the load, it must go through an adaptation stage which is a static converter, the latter will be controlled by a control called MPPT which will have the function of maintaining the operating point of the panel in the maximum power zone.

There are several types of MPPT commands all different from each other. In this chapter we will try to present the different types of MPPT commands and classify them according to their principle of operation and we have also looked at their advantages and disadvantages

Fuzzy logic is an extension of Boolean logic, fuzzy logic is a method of processing imprecise knowledge based on linguistic baths, it gives the means to convert a linguistic command based on human reasoning, into an automatic command, all this by introducing the notion of degree in the verification of a condition thus allowing a condition to be in different state, that true or false, therefore the fuzzy logic provides a kind of flexibility which gives the possibility to take into account certain uncertainties is imprecise, which allows us to control complex systems whose information is expressed in a vague and imprecise way.

One of the interests of fuzzy logic to formalize human reasoning is that the rules are stated in natural language, and to illustrate this presenting us in the following table with an example of some rules that a car driver in front of a traffic light

In this chapter we will present also the fuzzy logic, its principle, the steps, the constituents, also the principle of operation of a fuzzy regulator and the application of fuzzy logic in a photovoltaic MPPT control

II.1.2. Principle of operation of a PV generator at its maximum power

In an electrical system comprising a source and a load, the search for the optimal operating point by optimization techniques is what is most important. In the case of photovoltaics, this approach is more complex due to the fact that the characteristics of the cells strongly depend on the sunshine and the ambient temperature, among others. A device must be found that allows operation at all times according to the optimum operating point.

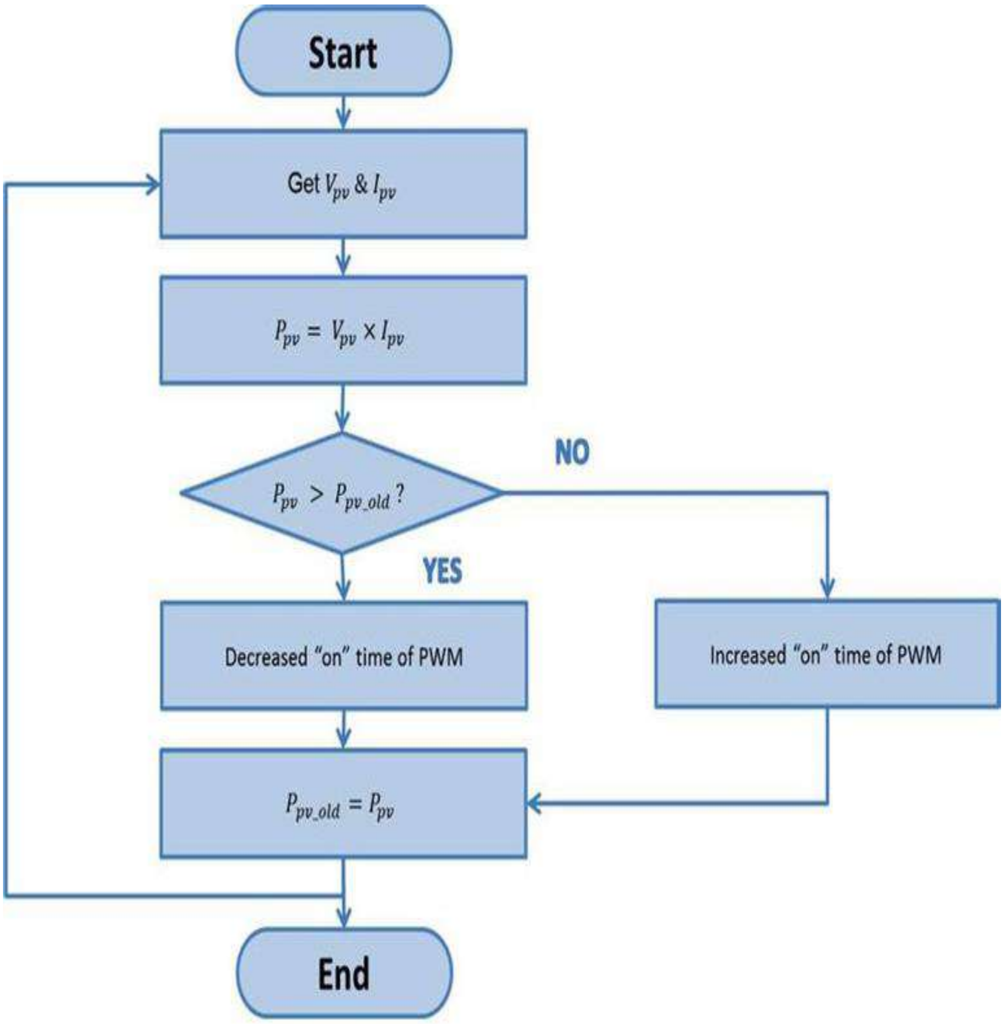
II.1.3. Synthesis of the different MPTPs encountered in the literature

Since the first publication of the first MPPT control law adapted to a photovoltaic generator in 1968, many publications have emerged on this field, given the large number of existing MPTPs.

II.1.3.1. The first types of MPPT

The first MPTPs that emerged had the particularity of being simple algorithms and this due to the low computing capacity of microcontrollers of the time, the first MPPT control applied to photovoltaics was carried out by BOEHRINGER in 1968, it was a simple algorithm that was intended for space applications that had much less constraints in temperature variation and illumination than terrestrial applications. [7]

Figure II.1 shows the principle of this algorithm



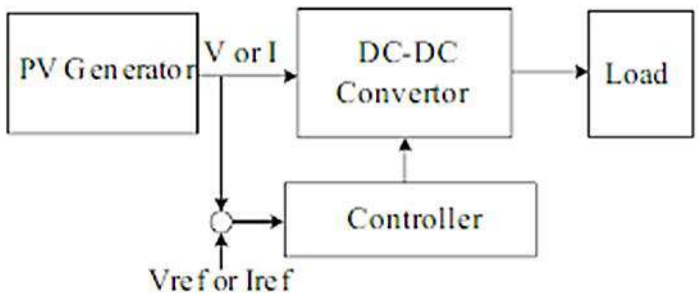
FigureII.1 basic MPPT algorithme

II.1.3.2. MPPT commands for space applications

Unlike terrestrial applications that are subject to climate change and daylight saving hours, space applications exhibit predictable behavior, so MPTPs dedicated to this purpose are simpler

II.1.3.3. MPPT control by cons voltage reaction

This kind of mechanism is based on the control of the operating voltage of the panels, by comparing this voltage with a reference voltage. This generates an error voltage that varies the duty cycle of the control PWM in order to cancel this error. Figure II.2 shows the structure of this mechanism. [8]

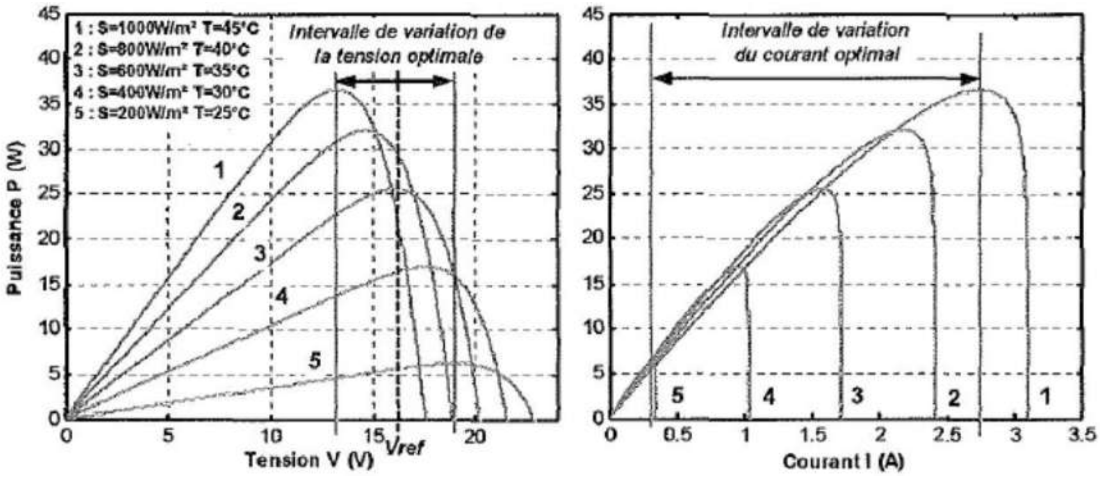


FigureII.2 MPPT on the counter reaction of voltage

There are several types of methods depending on the nature of this reference voltage (fixed or variable).

II.1.3.3.1. Fixed V_{ref} voltage reaction

Because of the dependence of the panel voltage on sunlight and temperature, the maximum power voltage is deflected, so the reference voltage must be corrected continuously for different sunshine and temperatures. [6]
In this method the reference voltage is predefined, as can be seen in Figure II.2, it corresponds to the average voltage of the interval of the points of the maximum powers recorded by tests under different conditions of sunshine and temperature.

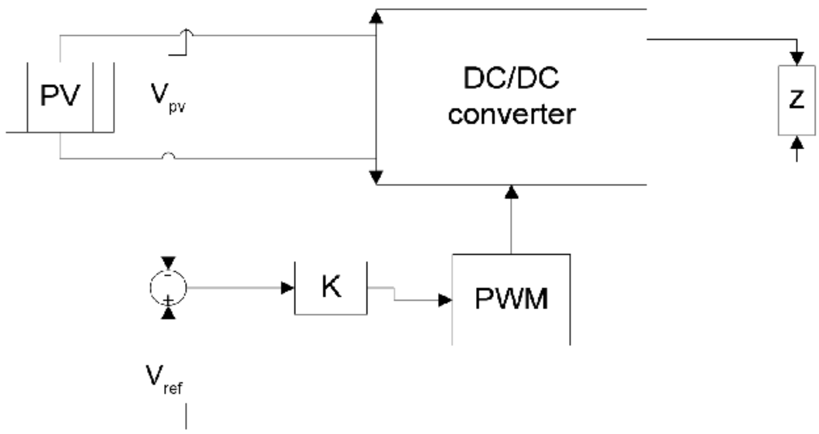


FigureII.3 the range of variation of the optimal operating voltage and current for variable sunshine and temperatures

In order to generate the maximum power is simply varied the different weighting factors during focusing, as can be seen in Figure I.

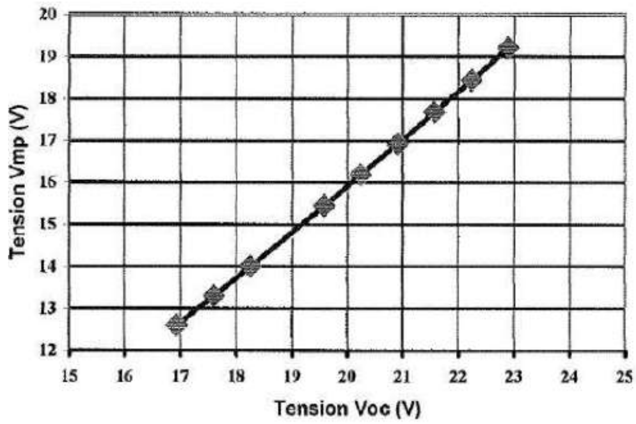
II.1.3.3.2. Voltage reaction by Vref = f(V_{OC})

This method exploits the quasi-linear relationship between the operating voltage in maximum power and the open circuit voltage Voc of the GPV (photovoltaic generator). [9] This value is taken regularly by disconnecting the panel for a short time to adjust the previous reference voltage by certain proportionality generally equal to 0.77 as shown in Figure II.4



FigureII.4 MPPT voltage feedback by V_{ref} = f(V_{OC}).

By tracing the function V_{mpp} = f (V_{oc}), we notice that this function is practically linear and it is of the form V_{mpp} = K *V_{oc}. By exploiting this property, one can constantly track maximum power point (MPPT)



FigureII.5 Voltage of the maximum power of the panel vs short- Open circuit of a photovoltaic panel

The advantage is that the control of the operating voltage of the photovoltaic panel takes into consideration the insolation and temperature, aging and accumulation of dust on the surface of cells.

But the disadvantage is that this method cannot be considered a real means of pursuing the MPP. Because the accuracy of the adjustment of the operating voltage to the maximum voltage V_{mpp} of power depends on the choice of this fraction compared to the real one

Report $\frac{\boldsymbol{Vmpp}}{\boldsymbol{Voc}}$ (**II.2**)

II.1.3.3.3. Counter-reaction of voltage by a pilot cell

In the previous method the interruption of the operation of the circuit to measure V_{oc} causes power losses and noise in the electronic circuits. To avoid these problems a pilot cell is added to the solar panel, it is a simple photovoltaic cell that is electrically independent of the rest of the row. The open circuit voltage of this cell that is measured continuously will give us implicit information of the open circuit voltage of all solar panels, multiplying this voltage with the number of cells in series.

This method avoids system interruption, but there are problems because the pilot cell used as a reference for row behavior is not easy to implement. The surface area of the photovoltaic modules and the location of the cell mean that it is not always faithful to what is felt by the panel.

To limit this disadvantage, an individual pilot cell is placed for each small group of panels in order to be able to estimate the factor for optimal operation. And as for the previous methods, this one uses a fixed factor to estimate the voltage Vmpp from the Voc voltage which causes the MPP (Maximum Power Point) not to be tracked correctly. Because of this, it is difficult to find an ideal place of the cell so that it gives perfect information of the Voc voltage of the whole for different sunshine and temperature.

II.1.3.4. MPPT control by cons current reaction

II.1.3.4.1. Current reaction by Iref = f(ICC)

In accordance with the voltage counter reaction methods, the short circuit current of the PV panel makes it possible to know the value of the optimal current in which the panel must operate to have the maximum power from the PV panel.

The optimal current is proportional to the short-circuit current, and this proportionality is almost constant depending on climatic conditions. In this case we have two types of operation, either we choose a constant value, designated according to the conditions of frequent operation to obtain the maximum power, or we vary the value according to the climatic conditions.

II.1.3.4.2. Counter-reaction by maximizing output current

This method is based on the fact that if the charge is made up of batteries the voltage of the charge is approximately constant, therefore to maximize the output power it will be necessary to maximize the charging current of the batteries, and this is true if the dP / di is bounded and strictly greater than zero. [15]

It can be written in the following form:

$$\mathbf{0} < \frac{V}{I} + \frac{dV}{dI} < \propto \tag{II.2}$$

Although this relationship is not true for all types of loads it is suitable for the load to low resistance such as batteries but if it is a DC motor or has another derivative $^{dp}/_{di}$ becomes zero at the point of maximum power, from this fact it would be impossible to find the MPP from the current alone.

The advantage of this method lies in its simplicity of calculation, we have fewer calculations, but this method still has disadvantages since there is a certain gap between the maximum power point and the point obtained by this method.

II.1.3.5. Power counter-reaction

Its principle is based on the measurement of the two main quantities, the I_{pv} current and the output V_{pv} voltage of the panel. The evaluation of the instantaneous power of the latter is elaborated by a simple multiplication of these two components $P_{pv} = I_{pv} * V_{pv}$ by an iterative search algorithm which is responsible for finding the position of the PPM, therefore the maximum power, by performing the search in one direction, The algorithm maintains this direction if the output power is constantly increasing and if not, it changes the meaning of research. The direction of the variation of the power P is known by the approximate calculation of the derivative dP over a sampling time that represents the velocity running the microprocessor or microcontroller. [10]

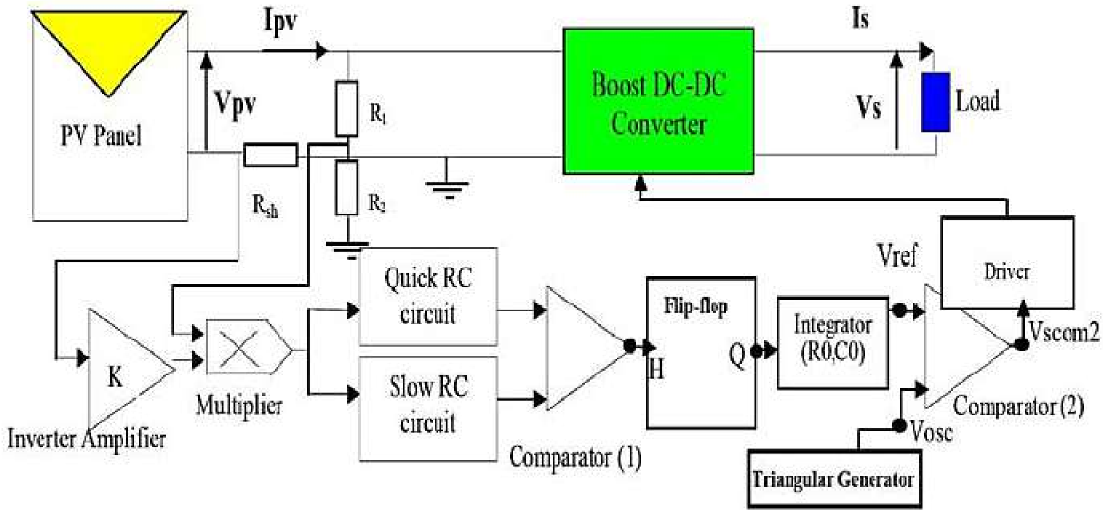
Because of the approximation of the derivative by discrete values the MPP is never reached but the operating point oscillates below this point, which generates instabilities and adds forms of noise to the circuit.

II.1.3.6. Analogue-based MPPT

Analog MPPT control is a method that involves only analog and logical components where no algorithm is needed, the speed of the system depends only on the delay time of the analog components which is usually low.

This analog MPPT control directly uses the voltage and current of the photovoltaic panel to find the operating point corresponding to the maximum power, and it can be applied to both step-down converters and elevators. The image of the power of the panel is obtained by multiplying the previous quantities. To deduce the direction of power variation two RC filters of different time constant create a different delay for two different branches, in association with a voltage comparator, these two signals generate a signal that represents the derivative dP/dt.

When the power decreases the output of the comparator is negative, otherwise it will be positive. These slots attack a JK toggle or its output switches for each front up or down from the comparator, the output of the rocker is integrated by a low-pass RC circuit to generate a DC voltage that serves as the reference voltage for the generation of the PWM signal.



FigureII.6 Explanatory diagram of the MPPT with analogue implantation

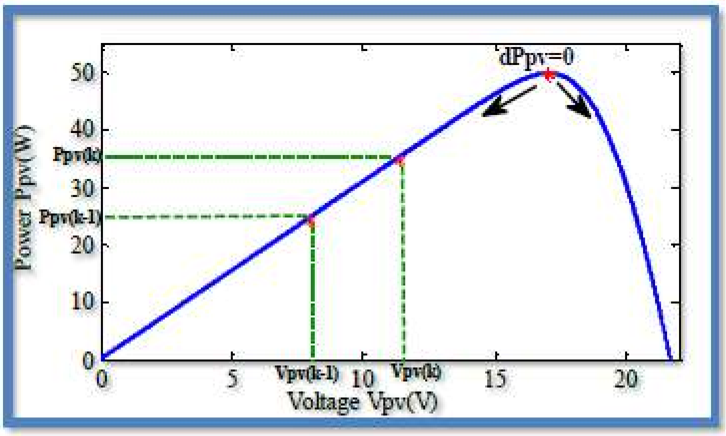
When there is a sharp increase in sunlight the tracking mechanism is unable to determine the cause of the power increase whether it is caused by the displacement of the operating point or by variations in operating conditions. This causes the MPP to deviate which causes power losses. Other unseemly, when one has rapid changes in sunlight or parasites in the current, the toggle changes state incorrectly and the operating point moves further and further away from the MPP until the output of the rocker attaches to the low level, and the duty cycle attaches to zero, then the system crashes and will need a reboot

II.1.3.7. Perturbation and observation algorithm (P &O)

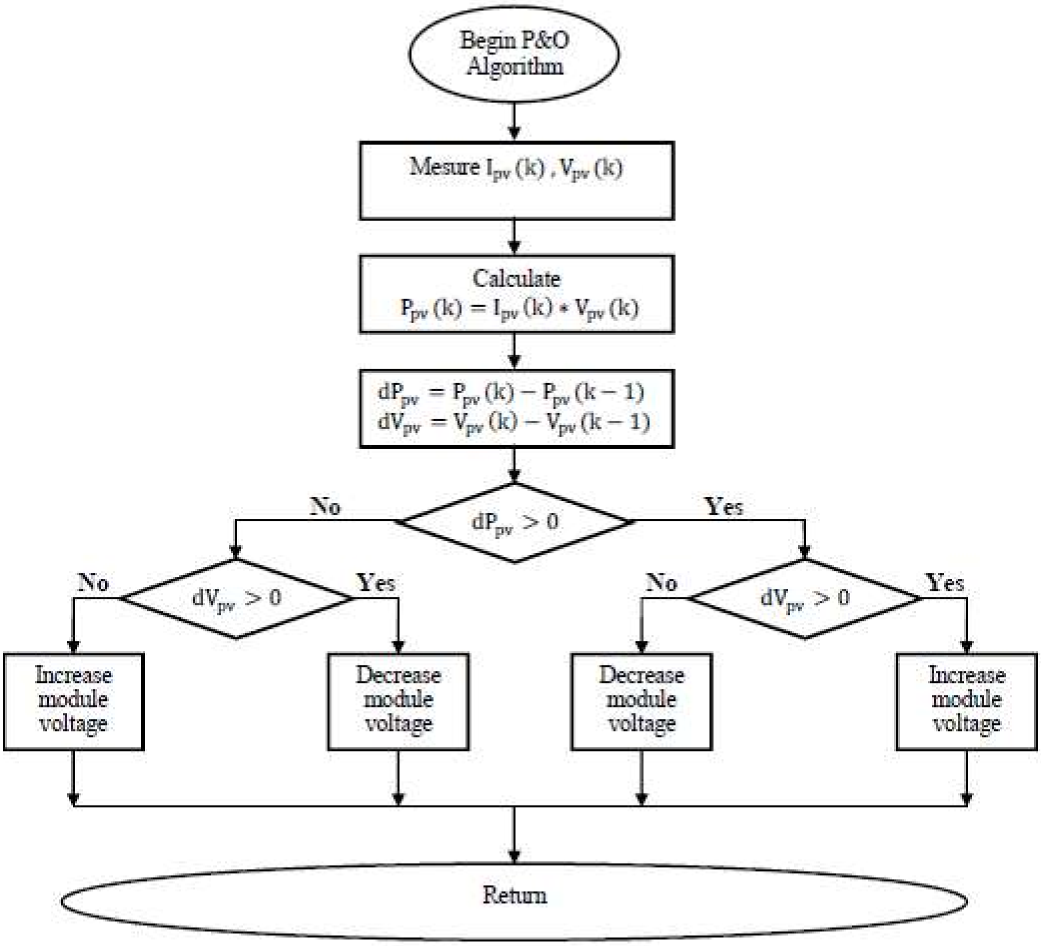
Given its simplicity the method of disturbance and observation is a very common approach in the field of pursuit of the maximum power point, the method of disturbance and observe can follow the maximum power point even during variations in temperature and sunshine, and it only requires measuring the Vpv voltage and the Ipv current of the photovoltaic panel.

The principle of operation of this method is to disturb the system by increasing or decreasing the operating voltage of the module and observing its effect on the output power, at each cycle of the algorithm the V_{pv} voltage and the I_{pv} current are measured to calculate the P_{pv} power and this P_{pv} value is compared to the previous value of P_{pv} that was calculated in the previous cycle. From the resulting value, if the output voltage is greater, then the voltage V_{pv} is adjusted in the same direction as in the previous cycle, and if the output voltage is lower, then the voltage V_{pv} is adjusted in the opposite direction than in the previous cycle, so the voltage is disturbed at each cycle of the algorithm When the system reaches its maximum power point, the V_{pv} voltage will oscillate around the optimal value, this causes a loss of power that increases with the increase in the increment pitch of the disturbance. The greater the step, the faster the algorithm responds to sudden changes in climatic conditions.

Unlike if the pitch is small, power losses are minimized during slow or stable climate changes, but the system will lose its speed of thinking about the change in temperature and sunshine, and to obtain the ideal pitch it must be defined experimentally according to the conditions.



FigureII.7 characteristic for the P&O MPPT algorithm



FigureII.8 MPPT algorithm disturb and observes (P&O).

If an increase or a sudden decrease in sunshine is produced, we will have an increase or a decrease in the power of the panel depending on the conditions of the sunshine, the algorithm reacts as if this increase is produced by the effect of the previous disturbance, so it continues in the same direction which is the wrong direction, which takes it away from the true point of maximum power And it is all this that causes delays in the rethinking of the algorithm during sudden changes in operating conditions and that causes power losses.

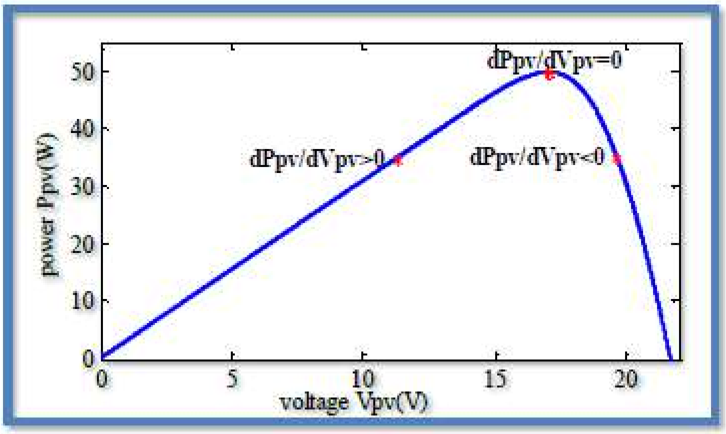
II.1.3.8. Improvement of the disturbance and observation algorithm (P&O)

The major disadvantage of the disruptive and observed algorithm is the divergence of the latter during sudden changes in operating conditions, and to remedy this an improved version of this algorithm has been proposed, this improvement is distinguished by the addition of a condition on the "yes" branch of the condition ΔP_{pv} (k) > 0 in the structure of the flowchart of the P&O algorithm. if the disturbance has taken the same direction for two consecutive cycles, the direction of the next disturbance will be reversed from the previous direction without having to take into account the power. [12]

II.1.3.9. incremental Conductance method

The IncCond algorithm is based on the fact that the slope of the curve power vs. voltage of the PV module is zero at the MPP. [15]

The output voltage and current from the PV array are monitored upon which the MPPT controller relies to calculate the conductance and incremental conductance and to make its decision (to increase or decrease the duty ratio output).The output power of PV array can be expressed as: $P_{pv} = I_{pv}*V_{pv}$ .Then, the derivative of the product yields:.



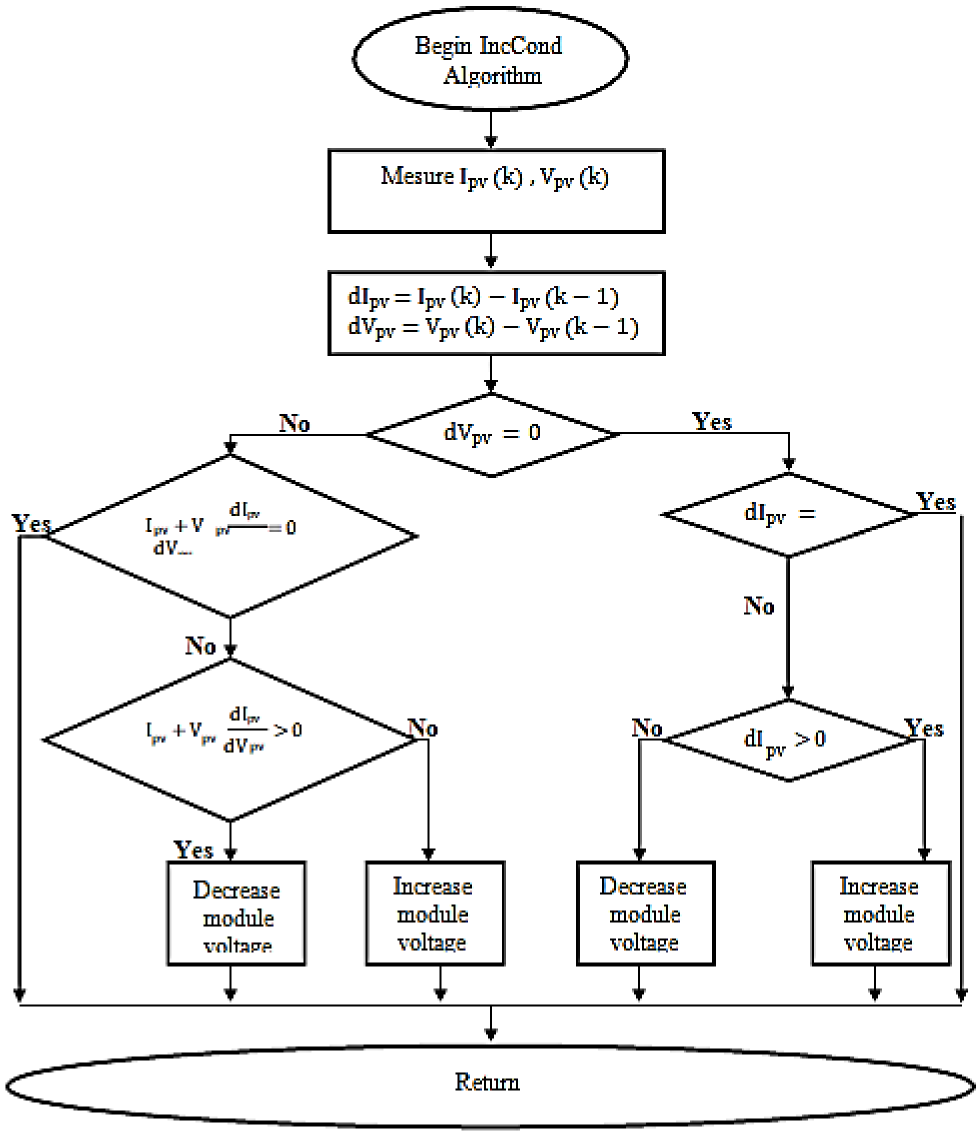
FigureII.9 P-V (Power-Voltage) characteristic

$$\begin{cases} \frac{dP}{dV} = 0 & at\ MPP \\ \frac{dP}{dV} > 0 & at\ the\ left\ of\ MPP \\ \frac{dP}{dV} < 0 & At\ the\ right\ og\ MPP \end{cases} \quad \text{(II.3)}$$

Because

$$\frac{dP}{dV} = \frac{d(IV)}{dV} = I + V\frac{dI}{dV} \cong I + V\frac{\Delta I}{\Delta V} \quad \text{(II.4)}$$

$$\begin{cases} \frac{\Delta I}{\Delta V} = -\frac{I}{V} & at\ MPP \\ \frac{\Delta I}{\Delta V} > -\frac{I}{V} & at\ the\ left\ of\ MPP \\ \frac{\Delta I}{\Delta V} < -\frac{I}{V} & at\ the\ right\ of\ MPP \end{cases} \quad \text{(II.5)}$$



FigureII.10 MPPT control algorithme Conductance incrémente méthode

II.1.3.10. Improved conductance increment method:

The conductance increment method can be improved by bringing the operating point close to the MPP in a first step, and then using the Conductance Incrementing algorithm to track exactly the MPP in a second step, or by adding a PI corrector.

II.2. Fuzzy logic

II.2.1. Principle and definition of fuzzy logic

Humans are able to handle situations and react to problems and find the right solution despite the uncertainty and inaccuracy of the data. With the classical method studying such problems amounts to having fairly advanced mathematical notions and the knowledge of different parameters that can interact with the said problem, such a study is often strewn with errors and inaccuracies that inevitably accompanies any process modeling. [14]

Thanks to the so-called robust methods it can solve these kinds of problems, and fuzzy logic is one of them. The latter comes from the capacity of man who decides and acts in a relevant way despite the vagueness of available knowledge.

To simplify the principle we present a small example: we want to classify people into three sets, young, between two ages and old.With Boolean logic that admits only the values 0 and 1 as variables, our classification will be done

Table II.1 example of control system in fuzzy logic controller

If the light is red	If my speed is high	And if the fire is close	Then I brake hard
If the light is red	If my speed is low	And if the fire is far away	then I maintain my speed
If the light is orange	If my speed is average	And if the fire is far away	then I brake gently
If the light is green	If my speed is low	And if the fire is near	then I accelerate

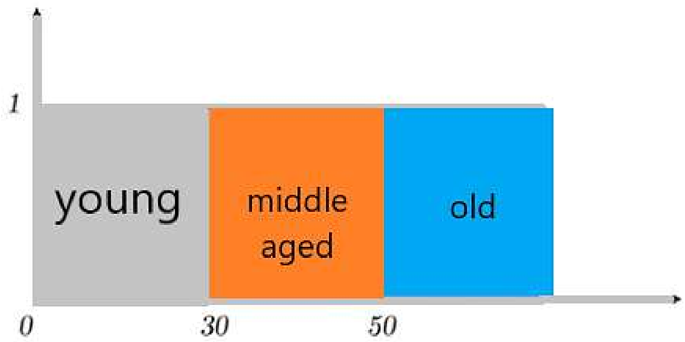
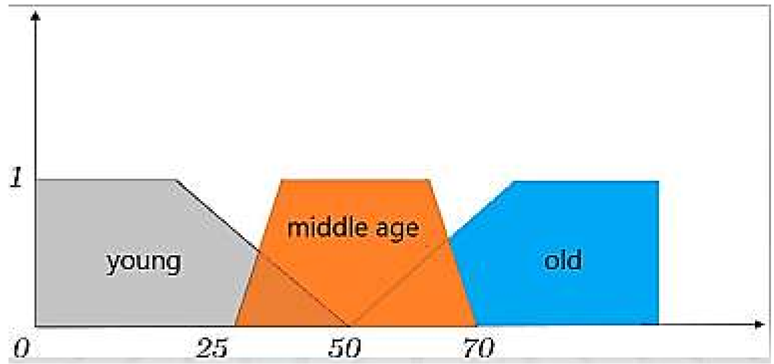


Figure FigureII.11 Classification according to classical (Boolean) logic.

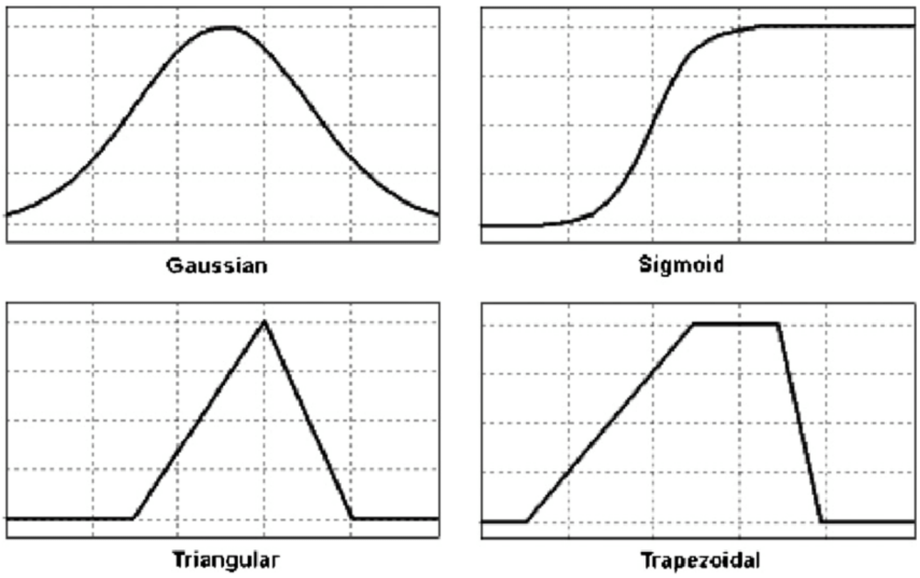
With Boolean logic a young person is a person who is under 30 years old, and a person who is between 30 and 50 is between two ages, and those who exceed 50 are considered old.

Contrary to classical logic the variables of fuzzy logic can take any value between 0 and 1, we then speak of belonging function, a person aged 35 years can be classified young and between two ages with degrees of truth so our classification can be expressed as shown in Figure 0-12 Classification according to fuzzy logic.



FigureII.12 Classification according to fuzzy logic

To represent the functions of belongings we use several shapes but most often we use triangular, Gaussian, rectangular, and trapezoidal shapes. These are the simplest forms, and Figure2.13 shows the forms of these membership functions

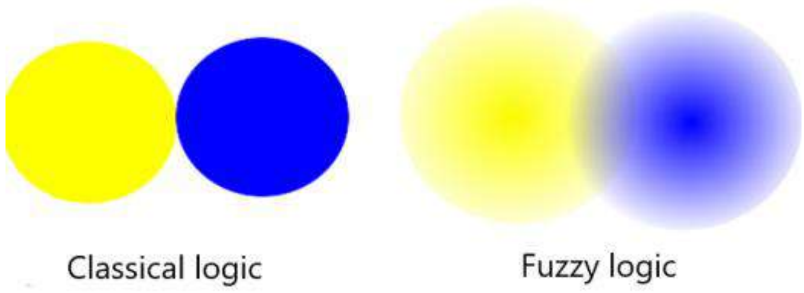


FigureII.13 Graphical representation of the basic forms of membership functions

So the idea of fuzzy logic is to translate human reasoning for a computer, and to be able to deal with problems with imprecise and incomplete input variables[15] .

II.2.1.1. Fuzzy subsets

Unlike fuzzy subsets, classical subsets are called net subsets as opposed to fuzzy, while classical subsets have a limit a net boundary and precise fuzzy subsets have an indefinite boundary, fuzzy Figure 2.14 shows us this difference between the two subsets.



FigureII.14 Representation of classical logic and fuzzy logic.

To better understand, we take our first example of the driver: First entry: the color of the light. Subsets: green, orange and red.

Second entry: the speed of the car. Sub-assemblies: high, medium and low Third entry: the distance of the car from the fire. Subsets: far and near Output: the driver's reaction. Sub-assemblies: brake hard, brake gently, maintain speed and accelerate

II.2.1.2. Language variables

The imprecision of descriptions of certain situations, phenomena or physical quantities can only be done by relative or fuzzy expressions namely (hot, cold, large, small, near, far, ...). These different classes of fuzzy expressions called fuzzy sets form what are called linguistic variables.

In order to be able to process these language variables numerically, they must be subjected to a mathematical definition based on membership functions that show the degree of verification of these linguistic variables in relation to the different fuzzy subsets of the same class.

II.2.1.3. Fuzzy operators

Several operators are used in classical logic such as union, intersection and complement, similarly in fuzzy logic the same operators are used, however operations on fuzzy sets cannot be defined in the same way as that of classical sets, [16] and there are several variants of these operators but the most used remains that of " Zadeh " which can be described as follows:

Let be two sets A and B, the union is defined as being the largest fuzzy set containing A and B, the intersection is defined as the smallest fuzzy set contained in A and in B we can write this differently:

$$\mu A \cup B = \max(\mu A , \mu B) \quad \textbf{(II.6)}$$

$$\mu A \cap B = min(\mu A , \mu B) \quad \textbf{(II.7)}$$

The complement of a fuzzy set A is defined as follows:

$$\mu_A = 1 - \mu_A \quad \textbf{(II.8)}$$

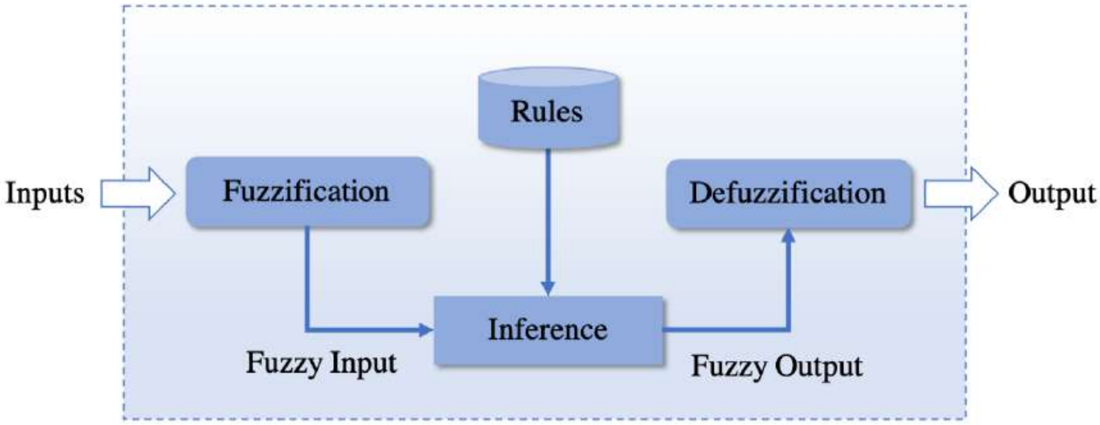
The Fuzzy Rules Database is the most used tool in fuzzy logic, a Fuzzy Rule Base is composed of rules that are typically described as follows: Operation: If condition AND condition, then consequence

II.2.2. Description and structure of a command by fuzzy logic

Unlike commands based on classical logic, commands based on fuzzy logic do not use very precise mathematical relationships, on the other hand they rely on the manipulation of inferences with several fuzzy rules based on fuzzy operators AND, OR, THEN ... etc. Applied to language variables In a fuzzy regulator we can find three main parts constituting the structure of the latter (Figure III.15).

- ✓ A Fuzzification interface.
- ✓ An inference mechanism.
- ✓ A Defuzzification interface

Figure 3.5 shows the explanatory diagram of a blur regulator with two inputs and one output or x1 and x2 represents the input variables and "y" the command.



FigureII.15 Internal structure of a fuzzy regulator

II.2.2.1. Fuzzification interface

Fuzzification is an operation that consists of transforming the numerical data of a phenomenon into linguistic values on a standardized domain to facilitate the calculation. Thanks to these numerical domains, which are called discourse universes, it will be possible to calculate the degrees of belonging of the fuzzy subsets of the linguistic variable for each input or output quantity.

Consider a fuzzy controller of the average output voltage of a chopper that has two inputs: the error of the output voltage of the converter with respect to the set point that is set as follows:

$$X_1 = e = \mathbf{V}_{ref} = Vs \qquad \textbf{(II.9)}$$

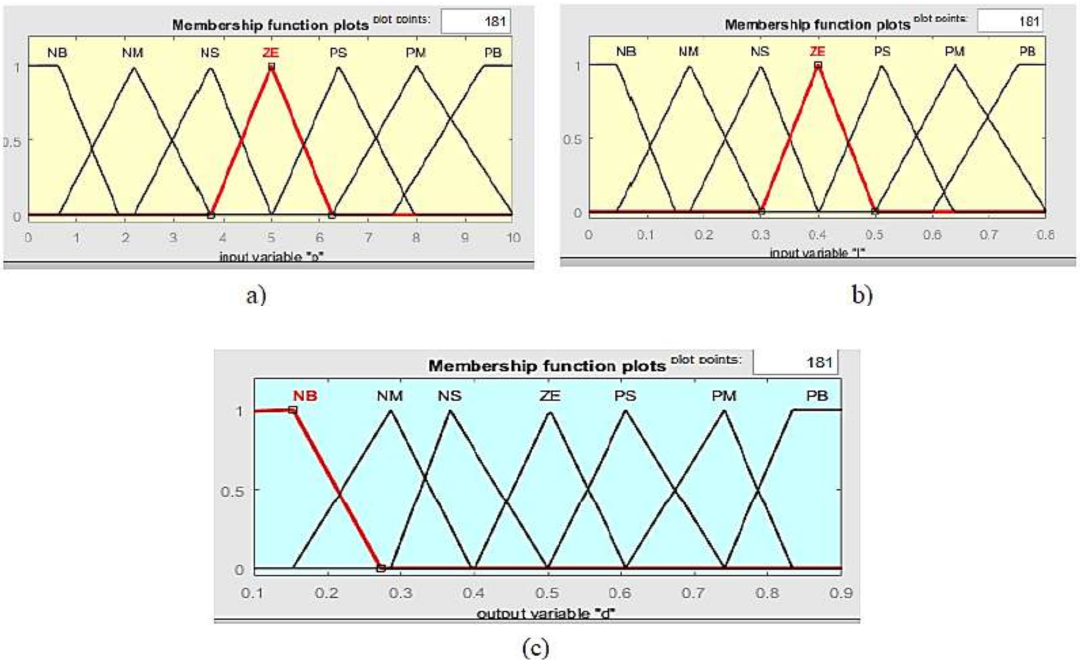
And the variation of this error is defined as follows: $x_2 = \Delta_e$

In particular, this command is better suited to nonlinear systems. The operation of this algorithm is done in three blocks: fuzzification, inference and defuzzification Figure (II.14) [16].

Fuzzification allows the conversion of physical input variables into fuzzy sets.

The linguistic variables are attributed to the input quantities: NG (Negative Large), NM (Negative Medium), NP (Negative Small), Z (Zero), PP (Positive Small), PM (Positive Medium) and PG (Positive Large).).

The representation of our input variables is shown in figure (II.15).



FigureII.16 Membership functions for (a) input current of converter , (b) input voltage of converter ,(c) output duty cycle of fuzzy controller

II.2.2.2. Inference mechanism

This step consists in linking the physical input variables of the regulator (measured or estimated quantities), which are transformed into linguistic variables during the fuzzification step, and the output variable of the controller in its linguistic form, by mental rules translating a linguistic action or decision on the command at the output of the regulator, faced with any situation arising at the entrance of this regulator.

These inferences are based on several rules established by expertise and human know-how regarding the system to be settled. They are structured in compact form in a multidimensional matrix called an inference matrix

Inferences are usually expressed by a linguistic and symbolic description based on rules pre-defined in the inference matrix. Each rule is composed of a condition preceded by the 'SI' operator called a premise, and a conclusion (action, decision, operation or command) proceeded by the 'THEN' operator.

Different methods exist for the digital processing of inference rules that makes it possible to obtain the linguistic or fuzzy output of the regulator and we quote mainly:

- ✓ The max-min inference method.
- ✓ The max-prod.
- ✓ sum-prod inference method

Each of these methods uses a digital processing specific to it, which we will try to explain:

For the max-min inference method, the OPERATOR AND is achieved by the formation of the minimum, the operator OR is achieved by the formation of the maximum, and THEN (the implication) is achieved by the formation of the minimum.

For the max-prod inference method, the AND operator is achieved by product training, or operator is achieved by maximum training, and THEN (involvement) is achieved by product training.

For the sum-prod inference method, the operator OR by the formation of the sum (average value), and the operator AND by the formation of the product, are realized at the level of the condition. For the conclusion, the then operator is carried out by a product

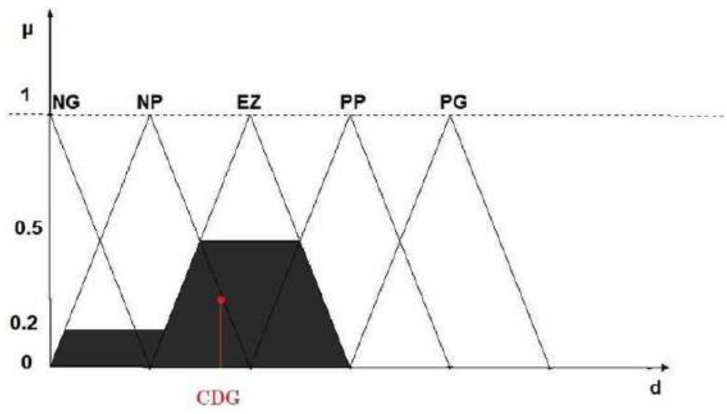
II.2.2.3. Defuzzification interface

Defuzzification is a step that consists in deducing a precise numerical value of the output of the regulator (y) from the results obtained in the inference step. There are several methods and the most commonly used are:

- ✓ The center of gravity method.
- ✓ The maximum method.
- ✓ The surface method.
- ✓ The height method.

The method of the center of gravity being the most used we will try to present it briefly in the following: the method consists in determining the center of gravity of the function of belonging resulting from the method of inference. It will be enough to calculate the abscissa of the center of gravity, to determine the latter we rely on the following general relationship:

$$CDG = \frac{\int \boldsymbol{y} * \boldsymbol{\mu}(\boldsymbol{y}) *}{\int \boldsymbol{\mu}(\boldsymbol{y})} \frac{\boldsymbol{dy}}{\boldsymbol{dy}} \qquad \textbf{(II.10)}$$



FigureII.17 Centre of gravity method.

II.2.3. Fuzzy logic MPPT Controller

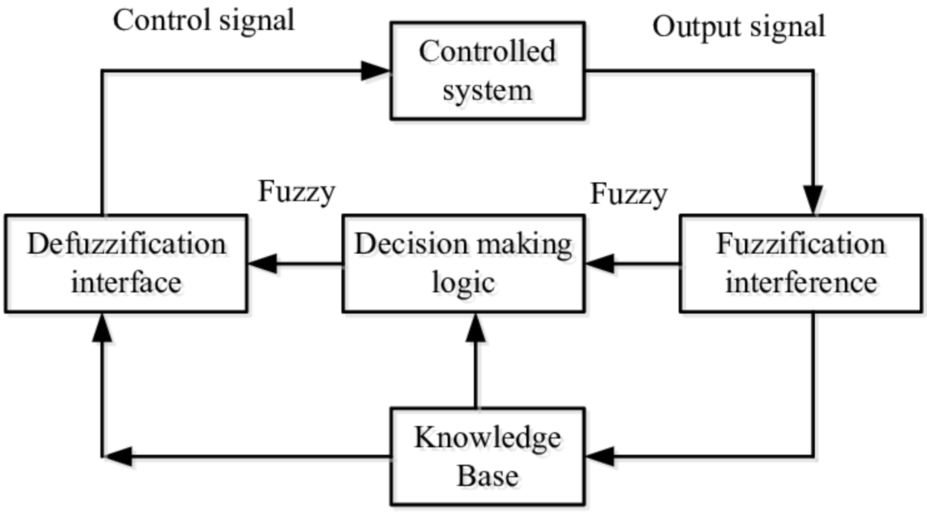
Thanks to the evolution of microcontrollers, commands based on fuzzy logic are much more used in several areas and over time become very popular. The advantage of this technique that we have already seen is that it can work in systems with inaccurate input values and without the need for a mathematical model of high precision, moreover they can deal with nonlinearities [18] .

The principle of a fuzzy command is based mainly on two input variables which are error E and error variation ΔE and an output variable ΔD (change in the duty cycle) .

The value of the output variable that drives the static converter to find the maximum power point is determined using a truth table and the evolution of the input parameters

II.2.3.1. Principle of fuzzy logic MPPT control (FLC)

In the following we will detail the steps of designing a fuzzy controller for the purpose of pursuing the maximum power point. As we presented earlier the fuzzy controller has three blocks, so three steps which consists in the fuzzification of the input variables by the use of membership functions, then the inference or fuzzified variables are compared with predefined sets to determine the appropriate rethink, and finally the defuzzification to convert the fuzzified subsets into values. The basic structure of our fuzzy controller is shown in IV7



FigureII.18 Basic diagram of a fuzzy controller

II.2.3.1.1. Fuzzification

The objective of fuzzification is to define the membership functions for the different variables that make the input variables blurred. A preliminary step is to define a maximum allowable range of variation for the input variables. The purpose of fuzzification is to transform input variables into linguistic variables or fuzzy variables.

In this case, we have two input variables which are error E (k) and variation of sampling error k which are defined as follows: ΔE (k) at the moment

$$E(k) = \frac{P(k)-P(k-1)}{V(k)-V(k-1)} \quad (II.11)$$

$$\Delta E = E(k) - E(k-1) \quad (II.12)$$

Where P (k) is the power of the photovoltaic generator and V (k) the voltage of the photovoltaic generator therefore:

E (k) is equal to zero at the maximum power point of the photovoltaic generator; these input variables are expressed in terms of language variables such as NG (large negative), NP (small negative), EZ (equal to zero), PP (small positive), and PG (large positive).

II.2.3.1.2. Inference method

The tuning strategy depends on the inferences adopted. They bind the input variables to an output variable. This step consists of defining a logical relationship between the inputs and the output.

The following table shows the rules of the fuzzy controller, where all the entries in the matrix are the fuzzy sets of the error (E), the error variation (ΔE) and the cyclic ratio variation (ΔD) of the static converter.

The control rule must be designed so that the input variable (E) is always zero.

. **Table II.2: table rules of fuzzy logic**

ΔE / E	PP	EZ	NP	NG	PG
NG	PG	PG	EZ	EZ	PG
NP	PP	PP	EZ	EZ	PP
EZ	EZ	EZ	EZ	PP	EZ
PP	EZ	NP	NP	NP	EZ
PG	EZ	NG	NG	NG	EZ

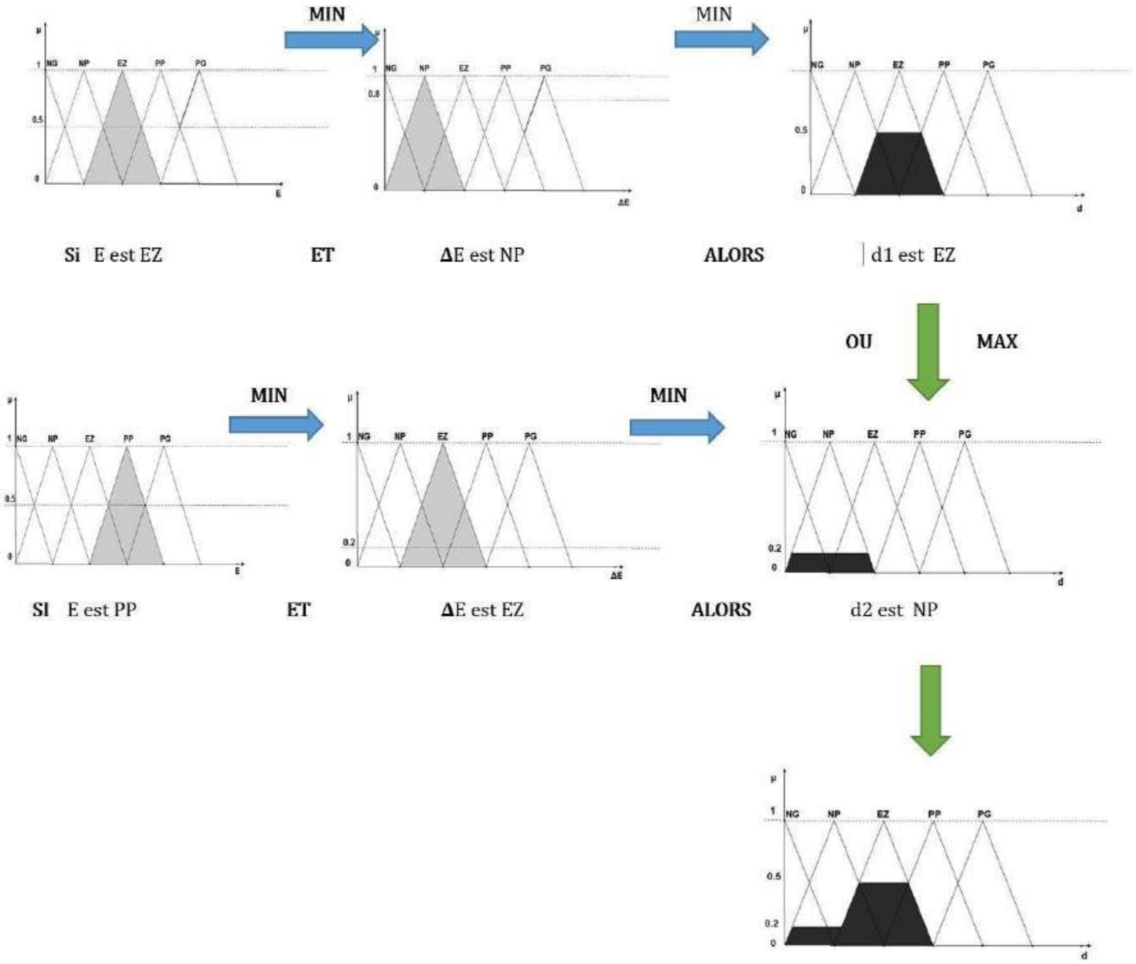
While the error allows to set the position of the operating point in the following way. To the left of the operating point of the curve the error is always positive. And to the right of the operating point it is always negative.

The variation of the error makes it possible to define the direction of displacement of the operating point on the curve. It is positive in the correct sense towards the MPP, and negative in the opposite direction.

In the inferences we will use fuzzy operators such as AND, OR, the operator AND is used within a rule, while the operator OR links the different rules, and in our study we will rely on the max-min inference method

II.2.3.1.3. max-min inference method

For this method of inference the operator AND is achieved by the formation of the minimum, the operator OR is realized by the formation of the maximum, and THEN (the implication) is realized by the formation of the minimum.
We will explain the principle in the following figure:



FigureII.19 Max-min inference method.

II.2.3.1.4. Défuzzification

Finally, we must carry out the inverse operation of fuzzification, here we must calculate a numerical value understandable by the external environment from a fuzzy definition is this is the purpose of defuzzification. Defuzzification can be achieved using the center of gravity method mentioned above

II.2.4. Conclusion

Fuzzy logic being a tool of artificial intelligence it has many advantages that its speed and precision also its ability to adapt to any environment, which distinguish it from classical logic and which pushes us to choose it in data processing.

In this chapter we introduced the fuzzy logic and explain the principle of its operation then we presented the MPPT command based on fuzzy logic and its operation

Chapter III:

Simulation and implementation in the PV system

III.1. Introduction :

This chapter studies the application of fuzzy logic control as algorithm for a maximum power point tracking of photovoltaic system. Also the design and performance of the fuzzy system was tested in Simulink/MATLAB with PV module and buck-boost converter and the rules of fuzzy logic were formulated and validated. Finally, the results in this section were useful to be implemented in the real fuzzy control system on actual hardware which is presented in next chapter.

III.2. PV model Simulation

The entire system was combined and tested in Simulink/MATLAB for various values of solar irradiation as shown in Figure III.1

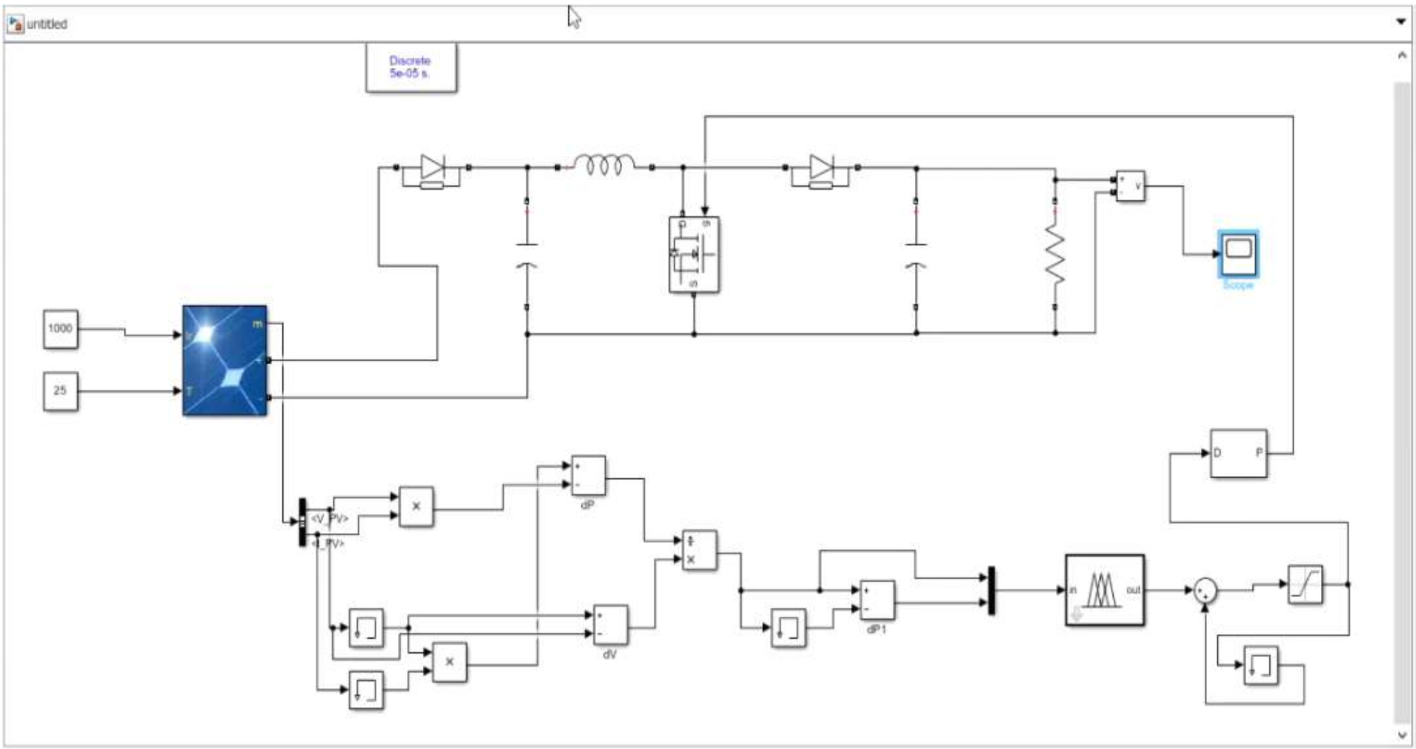


Figure III.1 Fuzzy logic based MPPT for Solar PV array in MATLAB _ SIMULINK

The simulation model shown in Figure III.1 was implemented in at Simulink/MATLAB at different changes of irradiance. In order to check the fuzzy controller performance and the efficiency of the converter the readings of input power and output power of the MPPT were taken at solar irradiance (1000w/m^2, 800w/m^2, 600w/m^2, 400w/m^2, 200w/m^2) and also duty cycle was observed at the same values of radiation.

Table III.1 characteristic of the PV model

Voc	21.21V
Isc	3.75A
K1	0.003
A	2.15
Np	1
Ns	36
Rs	0.001Ω
Rsh	1000Ω
P	60W

Table III.2 DC/DC Converter Parameter

R	500Ω
C	2*10^-4
C1	30*10^-4
L	0.1H

III.3. Characteristic of a photovoltaic panel facing different temperature:

From Figure III.1 we see that the photovoltaic panel is sensitive to the temperature of the operating environment, so we notice that the voltage of the PV varies much more than its current.

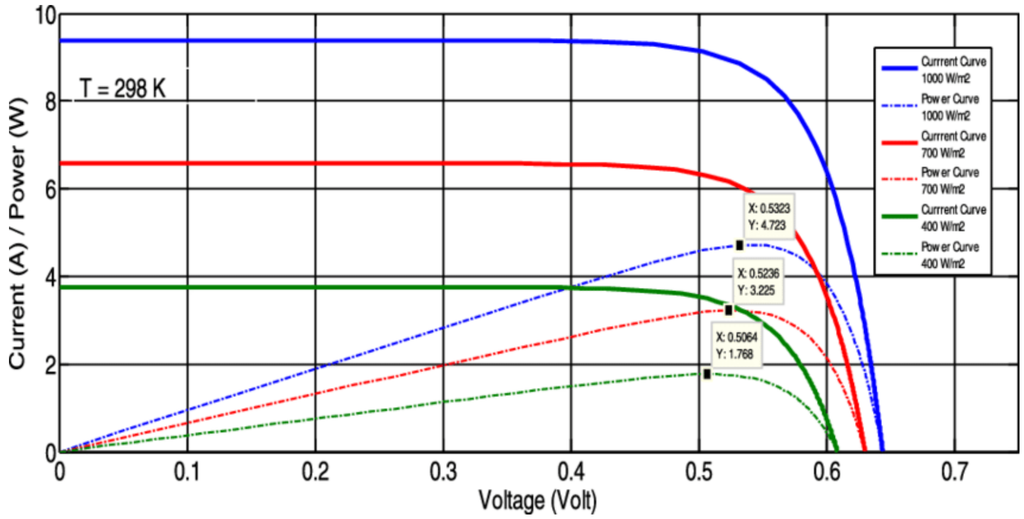


Figure III.2 Solar I-V and P-V characteristic with different insolation and for constant temperature.

III.4. Characteristic of a photovoltaic panel facing different amounts of sunlight:

From Figure III.2we see that the photovoltaic panel reacts differently to different degrees of sunshine

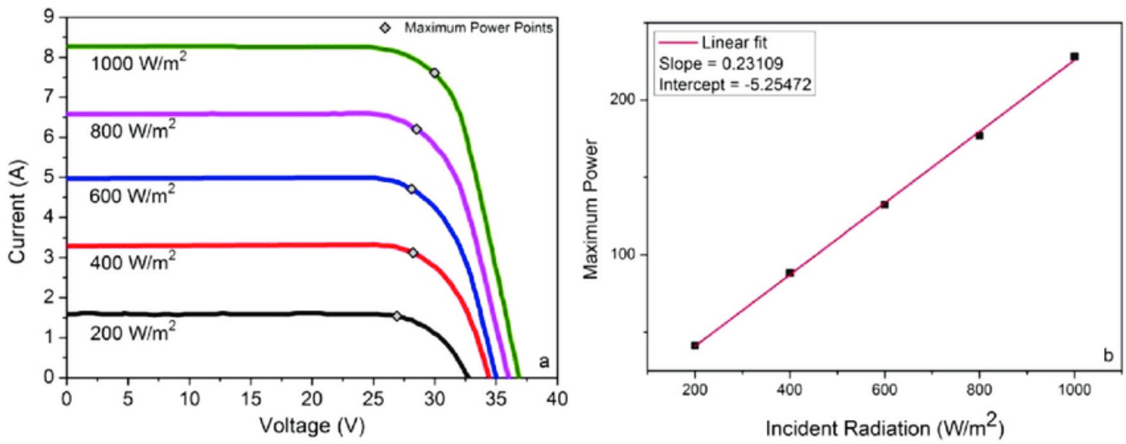


Figure III.3 a) IV-characteristics of a solar panel at different light intensities, b) straight line fit of maximum power point versus illumination intensity[7]

III.5. Résultats de simulation pour la commande MPPT basé sur la logique floue :

III.5.1. Behavior facing a variation of hours of sunshine:

The MPPT command based on fuzzy logic it was simulated in association with a DC/DC boost converter (booster), we start with a simulation facing a gradual decrease in sunshine that goes from 1000w/m² up to 500w/m² with a constant temperature, and Figure III.4 shows us this decrease.

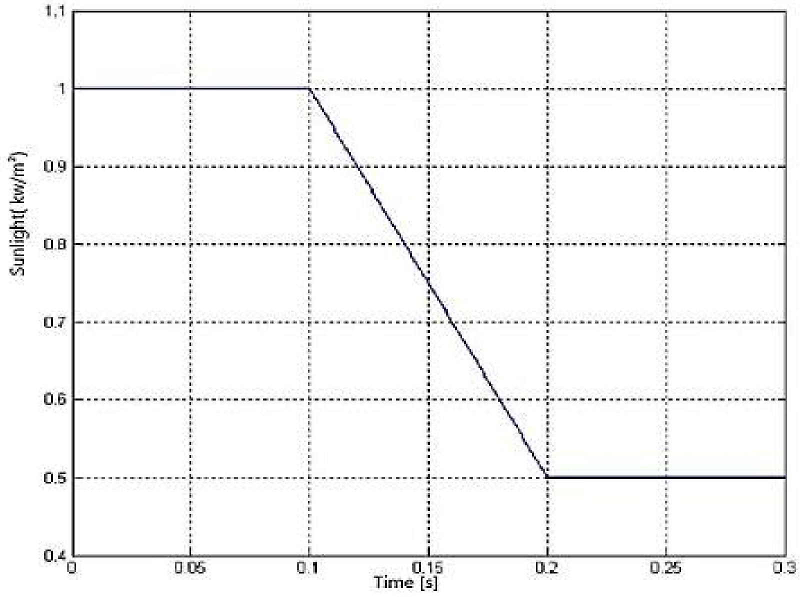


Figure III.4 sunlight variation from 1000w/m² up to 500w/m

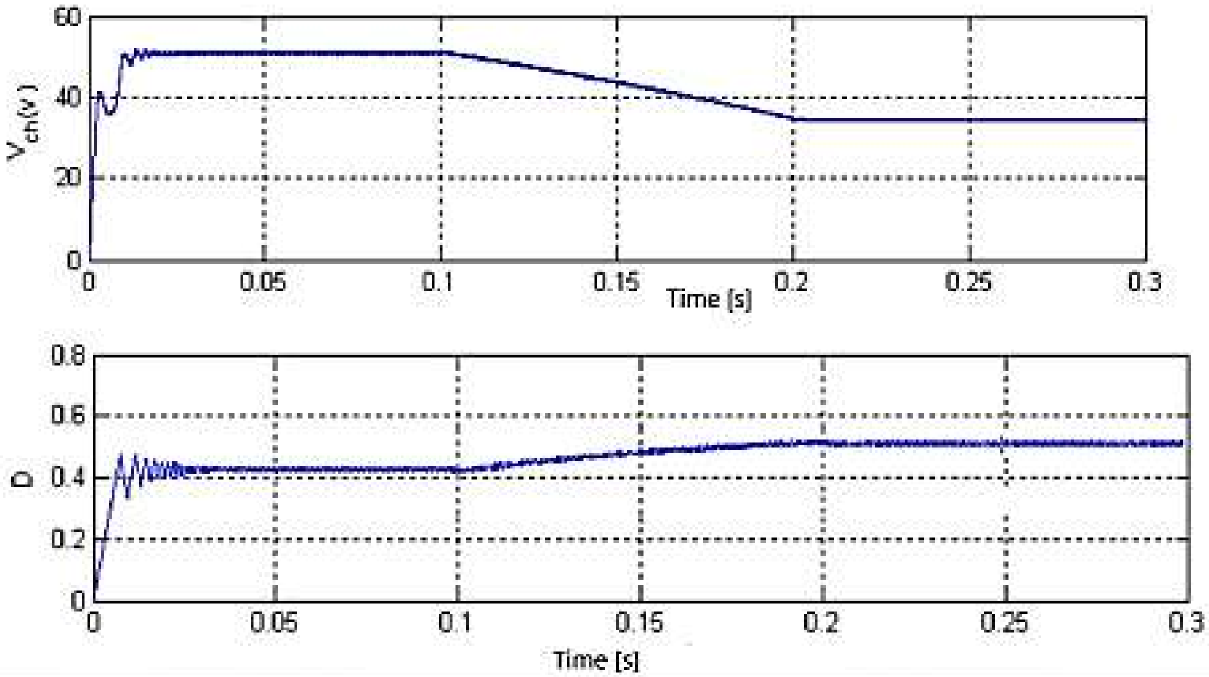


Figure III.5 variation of the voltage of the PV generator, voltage of the load, and the cyclic ratio facing the decrease in sunshine in fuzzy MPPT controller

For a fuzzy MPPT controller, we draw the curves load power and PV generator in Figure III.6

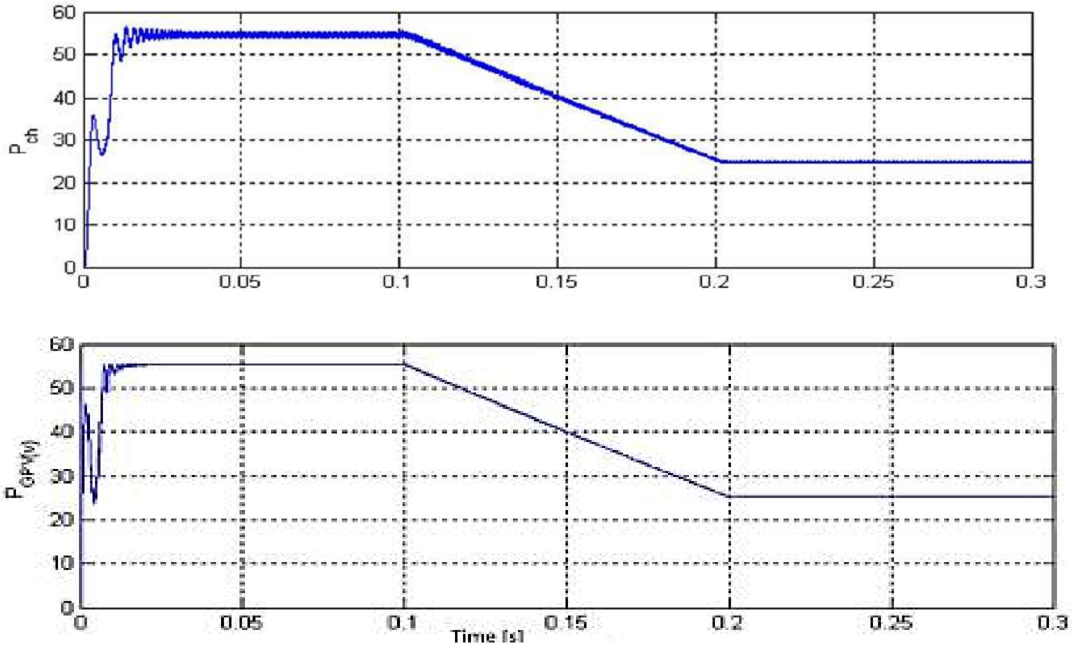


Figure III.6 power variation of the load and the PV generator facing decrease illumination in fuzzy MPPT controller

Figure III.6 shows us how the fuzzy MPPT controller continues the decrease sunshine which has led to a decrease in power.

III.5.2. Behavior of facing temperature variation

After the simulation with changes in sunshine we now move to the temperature variation, and for this we make our system undergo a temperature decrease ranging from 25 ° C to 10 ° C, with a stable sunshine of 500w / m², this variation is illustrated in Figure III.6

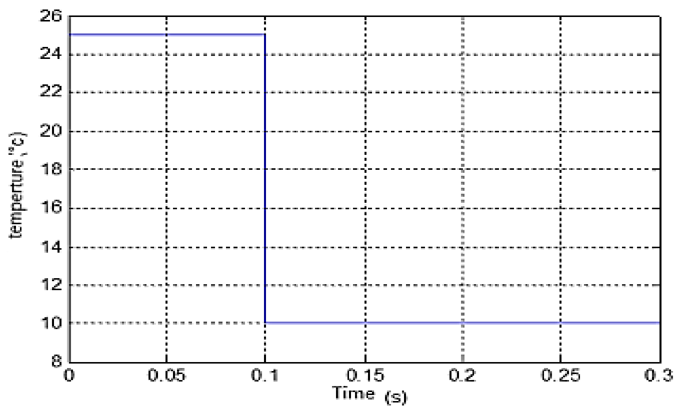


Figure III.7 temperature variation from 25°C to 10°C

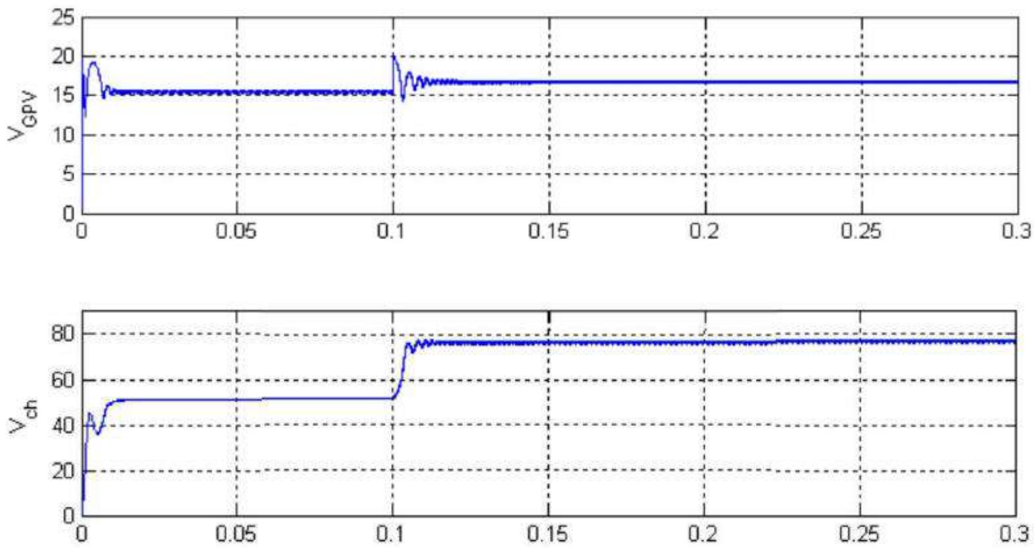


Figure III.8 voltage of the PV generator and the load with changed temperature with the fuzzy MPPT command

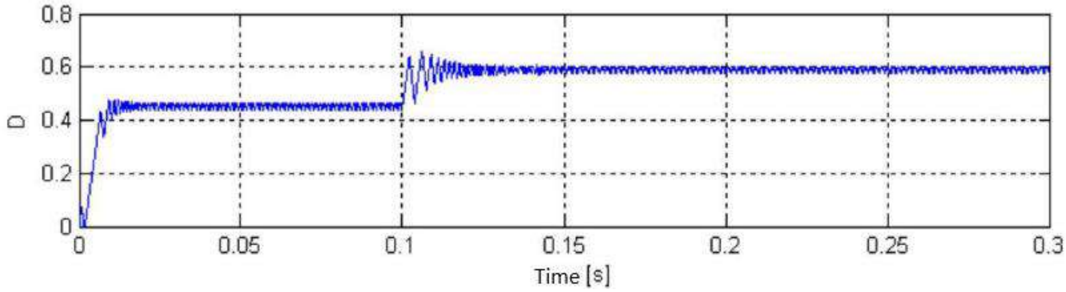


Figure III.9 change in the duty cycle by temperature change with the fuzzy MPPT Controller

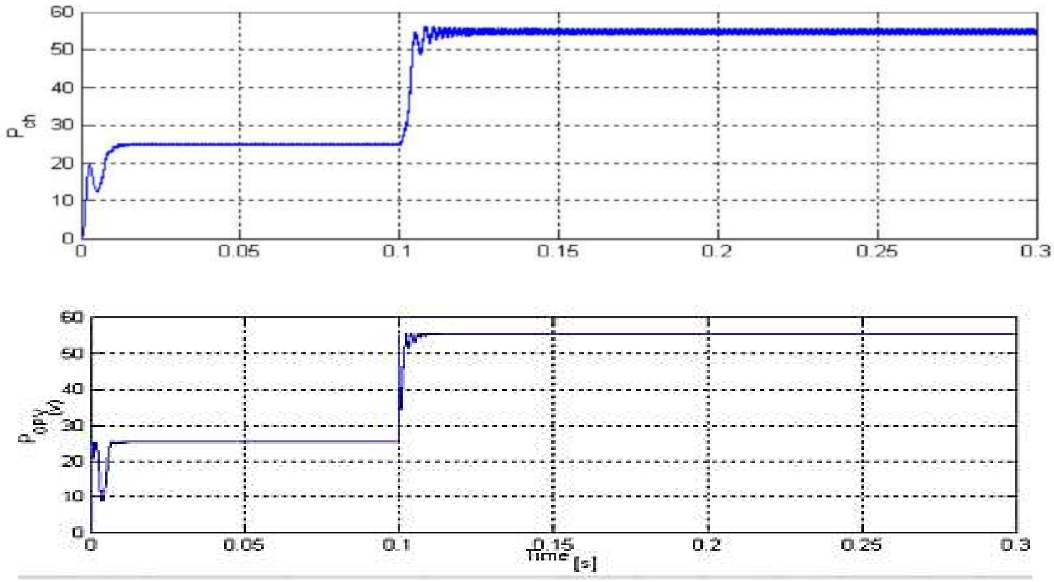


Figure III.10 load power and PV generator power when there's a decrease in temperature with fuzzy MPPT controller

III.6. **Conclusion:**

A Fuzzy controller for tracking maximum power point of photovoltaic source was proposed in this chapter and simulated in Simulink/MATLAB. The controller was based on the basic blocks of fuzzy system, which are (Fuzzification, Inference, and Defuzzification).

General conclusion

A large part of the power generated by a photovoltaic generator remains unexploited, this is due to internal or external disturbances, external such as variations in temperature or sunshine, internal due to the disturbances of the load, all this causes disturbances in the maximum power point of the PV generator, and to remedy this we have recourse to an MPPT control that adjusts the operating point of the PV generator under the conditions of operation. The MPPT control works by acting on the trigger of a DC/DC converter that serves as the interface between the photovoltaic generator and the load.

There is a very large range of MPPT controls. In our work we chose to highlight of them, the command based on fuzzy logic. We simulated the system with a fuzzy logical MPPT control. This has led to methods in the face of variations in temperature and sunshine,

After simulation and analysis of the different results we arrive at several conclusions:

- A photovoltaic generator facing a decrease in sunshine or an increase in temperature tends to lose power
- MPPT control based on fuzzy logic allows tracking of the maximum power point much more and accuracy

From the harsh results list it is clear that the method based on fuzzy logic is a method that offers a very good monitoring of the maximum power point with optimal efficiency Nevertheless these results are the result of theoretical simulation and it would be necessary to apply this method in the field to have definitive results