



PEOPLE'S DEMOCRATIC REPUBLIC OF ALGERIA

MINISTRY OF HIGHER EDUCATION AND SCIENTIFIC RESEARCH



ECHAHID HAMMA LAKHDAR UNIVERSITY OF EL OUED

Faculty of Technology

MASTER ACADEMIC DEGREE

Specialty: Electrical networks

Level: 02 Master

End of study dissertation

Presented for graduation from

**Control of a photovoltaic pumping system Based
on a Dc motor**

Presented by:

- ❖ DAHA Othmane
- ❖ Guediri Ali
- ❖ Ghrib Adnane

The defiance was made before a jury consisting of:

<i>President</i>	<i>D.r. Baba Elarbi Idrise</i>	<i>MCA</i>	<i>University of El-Oued</i>
<i>Examiner</i>	<i>D.r. Hamidani Bilal</i>	<i>MCA</i>	<i>University of El-Oued</i>
<i>Protractor</i>	<i>D.r. Toumi Dgaafar</i>	<i>MCA</i>	<i>University of El-Oued</i>

Academic Yrar :2024 / 2025

الشكر والتقدير

الْحَمْدُ لِلَّهِ الَّذِي بِنِعْمَتِهِ تَتِمُّ الصَّالِحَاتُ، وَبِفَضْلِهِ تُدَلُّ الصِّعَابُ وَتُنَالُ الْمَقَاصِدُ
أَمَا بَعْدُ،

فَقَدْ وَصَلْنَا بِفَضْلِ اللَّهِ تَعَالَى إِلَى مَحَطَّةٍ مُهِمَّةٍ مِنْ مَحَطَّاتِ الْحَيَاةِ الْعِلْمِيَّةِ، وَضَعْنَا فِيهَا بَيْنَ
أَيْدِيكُمْ ثَمَرَةَ سَعْيٍ طَوِيلٍ، وَجُهْدٍ مُضْنٍ، وَسَهْرٍ لَيَالٍ مَمْلُوءَةٍ بِالْأَمَلِ وَالْعَزِيمَةِ
وَلَوْلَا فَضْلُ اللَّهِ، ثُمَّ مَنْ أَكْرَمَنَا بِدَعْمِهِمْ وَتَشْجِيعِهِمْ وَمُسَانَدَتِهِمْ، لَمَا رَأَى هَذَا الْعَمَلُ النُّورَ
نَتَقَدَّمُ بِجَزِيلِ الشُّكْرِ وَالْأَمْتِنَانِ لِأَسْتَاذِنَا الْفَاضِلِ الدُّكْتُورِ ثُومِي جَعْفَرٍ، الَّذِي لَمْ يَبْخُلْ عَلَيْنَا
بِعِلْمِهِ وَخَبْرَتِهِ، وَكَانَ نِعْمَ الْمَوْجِبُ وَالِدَاعِمُ

فَنَوْجِيهَاتُهُ الرَّشِيدَةُ، وَمَلَاخِظَاتُهُ الدَّقِيقَةُ، وَصَبْرُهُ فِي الْمُنَابَعَةِ، كَانَ لَهَا الْأَثَرُ الْبَالِغُ فِي
اسْتِكْمَالِ هَذَا الْعَمَلِ وَإِخْرَاجِهِ بِهَذِهِ الصُّورَةِ

كَمَا لَا نُنْسَى أَنْ نُوجِبَ أَعْمَقَ عِبَارَاتِ الشُّكْرِ وَالْأَمْتِنَانِ لِعَائِلَاتِنَا، الَّتِي كَانَتْ دَائِمًا أَلْسِنَدَ
وَالِدَاعِمَ وَالْمَلَاذَ الْأَمِنَ فِي كُلِّ ظُرُوفِنَا. نَفِدَّرُ تَفَهُمَهُمْ، وَنَتَمَنُّ صَبْرَهُمْ وَحُبَّهُمْ فِي أَوْقَاتِ
الْغِيَابِ وَالْإِنْشِغَالِ

وَلَا يَسَعُنَا فِي هَذَا الْمَقَامِ إِلَّا أَنْ نُعَبِّرَ عَنْ عَظِيمِ أَمْتِنَانِنَا لِأَصْدِقَائِنَا الْأَعْرَاءِ، الَّذِينَ كَانُوا مَعَنَا
خِلَالَ هَذِهِ الرَّحْلَةِ، فَكَانُوا النُّورَ فِي طَرْقِنَا، وَالِدَاعِمَ عِنْدَ كُلِّ عَثْرَةٍ

وَأخيراً، إِلَى كُلِّ مَنْ كَانَ لَهُ أَثَرٌ جَمِيلٌ فِي مَسِيرَتِنَا، وَإِنْ لَمْ نَذْكُرْهُ بِالْأَسْمِ، فَلْيَعْلَمْ أَنَّ
الْعُرْفَانَ فِي الْقَلْبِ، أَعْمَقُ وَأَبْلَغُ مِنْ كُلِّ كَلِمَةٍ تُكْتَبُ أَوْ تُقَالُ
أَتَقَدَّمُ بِأَسْمَى عِبَارَاتِ الشُّكْرِ وَالْأَمْتِنَانِ مِنْ أَعْمَاقِ الْقَلْبِ

الإهداء

...إلى الَّذِينَ كَانَتْ خُطَاهُمْ الْأُولَى نُورًا سَاطِعًا فِي طَرِيقِي
إِلَى أُمِّي الْحَبِيبَةِ، أَنْتِ الَّتِي كُنْتِ لِي وَطَنًا قَبْلَ أَنْ أَعْرِفَ مَعْنَى الْأُوطَانَ، أَنْتِ الَّتِي لَخَّصْتِ فِي دُعَائِكَ كُلَّ
الْأُمْنِيَّاتِ، وَكَانَ لَحْنُ دُعَائِكَ يُرَافِقُنِي فِي لَحْظَاتِ الضَّعْفِ قَبْلَ الْقُوَّةِ، وَفِي السُّفُوطِ قَبْلَ النُّهُوضِ... أَنْتِ السِّرُّ،
وَالْبِدَايَةُ، وَالنَّهَائَةُ فِي كُلِّ نَجَاحٍ.

وَإِلَى وَالِدِي الْعَزِيزِ، أَنْتَ الَّذِي عَلَّمْتَنِي أَنَّ الْفَخْرَ فِي الْعِلْمِ، وَأَنَّ الرَّجُولَةَ لَا تُقَاسُ بِالْقُوَّةِ، بَلْ بِالثَّبَاتِ. شَكَرًا
لِصِرَامَتِكَ الَّتِي عَلَّمْتَنِي الْأَنْضِبَاطَ، وَلِصَبْرِكَ الَّذِي أَلْهَمَنِي الْاجْتِهَادَ... أَنْتِ الصَّخْرَةُ الَّتِي بَنَيْتُ عَلَيْهَا
طُمُوجِي.

وَإِلَى إِخْوَتِي وَأَخَوَاتِي، أَنْتُمْ نَبْضُ قَلْبِي وَسَنْدُ رُوحِي، كُنْتُمْ دَوْمًا خَلْفَ السِّتَارِ، تُزِيحُونَ عَنِّي التَّعَبَ بِكَلِمَةٍ،
وَتَدْفَعُونَنِي إِلَى الْأَمَامِ بِإِتِّسَامَةٍ... لَنْ أَنْسَى دِفْءَ وَجُودِكُمْ أَبَدًا.

وَإِلَى أَسَاتِدَتِي، مَشَاعِلَ الْفِكْرِ وَرُفَقَاءَ الْعَقْلِ، الَّذِينَ تَرَكُوا بَصْمَةً لَا تُمَحَى فِي رُوحِي، وَفَتَحُوا أَمَامِي آفَاقًا مَا
كُنْتُ لِأَدْرِكُهَا... أَنْتُمْ تَطْلُونَ دَوْمًا النُّورَ الْهَادِيَ لِكُلِّ طَالِبِ عِلْمٍ.

Table of Contents

Title	Page
General Introduction	1
Chapter I :General information on photovoltaic systems	
I.1 Introduction	3
I.2 Photovoltaic Solar Energy	3
I.3 Solar Radiation	3
I.4 Types of Radiation (Direct - Diffuse - Reflected - Global)	4
I.5 Solar Radiation Spectrum	5
I.6 Types of Photovoltaic Cells	5
I.7 The Photovoltaic Effect	6
I.8 Conversion Principle in PV Systems	6
I.9 Photovoltaic Generator (GPV)	7
I.10 PV Cell Modeling (Ideal and Real)	8
I.11 Protections	10
I.12 PV Generator Construction	11
I.13 Generator Simulation	13
I.14 Fill Factor (FF)	16
I.15 Efficiency	16
I.16 Advantages and Disadvantages of PV Energy	16
I.17 Conclusion	17
Chapter II : Continuation of the maximum power point	
II.1 Introduction	19
II.2 DC/DC Converters	19
II.3 Direct Load Connection	20
II.4 Indirect Connection	22
II.5 Boost Converter	23
II.6 Maximum Power of the Generator	25
II.7 MPPT Management	26

II.8 Perturb and Observe (P&O) Algorithm	27
II.9 Simulation Diagram	31
II.10 Conclusion	34
Chapter III :Control of a photovoltaic pumping system based on a DC motor	
III.1 PV Pumping Systems	37
III.2 DC Motor Modeling	37
III.3 Motor Equations	38
III.4 Pump Model	39
III.5 Hysteresis Control	39
III.6 Simulation and Results	40
III.7 Conclusion	47
I General Conclusion	50
References	51

Figure List

Figure (Number + Title)	Page Number
Chapter I :General information on photovoltaic systems	
Figure I.1: Types of solar radiation	5
Figure I.2: Spectral distribution of solar radiation	5
Figure I.3: Block diagram of a PV cell	7
Figure I.4: PN junction of a Photovoltaic Cell	7
Figure I.5: Components of a GPV	8
Figure I.6: Equivalent diagram of an ideal cell	8
Figure I.7: Equivalent diagram of a real photovoltaic cell	9
Figure I.8: Schematization of an elementary GPV with bypass diodes and non-return diodes	11
Figure I.9: Effect of the by-pass diode on the I(V) characteristic of a photovoltaic array	11
Figure I.10: Simulation diagram of a real photovoltaic module	12
Figure I.11: Diagram of 3 photovoltaic cells associated in series	12
Figure I.12: Diagram of 3 photovoltaic cells associated in parallel	13
Figure I.13: Parameters of the PV Generator 1 block	13
Figure I.14: P-V characteristic of a photovoltaic array	14
Figure I.15: I-V characteristic of a photovoltaic array	14
Figure I.16: P-V characteristic of the PV module according to the illuminance	15
Figure I.17: I-V characteristic of the PV module according to the illuminance	15

Figure I.18: P-V characteristic of the PV module according to temperature	16
Chapter II: Continuation of the maximum power point	
Figure II.1: DC/DC Converter	20
Figure II.2: Principle of direct coupling	20
Figure II.3: Types of Directly Connected Loads	21
Figure II.4: Connecting a GPV to a load through an adapter stage	22
Figure II.5: Boost converter	23
Figure II.6: Schematic diagram of a Boost converter	23
Figure II.7 : Schémas équivalents du hacheur.[29] survolteur	24
Figure II.8: The I-V, P-V characteristic and the PPM trajectory	25
Figure II.9: Elementary photovoltaic conversion chain	26
Figure II.10: Search for and recovery of the Maximum Power Point	27
Figure II.11: Operating characteristics of the Perturbation-Observation method	28
Figure II.12: Algorithm of the Perturbation and Observation method	29
Figure II.13: Simulation block diagram of the algorithm (P&O)	30
Figure II.14: Block diagram of a photovoltaic system equipped with MPPT	31
Figure II.15: Variation in illuminance	32
Figure II.16: Temperature variation	32
Figure II.17: P(t) characteristics of a PV system	33
Figure II.18: V(t) characteristics of a PV system	33

Figure II.19: I(t) characteristics of a PV system	33
Figure II.20: P(V) characteristics of a PV system	33
Figure II.21: I(V) characteristics of a PV system	34
Chapter III :Control of a photovoltaic pumping system based on a DC motor	
Figure III.1: Photovoltaic pumping systems	37
Figure III.2: Electrical diagram of a separately excited MCC	38
Figure III.3: Principle of control by Hysteresis	40
Figure III.4: Simulink block of a motor pump unit	41
Figure III.5: Variation of illumination	41
Figure III.6: Solar panel temperature	42
Figure III.7: PV Voltage	42
Figure III.8: The Power of the GPV for variable illuminance	43
Figure III.9: The Power of the GPV as a function of the voltage	43
Figure III.10: The Power of the GPV	44
Figure III.11: The Tension of MCC	44
Figure III.12: The MCC current	45
Figure III.13: Variation of engine rotation speed	45
Figure III.14: The MCC Couple	46

List of tables

Chapter II	Continuation of the maximum power point
Table II.1: Technical data sheet for KC200GT to STC conditions .	31
Table II.2: Converter parameters.	32

summary

In this thesis we aim to: study MPPT control of a PV pumping system based on the technique disturbance and observation (P&O), We then studied the case of a pumping system using a direct current motor, We carried out a general study with the modeling and simulation of a systemsolar pumping connected to a DC-DC converter. In order to have the possibility of adjusting the water flow of the centrifugal pump, the hysteresis control used for controlling the rotation speed of the DC motor pump .

Tags:

Photovoltaic Array, DC-DC Converters, MPPT, DC Motor;
Pumping System, Hysteresis Control

المخلص

هدفنا في هذه الرسالة هو: دراسة التحكم في MPPT في نظام الضخ الكهروضوئي بناءً على تقنية الاضطراب والملاحظ (P&O)، ثم درسنا حالة نظام الضخ باستخدام محرك، وقمنا بإجراء دراسة عامة مع نمذجة ومحاكاة نظام ضخ بالطاقة الشمسية متصل بمحول DC-DC من أجل الحصول على إمكانية ضبط تدفق المياه لمضخة الطرد المركزي، يتم استخدام التحكم في التباطؤ للتحكم في سرعة دوران مضخة محرك التيار المستمر.

الكلمات المفتاحية:

نظام الضخ MPP، محرك DC-DC المولد الكهروضوئي، محولات .

General Introduction :

Photovoltaic solar energy is one of the most widely used renewable energies. It consists of directly converting solar radiation into electricity using the photovoltaic effect. Photovoltaic (PV) panels have the ability to transform photons into electrons. The energy in the form of direct current is therefore directly usable. Due to the highly nonlinear electrical characteristics of PV cells and their combinations, the efficiency of PV systems can be improved by solutions using maximum power point tracking (MPPT) techniques.

In this context, we are mainly interested in this work, in the study and development of the maximum power point tracking (MPPT) of a photovoltaic generator (GPV), for a good operation, whatever the weather conditions (temperature and illumination). This requires the implementation of a maximum power point tracking technique, such as the Perturbation-Observation (P&O) method, Incremental (INC) and Fuzzy (FL) approach.

In this thesis we started by presenting general notions on photovoltaic systems, We then presented in the second chapter the DC/DC type power converter with the MPPT control algorithm of a photovoltaic system and their classifications. In the third chapter we present the MPPT control of a PV pumping system based on a DC motor speed control whose aim is to force the machine to operate around its reference speed .

Chapter I

General information on photovoltaic systems

I.1. Introduction :

Photovoltaic energy is the result of the direct transformation of sunlight into electrical energy by means of cells generally based on crystalline silicon, which remains the most technologically and industrially advanced sector, in fact silicon is one of the most abundant elements on earth in the form of non-toxic silica.

For definition, the word "photovoltaic" comes from the Greek "photo" which means light and "voltaic" which originates from the name of an Italian physicist Alessandro Volta (1754 - 1827) who contributed a lot to the discovery of electricity, so photovoltaics literally means light electricity [1].

I.2 Photovoltaic solar energy:

Solar energy is an energy source that is dependent on the sun. This means that the raw material is the sun.

It is in the category of renewable energies since it is considered inexhaustible.

It is also said to be a 100% green energy because its production does not directly emit CO₂.

Thanks to this energy, it is possible to produce electricity. It will be captured by solar panels or thermal power plants. These installations capture the rays produced by the sun. They then convert the sun's energy into electricity.

More precisely, the principle is to transform the energy carried by photons in light into electricity.

This is where the photovoltaic cell comes into play: when exposed to light, it absorbs the energy of the light photons. These generate a direct electric current.

It was in 1839 that Antoine Becquerel discovered that semiconductor materials were capable of transforming solar energy into electricity. This is known as the photovoltaic effect [2].

I.3. Solar radiation:

The sun is one star among many. It has a diameter of 1390000 km, or about 50 times that of the earth. It is composed of 80% hydrogen, 19% helium and 1% a mixture of 100 elements, i.e. practically all the chemical elements known since Langevin and Perrin, based on Einstein's theory of relativity, put forward the idea some sixty years ago that it is the energy of nuclear

fusion that provides the sun with its power. It is now accepted that the Sun is a hydrogen-helium thermonuclear bomb transforming 564 million tons of hydrogen into 560 million tons of helium every second; the reaction takes place in its core at a temperature of about 25 million degrees Celsius. Thus, every second, the sun is lightened by 4 million tons dispersed in the form of radiation. [3]

Its light, at a speed of 300000 km/s, takes about 8 minutes to reach the earth, its spectral distribution of the atmosphere is presented a maximum for a wavelength of about $0.5\mu\text{m}$, the blackbody temperature on the surface of the sun is about 5780°K [3]:

- Sun diameter $D_s = 1.39.10^9\text{m}$;
- Diameter of the earth $D_t = 1.27.10^7\text{m}$;
- Average distance soleil_ land $L_{ts} = 1.5. 10^{11}\text{m}$.

I.4. Types of radiation:

I.4.1 Direct radiation:

Solar flux in the form of parallel rays coming from the sun's disk without having been scattered by the atmosphere. [3]

I.4.2 Diffuse radiation:

It is the part of the radiation coming from the sun, which has undergone multiple reflections (scatterings), in the atmosphere. [3]

I.4.3 Reflected radiation:

This is the part of the solar irradiance reflected by the ground, this radiation depends directly on the nature of the ground (cloud, sand, etc.). It is characterized by an eigencoefficient of the nature of the link called Albedo(ϵ) 0 . [3]

I.4.4 Global Coverage:

A plane receives from the ground a global radiation which is the result of the superposition of the three compositions, direct, diffuse and reflected. [3]

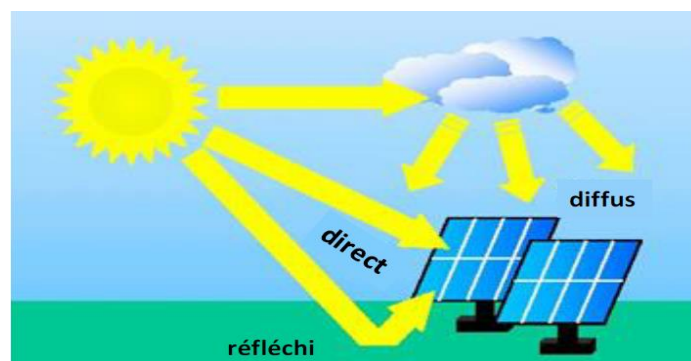


Figure.I.1: Types of solar radiation [4].

1.5. Spectrum of solar radiation:

Electromagnetic radiation is made up of "grains" of light called photons. The energy of each photon is directly related to the wavelength:

The spectrum of extraterrestrial radiation corresponds approximately to the emission of a blackbody heated to 5800° K. A standard curve, compiled according to data collected by satellites, is referred to as AM0. Its energy distribution is divided into:

- Ultraviolet **UV** $0.20 < \lambda < 0.38 \text{ mm}$ **6.4%**
- Visible **0.38 < \lambda < 0.78 mm** **48.0%**
- Infrared **IR** $0.78 < \lambda < 10 \text{ mm}$ **45.6%**

The solar radiation received at the top of the atmosphere, in a plane perpendicular to the sun's rays and for a distance from the earth to the sun equal to its average value. When this radiation passes through the atmosphere to reach the Earth's surface, it is strongly attenuated due to the phenomena of absorption and scattering by the different constituents of the atmosphere [5].

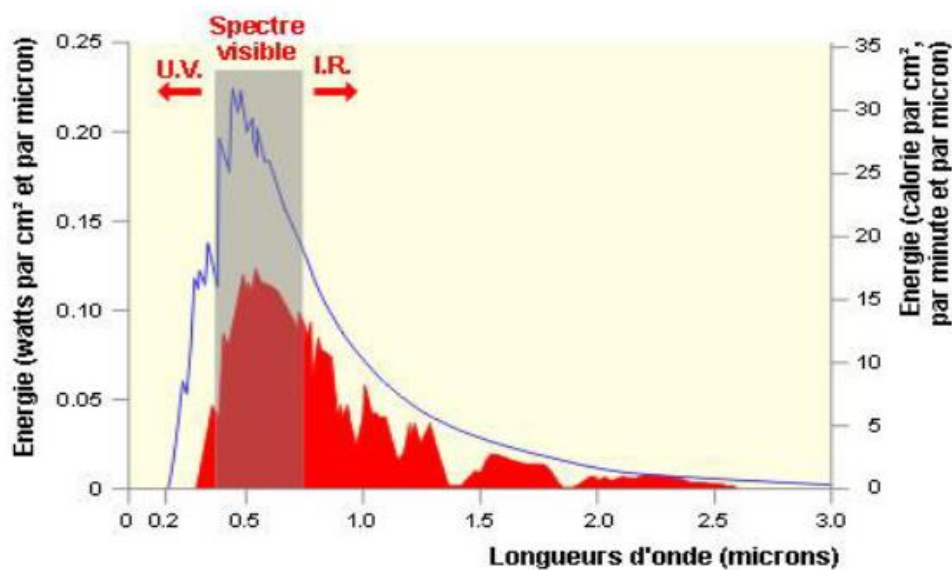


Figure I. 2 : Spectral distribution of solar radiation.

1.6. The PV cell:

1.6.1.Types of PV cells:

There are different types of photovoltaic cells with varying yields and costs. However, regardless of their type, their efficiency remains quite low from 8 to 23% of the energy they receive. There are three main types of cells currently in use.

1.6.2 Monocrystalline cells:

These are the ones with the best efficiency (12-16%), but also those with the highest cost, due to complicated manufacturing [6] .

I.6.3 Polycrystalline cells:

As they are easier to design, their manufacturing cost is lower, but their efficiency is lower: (11%-13%) [6] .

I.6.4 Amorphous cells:

They have a low efficiency (8% - 10%), but require only very low thicknesses of silicon and have a low cost. They are commonly used in consumer products such as solar calculators and watches [6]

I.7. The Photovoltaic Effect:

Photovoltaic (PV) energy is the direct transformation of light into electricity. Unlike passive solar energy, which uses the structural elements of a building to better heat (or cool) it, and active solar energy, which uses a heat transfer fluid (liquid or gas) to transport and store the sun's heat (we think of a water heater), photovoltaic energy is not a form of thermal energy. It uses a PV cell to directly convert solar energy into electricity.

The photovoltaic effect, i.e. the production of electricity directly from light, was first observed in 1839 by the French physicist Edmond Becquerel. However, it was not until the 1950s that researchers at Bell Telephone in the United States succeeded in manufacturing the first solar cell, the primary element of a photovoltaic system.

I.8 . Principles of Conversion in PV Systems:

The photovoltaic effect used in solar cells makes it possible to convert the light energy of the sun's rays directly into electricity through the production and transport of positive and negative electric charges in a semiconductor material under the effect of light. This material has two parts, one with an excess of electrons and the other with an electron deficit, respectively called n-type doped and p-doped doped p. When the former is brought into contact with the latter, the excess electrons in the material n diffuse into the material p. The initially n-doped area becomes positively charged, and the initially p-doped area negatively charged. An electric field is therefore created between them that tends to push the electrons back into the n zone and the holes towards the p zone.

A junction (called p-n) is formed By adding metal contacts on the n and p zones, a diode is obtained. When the junction is illuminated, photons with energies equal to or greater than the width of the bandgap impart their energy to the atoms, each of which causes an electron from the valence band to pass through the conduction band and also leaves a hole capable of moving, thus generating an electron-hole pair. If a charge is placed across the cell, the electrons in the

n-zone join the holes in the p-zone via the outer connection, giving rise to a potential difference in the electric current flowing [8].

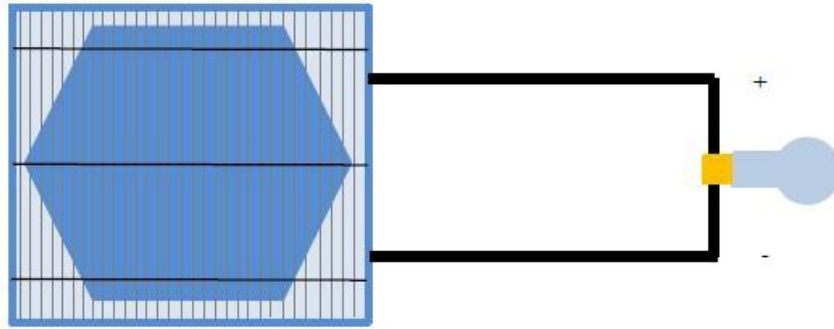


Figure I.3: Block diagram of a PV cell.

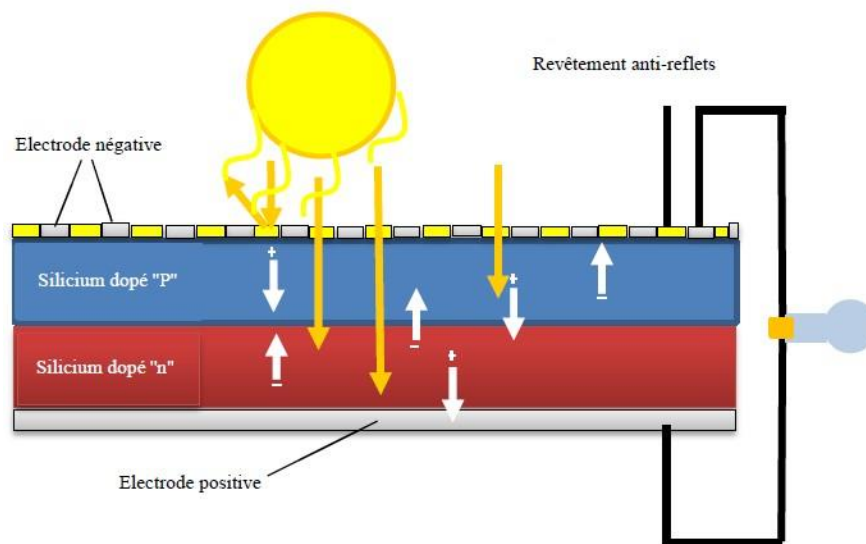


Figure I.4: PN junction of a Photovoltaic Cell.

I.9. GPV photovoltaic generator:

Solar cells are usually combined in series and parallel, and then encapsulated under glass to obtain a photovoltaic module. A PV generator consists of interconnected modules to form a unit producing high continuous power compatible with the usual electrical equipment (**Figure 1.3**). PV modules are usually connected in parallel series to increase the voltage and current at the generator output. The interconnected modules are mounted on metal supports and inclined at the desired angle depending on the location, this assembly is often referred to as a module field [9].

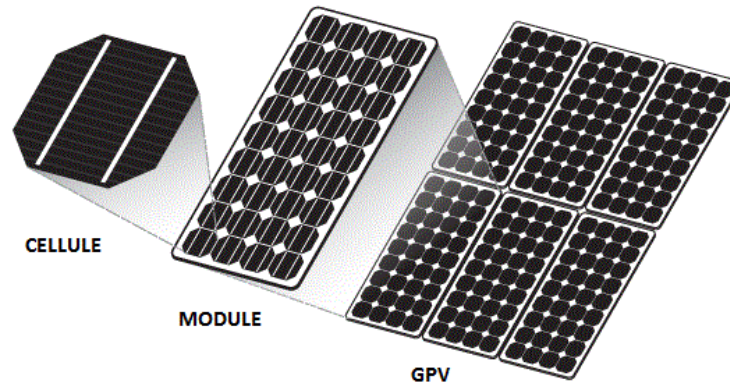


Figure. I.5 : Components of a GPV.

I.10. Modeling of a photovoltaic cell:

I.10.1. Case of an ideal cell:

Ideally, the cell of a PN junction subject to photovoltaic irradiance connected to a load can be schematized by a current generator in parallel with a diode. This generator is delivering a current I_{ph} according to Figure (I.6), which represents the equivalent circuit of an ideal solar cell [10].

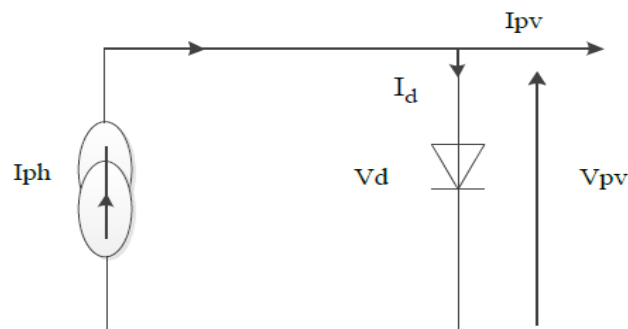


Figure. I .6: Equivalent diagram of an ideal cell.

- The equations used in this model are:

$$I_{pv} = I_{ph} - I_d \quad (I.1)$$

The current I_{ph} is assimilated to the current I_{sc} with $V_{pv} = 0$, the short-circuit current obtained by short-circuiting the load.

$$I_{ph} = I_{sc} \frac{E}{E_{ref}} \quad (I.2)$$

E: The illuminance absorbed by the cell;

Eref: The reference illuminance (1000 w/);m²

$$I_d = (-1) I_0 e^{\frac{V_d}{V_t}} \quad (I.3)$$

I₀ : Reverse saturation current of the diode;

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

V_t: Thermal Tension;

N: Ideality factor of the solar cell; **K:** Boltzmann's constant (1.38. J/K); 10⁻²³

q: Charge of the electron (1.6. C). 10⁻¹⁹

I.10.2. Case of a real cell:

The equivalent diagram of the real photovoltaic cell takes into account parasitic resistive effects due to manufacturing and shown in Figure I.7).

This equivalent scheme consists of a diode (d) characterizing the junction, a current source (*I_{ph}*) characterizing the photocurrent, a series resistor (*R_s*) representing Joule losses, and a shunte resistor (*R_{sh}*) characterizing a leakage current between the upper gate and the rear contact that is generally much greater than (*R_s*) [11].

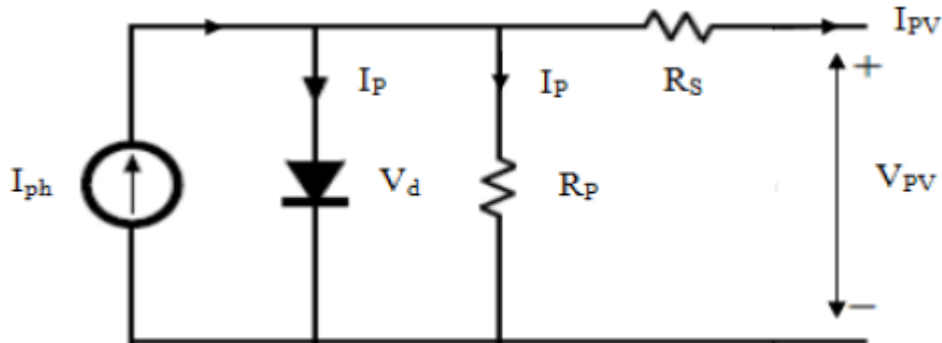


Figure.I. 7: Equivalent diagram of a real photovoltaic cell.

In our work, we used the mathematical model of the simple exponential solar module.

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

$$I_{pv} = - I_{ph} - I_d \quad (I.4)$$

I_{pv} : Current generated by the photovoltaic cell;

I_{ph} : Current photo created by the cell (proportional to the incident radiation);

I_d: The current flowing through the diode, equation (I.3).

$$I_d = (-1) I_0 e^{\frac{V_d}{V_t}} \quad (I.5)$$

$$I_0 = I_{0r} \left(\frac{T}{T_n} \right)^3 e^{\left[\frac{E_g}{BK} \left(\frac{1}{T_n} - \frac{1}{T} \right) \right]} \quad (I.6)$$

I_{0r} : is the short-circuit current of the cell at the reference temperature and the reference illuminance $E_{ref}; T_n$

T : Temperature of the PV cell junction [$^{\circ}\text{K}$];

T_n : PV cell reference temperature [$^{\circ}\text{K}$];

B : Ideality factor of the junction;

E_g : Gap energy [eV];

$$V_d = + V_{pv} R_s I_{pv} \quad (I.7)$$

R_s : series resistor symbolizes the ground resistance of the semiconductor material, as well as the ohmic and contact resistances at the cell connections;

V_{pv} : The output voltage;

I_p : The current flowing through the resistor; R_p

R_p : Shunt resistor represents leakage around the p-n junction due to impurities and on the corners of the cell.

By substituting equations (I.5; I.6) in equation (I.4) the current becomes: I_{pv}

$$I_{pv} = I_{ph} - I_0 \left(e^{\frac{V_{pv} + R_s I_{pv}}{V_t}} - 1 \right) - \frac{V_{pv} + R_s I_{pv}}{R_p} \quad (I.8)$$

Therefore:

$$I_{ph} - I_0 \left(e^{\frac{V_{pv} + R_s I_{pv}}{V_t}} - 1 \right) - \frac{V_{pv} + R_s I_{pv}}{R_p} - I_{pv} = 0 \quad (I.9)$$

I.11. Generator Protections:

To ensure a long service life of a photovoltaic system intended to produce electrical energy over years, electrical protections must be added to commercial modules to avoid destructive failures due to the combination of cells in series and panels in parallel. For this purpose, two types of conventional protection are used in the current Figure installations. (I.8):

- the non-return diode preventing a negative current in the PVs. This phenomenon can occur when several modules are connected in parallel, or when a directly connected load can switch from receiver mode to generator mode, for example a battery at night.

- By-pass diodes can isolate a subarray of cells when the illumination is not homogeneous, thus avoiding the appearance of hot spots and the destruction of poorly lit cells. The conduction

of these diodes affects the output characteristic of the generator, as shown in the Figure. (I.9), by the loss of part of the energy production and by the presence of two power maximums [12].

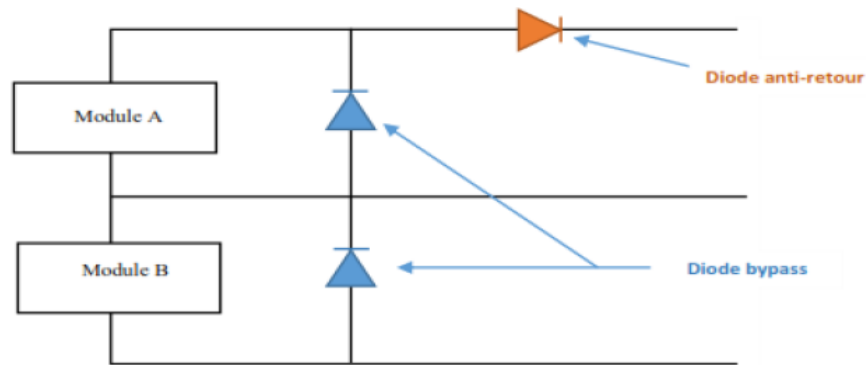


Figure. I.8: Schematization of an elementary GPV with bypass diodes and non-return diodes.

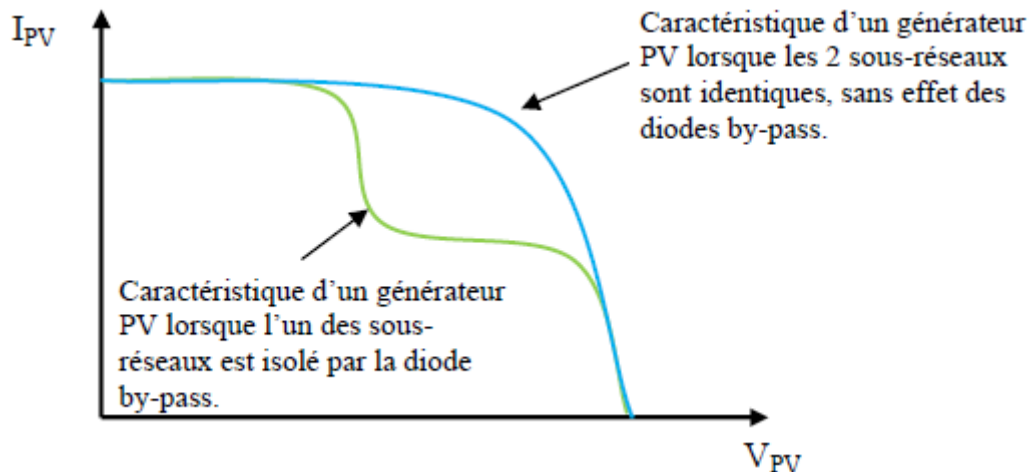


Figure. I. 9: Effect of the bypass diode on the $I(V)$ characteristic of a photovoltaic array.

I.12 . Creation of a photovoltaic generator (GPV):

The combination of several photovoltaic modules in series/parallel results in a photovoltaic array. If the cells connect in series, the voltages of each cell add up, increasing the total voltage of the generator. On the other hand, if the cells connect in parallel, it is the amperage that will increase as shown in the following figures [13].

I.12.1. Association of photovoltaic modules In series:

when cells are combined in a Figure series (I.14), the voltage is added and the same current passes through them.

$$i_{sc} = I_{cc} \quad (I.10)$$

And

$$V_{cs} = N_s \cdot V_c \quad (I.11)$$

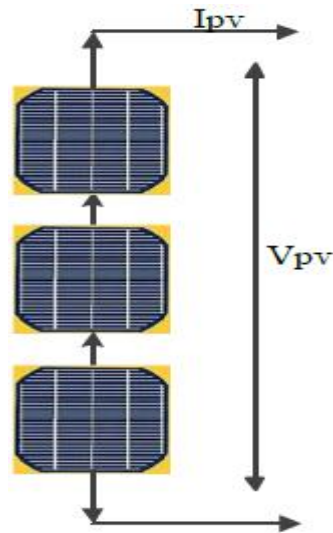


Figure. I.10: Diagram of 3 photovoltaic cells associated in series.

I.12.2. Association of Photovoltaic Cells in Parallel:

when they are combined in parallel Figure (I.15) , the resulting current corresponds to the sum of the currents generated by each cell

$$I_{pcc} = N_p \quad I_{cc} \quad (I.12)$$

And

$$V_{pco} = V_{co} \quad (I.13)$$

Modules are thus associated in series to increase the voltage, and in parallel to increase the current, but it is also common to make combinations in series and parallel to increase the maximum power. This reasoning can thus be extrapolated to the association of solar panel modules, which are themselves made up of several cells with an association defined by the manufacturer [14].

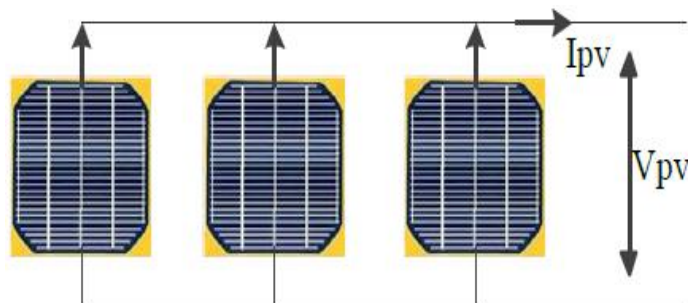


Figure. I.11: Diagram of 3 photovoltaic cells associated in parallel.

I.13. Simulation of a GPV:

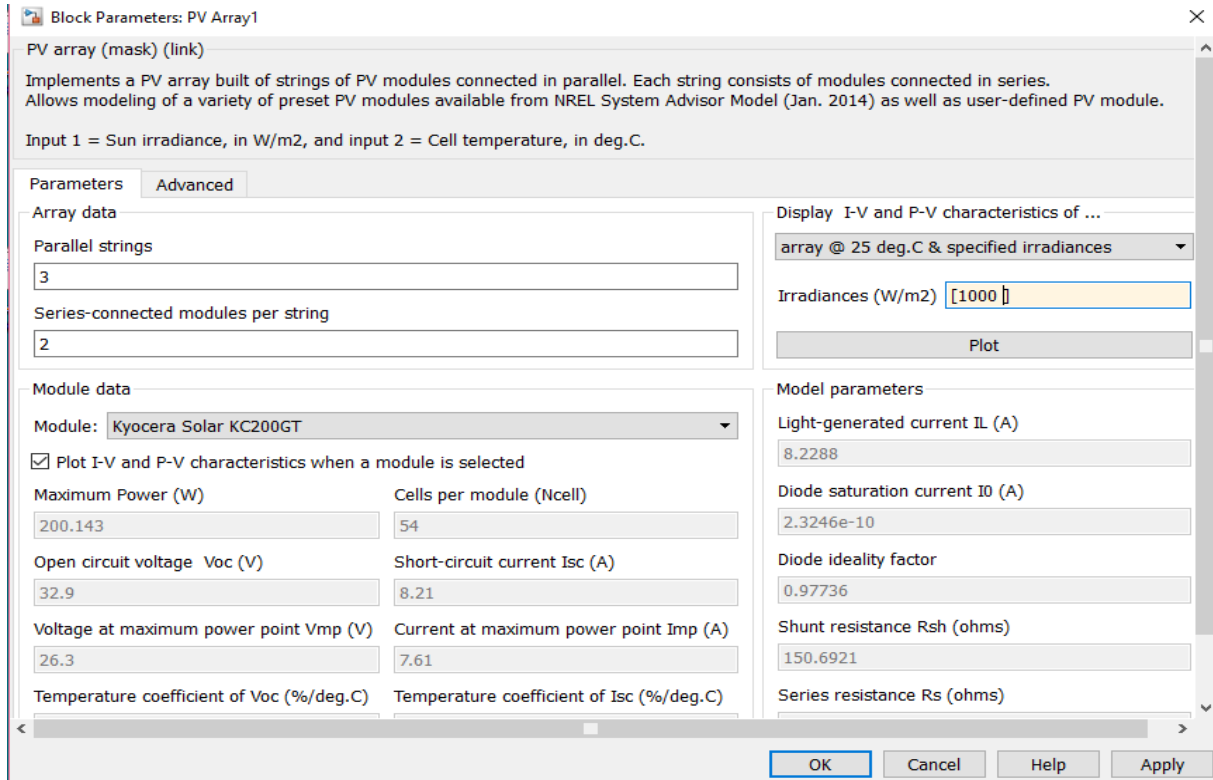


Figure. I.12 : Parameters of the Photovoltaic Generator Block

The maximum power delivered by the photovoltaic panel given by the product between the V_{op} voltage and the current I_{op} as represents the following formula:

$$P_{\max} = V_{op} I_{op} \quad (I.14)$$

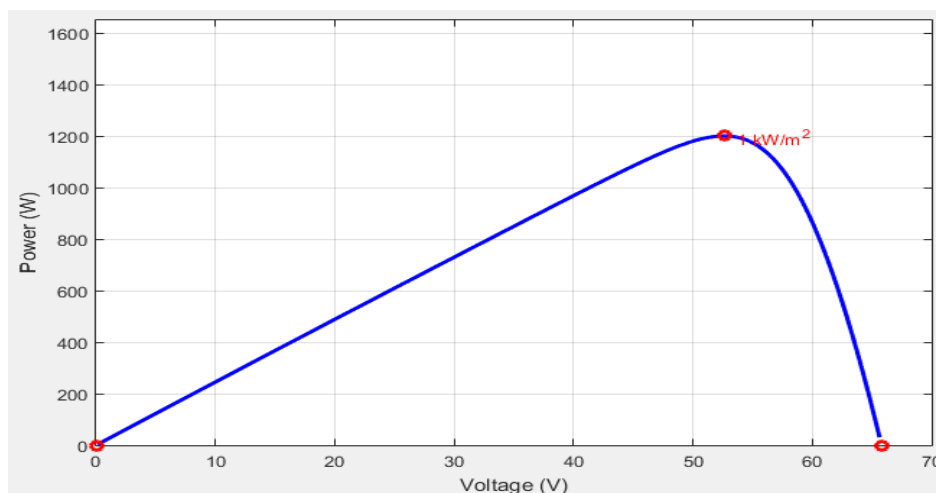


Figure. I.13: P-V characteristic of a photovoltaic generator.

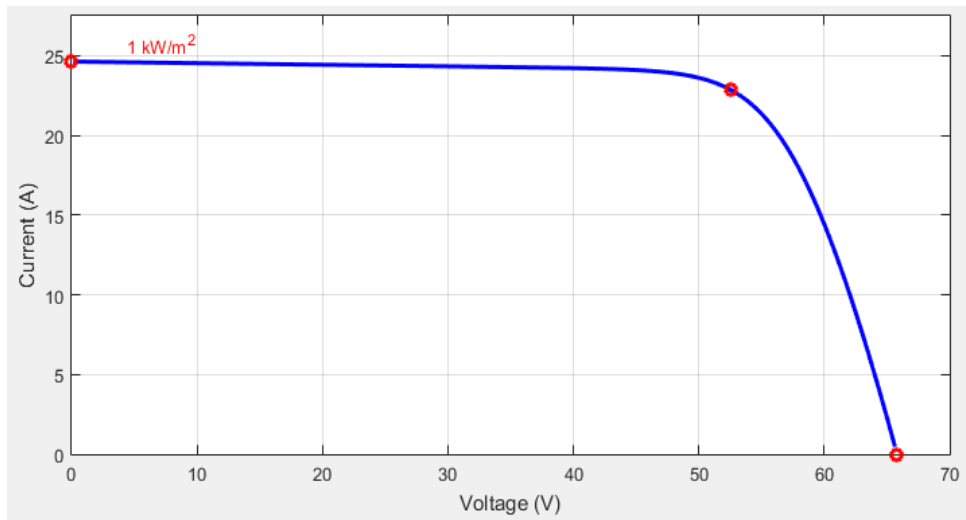


Figure. I.14: *I-V characteristic of a photovoltaic array.*

I.13.1. Influence of Illumination:

By varying the illuminance between 200 w/m^2 and 1000 w/m^2 with a step of 200, the characteristic ($I_{pv}=f(V_{pv})$) is given by the figures (I. (15,16)). It can be seen that the value of the short-circuit current is directly proportional to the intensity of the radiation. By

On the other hand, the voltage in an open circuit does not vary in the same proportions, it remains almost identical even in low illumination. [15]

The internationally accepted standard irradiation to measure the response of photovoltaic panels is a radiant intensity of 1000 W/m^2 and a temperature of $25 \text{ }^\circ\text{C}$.

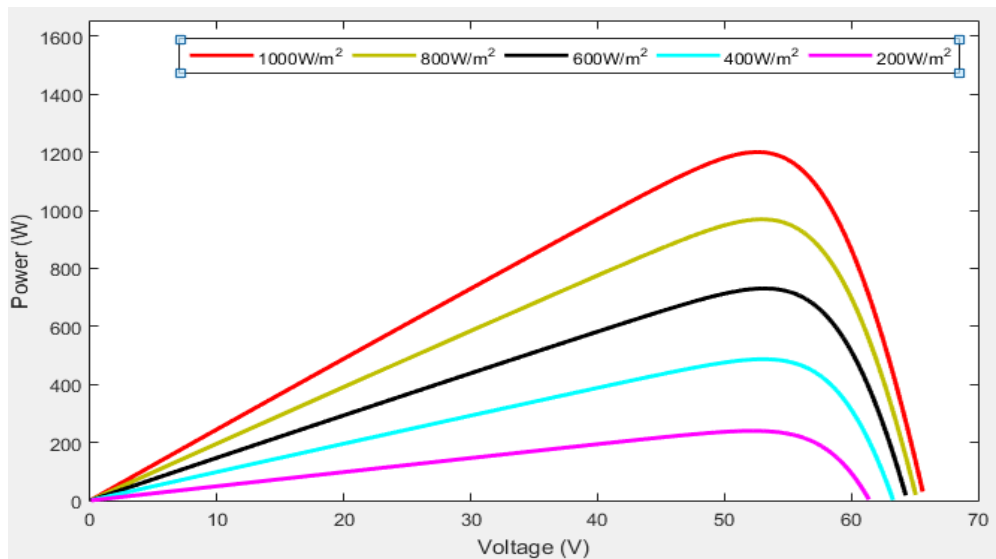


Figure. I.15: *P-V characteristic of the PV module according to the illuminance.*

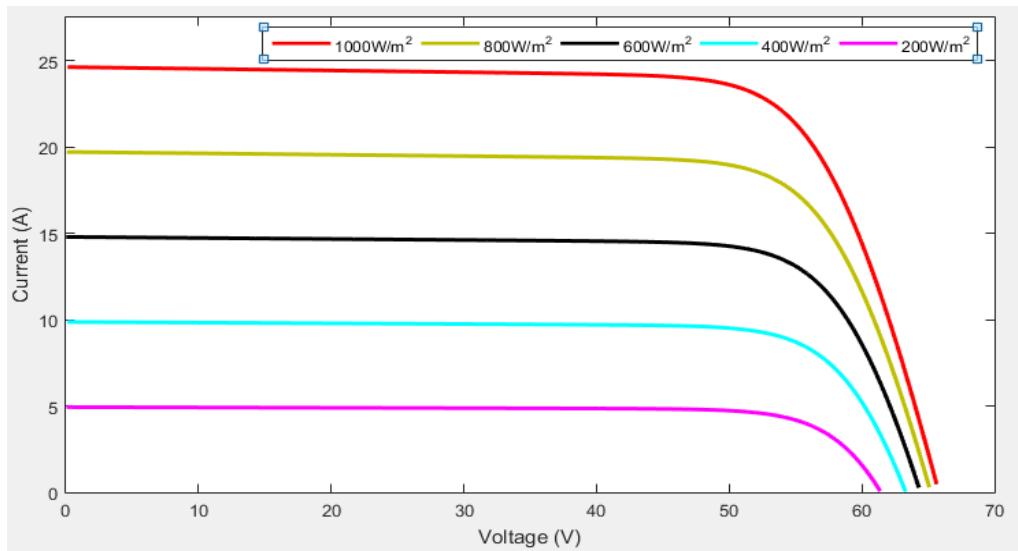


Figure. I.16: I-V characteristic of the PV module depending on the illuminance.

I.13.2. Influence of Temperature:

By varying the temperature from 25°C to 50°C, the characteristic ($I_{pv}=f(V_{pv})$) is given by figures (2. (21,22)). It will be noted that temperature has a negligible influence on the value of the short-circuit current. On the other hand, the open-circuit voltage decreases quite sharply as the temperature increases, consequently the extractable power decreases. When sizing an installation, the variation in the temperature of the site will be taken into account [15].

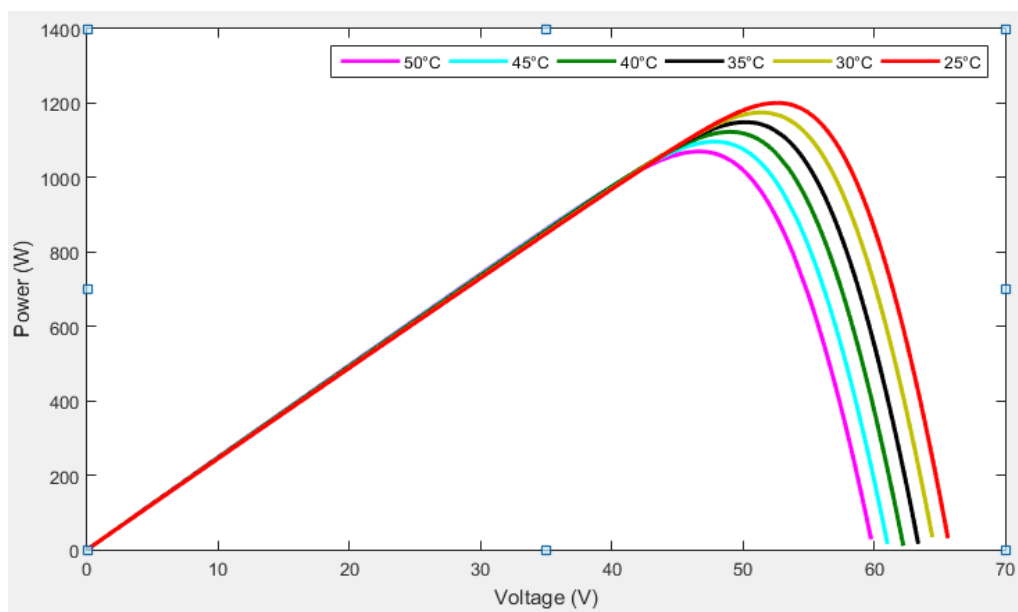


Figure. I.17: P-V characteristic of the PV module according to temperature.

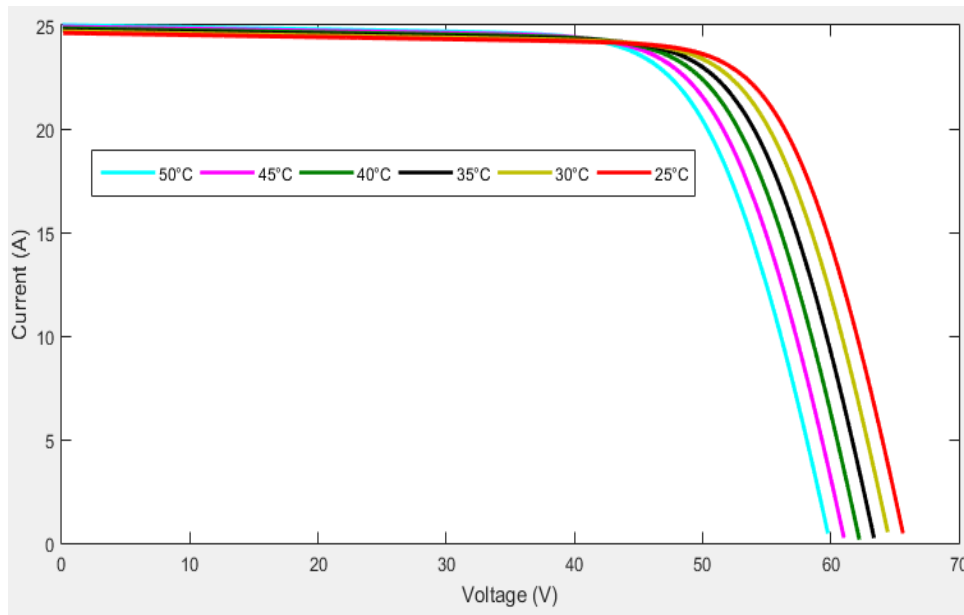


Figure. I.18 :: The I-V characteristic of the PV module according to the temperature.

I.14. Form Factor, FF:

The form factor or fill factor where Fill Factor FF(%) is used to qualify the quality of a PV cell or generator. This coefficient represents the ratio between the maximum power that the cell can deliver (P_{max}) and the power formed by the rectangle $I_{cc} \cdot V_{oc}$. It is defined by the following relationship:

$$FF = \frac{P_{max}}{V_{co} \cdot I_{cc}} = \frac{V_m \cdot I_m}{V_{co} \cdot I_{cc}} \quad (I.15)$$

The FF reflects the losses caused by the R_s series and parallel R_p resistors of the cell [16]. In the limit case $FF=1$, the power extracted from the cell is maximum [17].

I.15. The Yield:

The η efficiency (%) of the solar cells indicates the efficiency of conversion to power. This is the ratio between the maximum power delivered by the cell and the light output incident, P_{in} .

$$\eta = \frac{FF \cdot V_{co} \cdot I_{cc}}{P_{in}} = \frac{P_{max}}{P_{in}} \quad (I.16)$$

This efficiency can be improved by increasing the form factor, short-circuit current, and open-circuit voltage. The conversion yield is an essential parameter. Indeed, the mere knowledge of its value makes it possible to evaluate the performance of the cell [18] **I.16. The**

1.16 .advantages and disadvantages of photovoltaic energy:

I.16.1. The advantages of photovoltaic energy:

Photovoltaic systems have several advantages:

- They are non-polluting, with no discernible emissions or odours.
- They can be stand-alone systems that operate safely, unattended for long periods of time.
- They do not need any connection to another energy source or fuel supply.
- They can be combined with other energy sources to increase system reliability.
- They can withstand harsh weather conditions such as snow and ice.
- they do not consume any fossil fuels and their fuel is abundant and free.
- High reliability as the facility has no moving parts, making it particularly suitable for remote areas, hence its use on spacecraft.
- the modular system of photovoltaic panels allows for assembly that can be adapted to various energy needs; The systems can be sized for applications ranging from milliwatts to megawatts.
- Photovoltaic technology has ecological qualities because the product is non-polluting, silent, and does not cause any disturbance to the environment.
- They have a long lifespan.
- The costs and risks of transporting fossil fuels are eliminated.

I.16.2. The disadvantages of photovoltaic energy:

- The manufacture of photovoltaic modules is high-tech, which makes the cost very high.
- the actual efficiency of a photovoltaic module is around 10 to 15%,
- they are dependent on weather conditions.
- the energy from the photovoltaic generator is continuous and low voltage (< to 30 V) so it must be transformed through an inverter.
- many devices sold on the market work with 230 V AC.

I.17. Conclusion:

In this chapter, we have presented generalities about photovoltaic systems such as solar cells, photovoltaic modules and solar panels.

We have explained how the photovoltaic cell works as well as these types. Then we presented the structure of photovoltaic panels plus the different types of photovoltaic systems for the home[19].

In the next chapter, we will present the DC/DC static converters which are the Hashers as well as the MPPT control with the perturbation and observation (P&O) method.

Chapter II

Continuation of the maximum power point

II.1. Introduction

Power electronics, or more correctly "energy conversion electronics", are less than 50 years old. It has grown so much that today nearly 15% of the electrical energy produced is converted into one form or another. During these years, the size, weight, and cost of converters have only decreased, largely due to advances in electronic switches.

The growing number of renewable energy sources requires new strategies for the operation and management of the electricity grid in order to maintain or even improve grid reliability and energy quality. In addition, new energy management structures are becoming increasingly important.

Power electronics is still an emerging technology and its applications are tending to multiply. Its main function is to convert electrical energy from one stage to another. It plays an important role in the production of electrical energy and the integration of renewable energy sources into the electricity grid. In addition, power electronics are widely used as its applications become more integrated into grid-connected systems, such as photovoltaic (PV) systems.

In recent years, power electronics have undergone rapid development due mainly to two factors. The first is the rapid development of semiconductors and advances in transistor technology, which are capable of rapidly switching and manipulating high powers. Thyristors have been replaced by MOSFETs and IGBTs while thyristor-based switched inverters have been replaced by self-switched inverters based on MOSFET transistors and IGBTs. Self-switched UPS typically use PWM (Pulse-Width Modulation) control and a high switching frequency (1 kHz to 20 kHz), which allows an output signal to be generated that can be completely sinusoidal. This design is robust, efficient, and ensures high reliability [20,21].

The second factor is the introduction of regulators capable of implementing powerful and complex control and regulation algorithms. A very important interest in digital control, due to its low power consumption and noise immunity using new processors, next-generation DSPs microcontrollers and basic FPGA (Field Programmable Array) platforms

II.2. Convertisseurs DC/DC (Hacheur) :

For power conversion, it is essential that the efficiency is kept high to prevent power dissipation and to avoid excessive heating in the electronic components. For this reason, all the power conversion exchanged must be carried out around the energy storage components (inductors and capacitors) and switches. The power switches used depend on the level of power

to be converted or controlled. MOSFETS (metal oxide field-effect transistors) are usually used at relatively low power (a few kW) and IGBTs (isolated trigger bipolar transistors) at higher powers. Thyristors have been generally used and accepted in the highest power levels. Figure I.1 shows the representation of a DC/DC converter, which can be used as an interface between the source and the load [22]

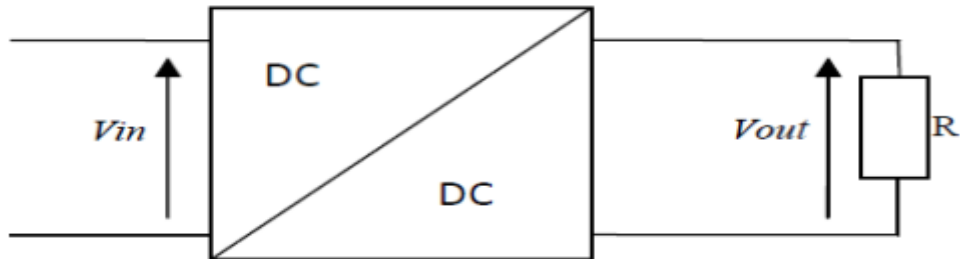


Figure. II.1: DC/DC converter [22].

II.3. Direct connection to the photovoltaic source charge[[23:

The simplest system that can be designed consists of a GPV photovoltaic generator and a load that directly uses the energy produced by the GPV.

This energy is highly dependent on illuminance, the nature of the charge and temperature. The direct connection is mainly used because of its simplicity of implementation, its minimal cost due mainly to the absence of electronics, not to mention a low cost. Figure 1 shows this case. The disadvantage of this configuration is that it does not offer any type of operating 'adjustment'. The transfer of the optimal power available at the GPV terminals to the load is also not guaranteed. The direct connection of the photovoltaic array to a load is currently the cheapest and most widespread operating principle. It is necessary to make sure, beforehand, that the load accepts the direct connection to the photovoltaic array: this is the problem of sizing.

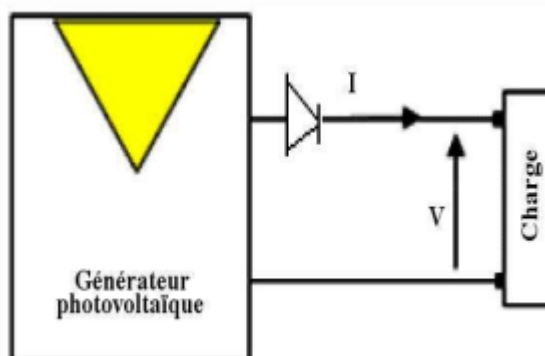


Figure. II.2: Principle of direct coupling.

A precaution must be taken to avoid deteriorating the generator by a return of current to it. Thus, a non-return diode is placed between the source and the load. The principle of direct GPV-Charge coupling is based on the transfer of the output power from the photovoltaic source to the equipment to be powered, without any intermediary system. This operation is recognized under the name 'operation over the sun'. The operating point is particularly dominated by several factors, namely [22-23]:

- _ the load,
- _ operating conditions: lighting, temperature,
- _ the types of connections established of the photovoltaic modules (parallel, series, mixed).

The major disadvantage of this connection is its direct dependence between the power supplied by the generator and the load. In fact, the power supplied by the photovoltaic module results from the intersection between the current-voltage characteristic $I - V$ of the GPV and that of the load. The electrical characteristics of a GPV can change rapidly depending on solar irradiance, temperature, and in the longer term the aging of the cells. The present study aims to analyze the results obtained for a direct connection for various loads. Given a resistive load coupled directly to the photovoltaic array, the operating point is given by the intersection of the electrical characteristic of the load with that of the GPV. To ensure that the cells are working at their maximum power, it is necessary to ensure that the load imposes this optimal operating point. In the case of the connection of a resistive load, the impedance of the load must evolve so that the modules remain at their optimal operating point at all times in order to ensure proper operation of the photovoltaic cells. This is not always the case. We assume that the nature of the charge is of the continuous type (DC). This is because an AC type of charging is not compatible with the direct connection at all, because the GPV provides a direct current. Three types of typical DC loads exist: a purely resistive load, a voltage source type load, and a current source type load. In Figure 3, we have shown the current-voltage characteristics $I - V$ of a GPV, as well as the $I - V$ characteristics of the three types of loads.

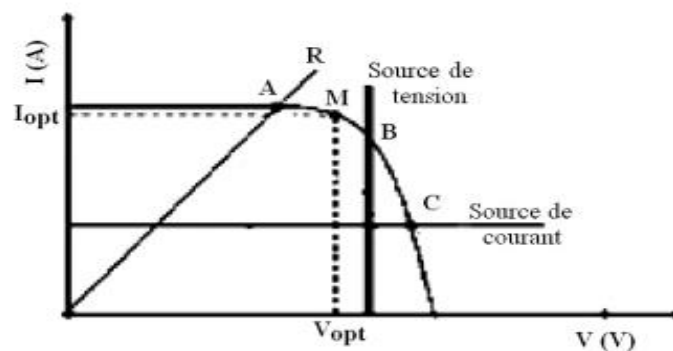


Figure. II.3 : Types of Directly Connected Loads .

We can identify the operating point where the power supplied by the generator is maximum: point M for optimal current (I_{opt}) and optimal voltage (V_{opt}). Then we can find the point of intersection between the characteristics $I - V$ of the generator and those of the three types of loads: - Point A for a resistive load, - Point B for a load of the voltage source type and - Point C for a load in a current source, corresponding to power values lower than the maximum available power P_{opt} . Therefore, a loss of part of the power deliverable to the terminals of the PV generator can occur, which in the long run implies significant losses in energy production.

This is not observed in all cases of direct connection GPVCharge, as this work can show. [24]

II.4. Indirect connection:

As we have seen before, a GPV has nonlinear $I(V)$ characteristics with points of maximum power. These characteristics also depend on the level of illumination and the temperature of the cell. In addition, according to figure (3), the value of the nominal power delivered by the GPV differs greatly from that actually transferred to the load. It is therefore necessary to use an adaptation stage between the GPV and the load as described in Figure (4) to extract at any moment the maximum power available at the terminals of the GPV and to transfer it to the load. This stage acts as an interface between the two elements by ensuring the transfer of the maximum power supplied by the generator using a control system used for this purpose. In our case, the adaptation stage that concerns us is the DC-DC converter

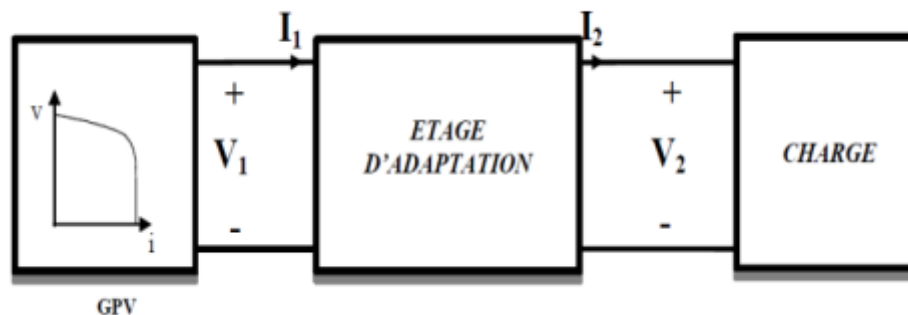


Figure. II.4: Connecting a GPV to a load through an adapter stage

. II.5. Boost Chopper:

The latter is a boosting converter, also known as a "boost" or parallel chopper; its basic schematic diagram is that of Figure 6 Its typical application is to convert its input voltage to a higher output voltage [25].

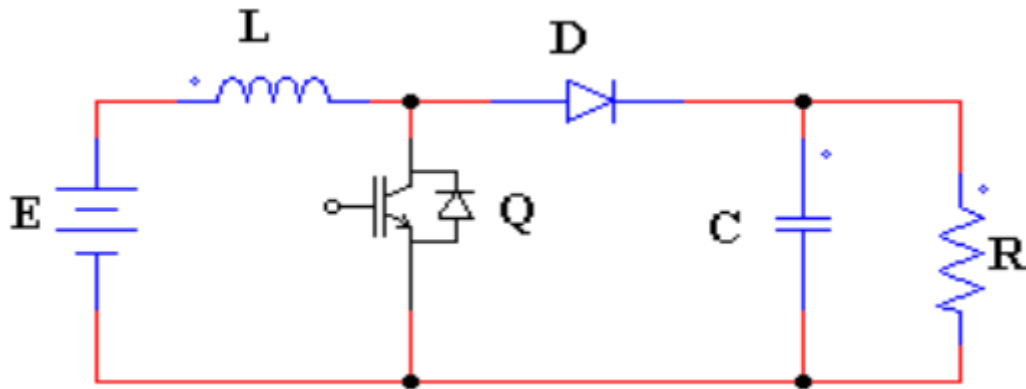


Figure. II.5: Boost converter [25].

II.5.1. Modeling of the Booster Chopper:

The booster converter can often be found in the literature as a boost chopper or parallel chopper. The figure. II.8 represents the booster converter. This converter consists of a direct input source: inductance in series with a voltage source, and a continuous type output (the load): capacitor in parallel with the resistive load. Since the current is always positive and the switches must be controlled (at locking and priming), the switch K can be replaced by a transistor [26].

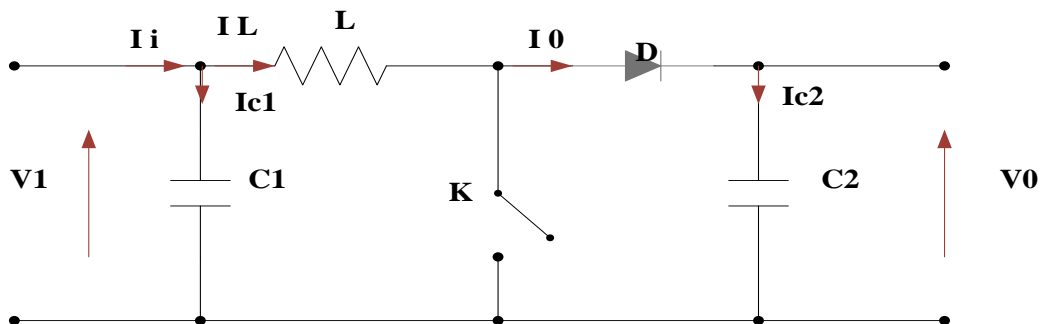


Figure. II.6: Schematic diagram of a Boost converter [29]

During the αT time, the switch is closed and the current in the inductor increases linearly.

The voltage across K is zero. During the time $[\alpha T, T]$ the switch opens and the energy stored in the inductor controls the flow of current in the freewheel diode D. By writing that the voltage across the inductance is zero, we arrive at [27]: $V_K = V_0$

$$V_0(1 - \alpha) = V_i \quad (\text{II.1})$$

Knowing the real behavior of this converter requires knowing its mathematical model in detail. To do this, we need to represent the equivalent circuit by the two states of the switch and then draw the mathematical model linking the input/output variables. Figure II.9 shows the

diagrams of the equivalent circuits of a booster converter in both cases: the so-called closed switch during and the open switch during $(1-d)$ TS. [28]

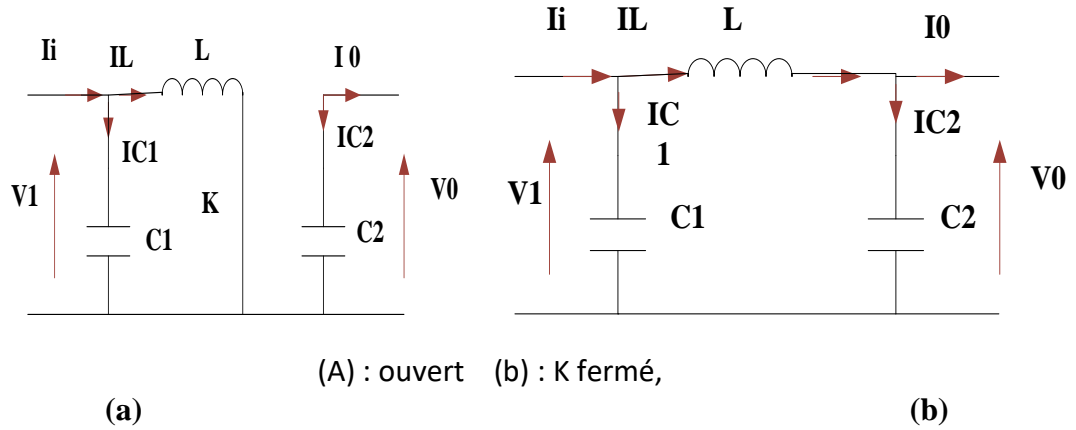


Figure. II.7 : Schémas équivalents du hacheur.[29]

Applying Kirchoff's laws to the equivalent circuits of the supercharger converter of the two phases of operation, we have the following systems of equations:

- For the first period $T \in [0, \alpha T]$:

$$\begin{cases} i_{C1}(t) = C_1 \frac{dv_1(t)}{dt} = i_i(t) - i_L(t) \\ i_{C2}(t) = C_2 \frac{dv_0(t)}{dt} = -i_0(t) \\ V_L(t) = L \frac{di_L(t)}{dt} = +V_i(t) \end{cases} \quad (\text{II.2})$$

- ❖ For the second period $T \in [T, \alpha T]$:

$$\begin{cases} i_{C1}(t) = C_1 \frac{dv_1(t)}{dt} = i_i(t) - i_L(t) \\ i_{C2}(t) = C_2 \frac{dv_0(t)}{dt} = i_L(t) - i_0(t) \\ V_L(t) = L \frac{di_L(t)}{dt} = V_i(t) - V_0(t) \end{cases} \quad (\text{II.3})$$

To find a dynamic representation valid for the entire period T , the following expression is generally used [29]:

$$\left\langle \frac{dx}{dt} \right\rangle T_s = \frac{dx}{dt} dT_s + \frac{dx}{dt(1-d)T_s} (1-d)T_s \quad (\text{II.4})$$

Applying the relation (II.5) to the systems of equations (II.3) and (II.4), we find the approximate model of the booster converter: [30]

$$\begin{cases} i_L = i_i - C_1 \frac{dv_1(t)}{dt} \\ i_0 = (1-d)i_L - C_2 \frac{dv_0(t)}{dt} \\ V_i = L \frac{di_L(t)}{dt} + (1-d)V_0 \end{cases} \quad (\text{II.5})$$

II.6 Maximum power of a PV generator

An MPPT, or "Maximum Power Point Tracking", is a principle that makes it possible to monitor, as its name suggests, the maximum power point of a non-linear electric generator. As a result, for the same light, the power delivered will be different depending on the load. An MPPT controller therefore makes it possible to control the static converter connecting the load (a battery for example) and the photovoltaic panel in order to continuously provide the maximum power to the instant charge. The (Figure III.1) represents the trajectory of the point of maximum power produced by the generator.

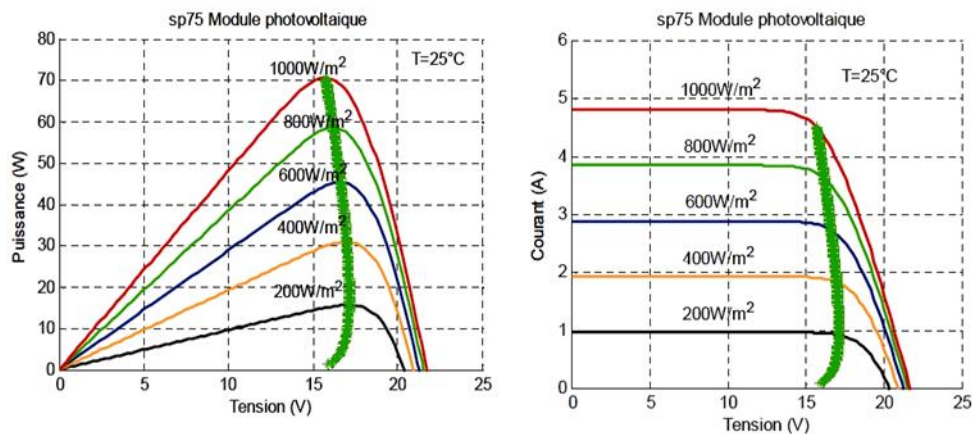


Figure. II.8: The I-V, P-V characteristic and the PPM trajectory.

Figure III.2 shows the schematic diagram of a photovoltaic module with a DC-DC matching stage between the GPV and the output load. This structure corresponds to a system more commonly known as an autonomous system. This adapter stage has an MPPT (Maximum Power Point Tracking) control that allows it to search for the PPM that a photovoltaic solar panel can provide. The MPPT search algorithm can be more or less complex depending on the type of layout chosen and the desired performance. However, in the end, all efficient algorithms must play on the variation of the duty cycle of the associated power converter[29].

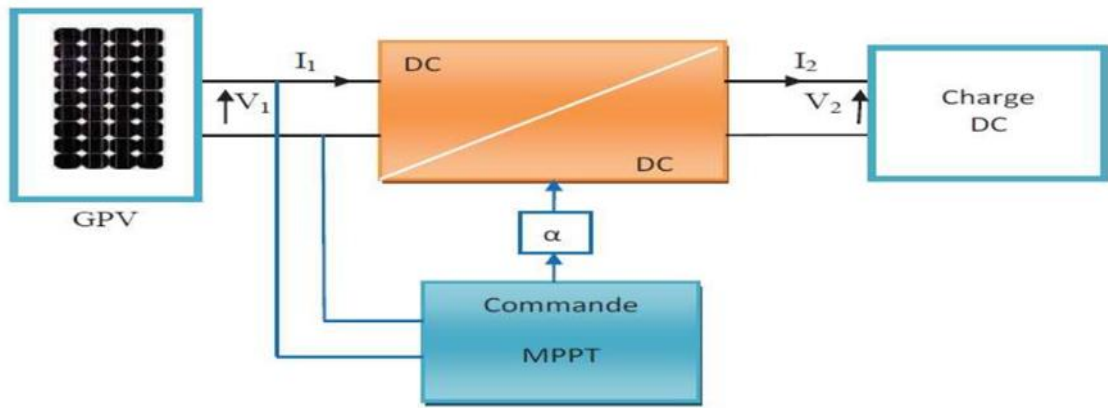


Figure. II.9: Elementary photovoltaic conversion chain.

To ensure the operation of a GPV at its maximum power point (PPM), MPPT controllers are used, these controllers are intended to minimize the error between the operating power and the maximum reference power varying according to climatic conditions based on optimal methods [31].

II.7. Management of the MPPT:

La figure III. 3 illustrates three cases of disturbances. Depending on the type of disturbance, the operating point switches from the maximum power point PPM1 to a new operating point P1 more or less distant from the optimum.

In this case, for a variation in sunshine, it is sufficient to readjust the value of the duty cycle to converge to the new maximum power point PPM2. In case b, for a load variation, a change in the operating point can also be observed, which can be found in a new optimal position thanks to the action of a control. Finally, in the last case, c of variation in the operating point can occur related to variations in the operating temperature of the GPV. Although it is also necessary to act at the level of the control [32].

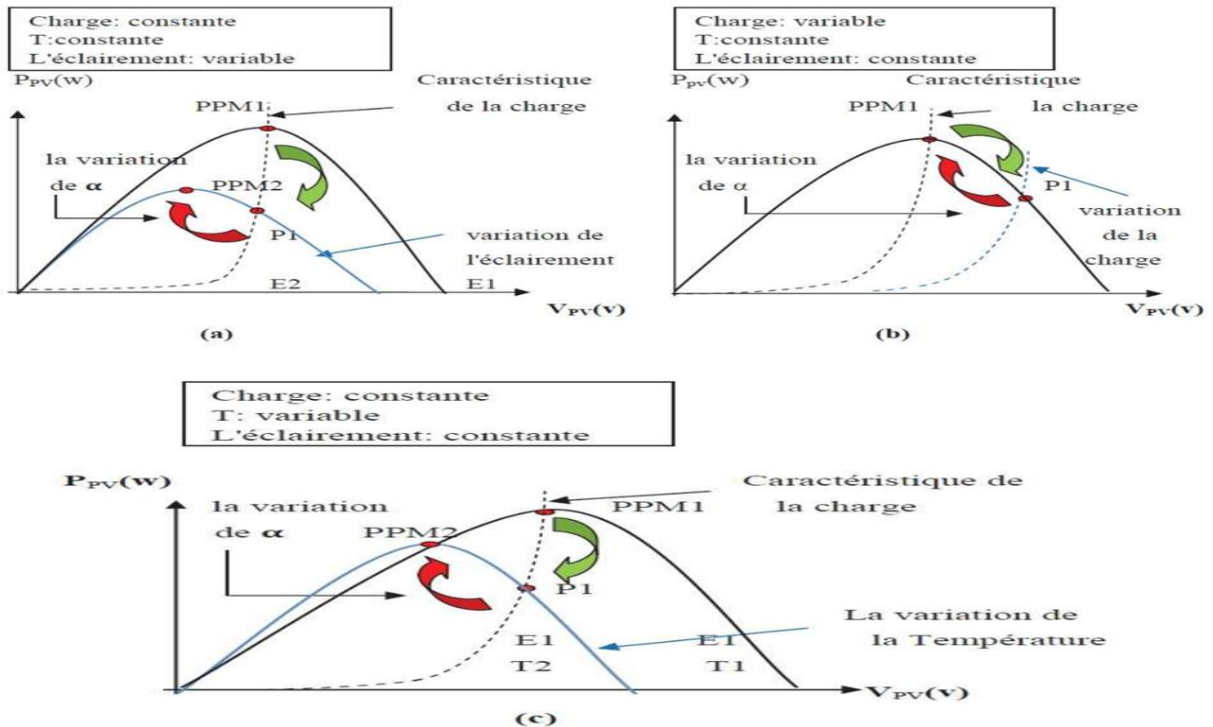


Figure. II.10 : Search for and recovery of the Maximum Power Point a) following a variation in illumination, b) following a variation in load, c) following a variation in temperature .

II.8. Perturbation method and observation (P&O):

This is the most widely used PPM tracking algorithm, and as the name suggests, it is based on disturbing the system by increasing or decreasing V_{ref} or acting directly on the duty cycle of the DC-DC converter and then observing the effect on the output power of the panel. If the value of the current power $P_{Gpv}(n)$ of the panel is higher than the previous value $P_{Gpv}(n-1)$ then we keep the same direction of the previous disturbance otherwise we reverse the disturbance of the previous cycle. Figure III.3 shows the flowchart of this algorithm.

With this algorithm, the operating voltage V is disturbed at each cycle of the MPPT. As soon as the MPP is reached, V will oscillate around the ideal operating voltage V_{mp} . This causes a loss of power that depends on the pitch width of a simple disturbance.

If the pitch width is large, the MPPT algorithm will respond quickly to sudden changes in operating conditions, but losses will be increased under stable or slowly changing conditions.

If the pitch width is very small, losses under stable or slowly changing conditions will be reduced, but the system will no longer be able to keep up with rapid changes in temperature or insolation.

The disadvantage of the P&O method is that when a sudden increase in sunlight is produced there will be an increase in the power of the panel, the previous algorithm reacts as if this increase is produced by the previous disturbance effect, then it continues in the same direction which is a wrong direction, which it takes away from the true point of maximum power.

The P&O method works by periodically disturbing the voltage of the VPV panel with a ΔV and the variation in the electrical energy delivered to the PV output is observed.

If $\Delta P > 0$ then the voltage disturbance moves the operating point to a point closer to the MPP and the voltage continues to be disturbed in the same direction, this will move the operating point until the MPP is reached.

If $\Delta P < 0$ the operating point moves away from the MPP, then the voltage is perturbed with an algebraic sign contrary to the previous sign to move the operating point until the MPP is reached [33].

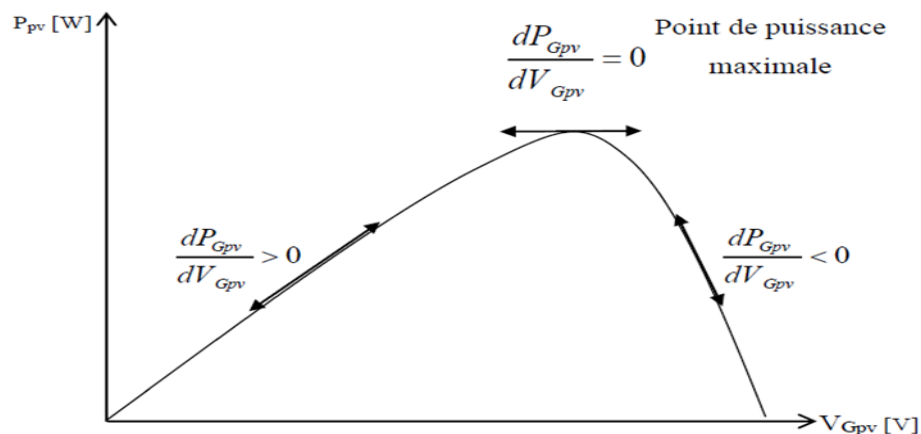


Figure II.11: Operating characteristics of the Perturbation-Observation method

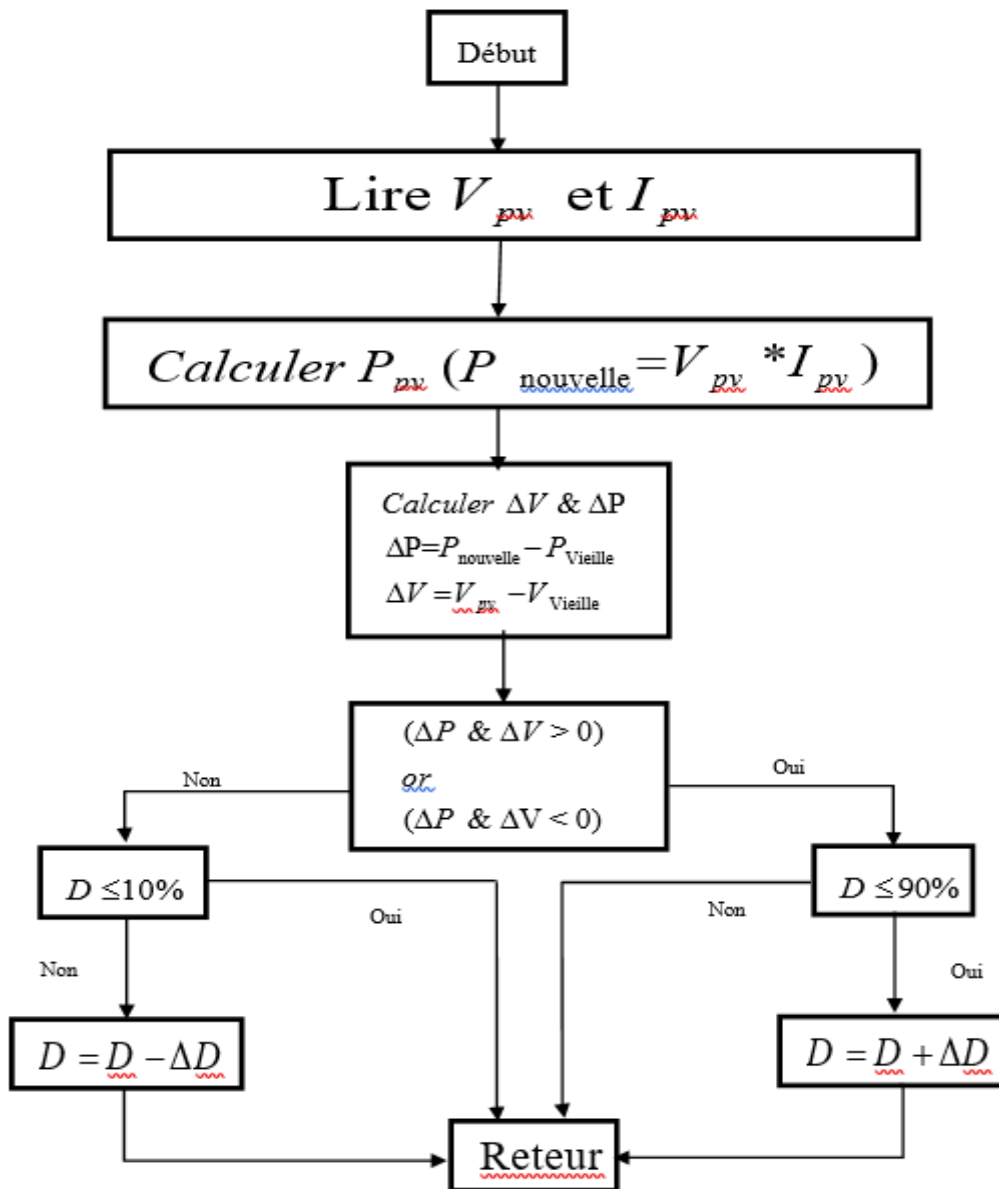


Figure II.12: Algorithm of the Perturbation and Observation method [36].

The Perturbation-Observation "P&O" algorithm is often the most widely used in practice due to its ease of implementation. For this method, based on the PV characteristic, the photovoltaic array is considered to be operating at a point that is not necessarily the MPP.

The operating voltage is disturbed with (ΔV_{Gpv}) and the variation (ΔP_{Gpv}) of the electrical power is observed. If (ΔP_{Gpv}) is positive, then the voltage disturbance moves the operating point to a point closer to the MPP. Other successive disturbances of the voltage in the same direction (i.e. with the same algebraic sign) should shift the operating point until the MPP is reached. In the case where (ΔP_{Gpv}) is negative, the operating point moves away from the MPP, and thus the algebraic sign of the voltage disturbance should be reversed to move the operating point back to the MPP [34].

In Figure III.4 we consider that the operating point is on curve (1), the MPPT oscillates around the MPP, from point A2 to point A then to point A1 and vice versa, if the value of the illuminance increases the curve P(V) of the panel moves towards the curve then the MPPT perturbs the operating point from point A to point B1 which if we take us to $\Delta P > 0$ with $[\Delta P = P(i) - P(i-1)]$ the MPPT continues to perturb the voltages in the same direction, i.e. towards the point B2.

If the illuminance is still increasing, the operating point is moving to the C1 point of the curve (3) instead of the B2 point on the curve (2), then the MPPT still has $\Delta P > 0$ and it is moving the operating point to the C2 point.

From points $A \rightarrow B1 \rightarrow C1 \rightarrow C2$ the P&O algorithm continues to move away from the MPP which results in power that will be lost and efficiency decreases [37], [38].

II .9: The Simulation block of the perturbation and observation (P&O) algorithm:

We have made the simulation model of the P&O algorithm figure (III. 6), based on the flowchart illustrated in the figure.

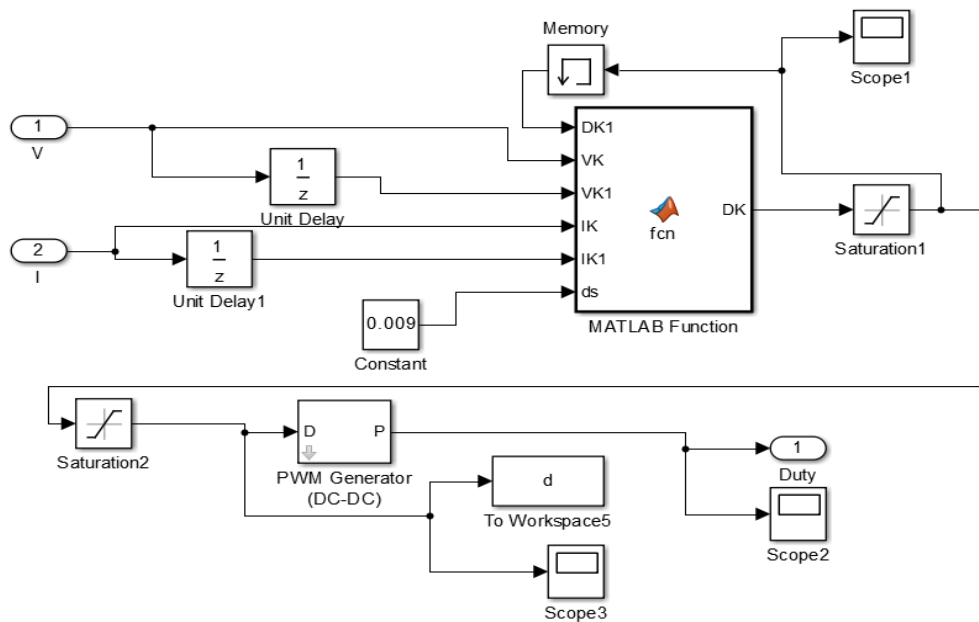


Figure. II.13: Algorithm simulation block scheme (P&O).

II.10. Simulation of a photovoltaic panel with MPPT and DC-DC converter:

- **Block diagram:**

Figure II.14 shows the SIMULINK schematic block of the photovoltaic system adapted by the MPPT control.

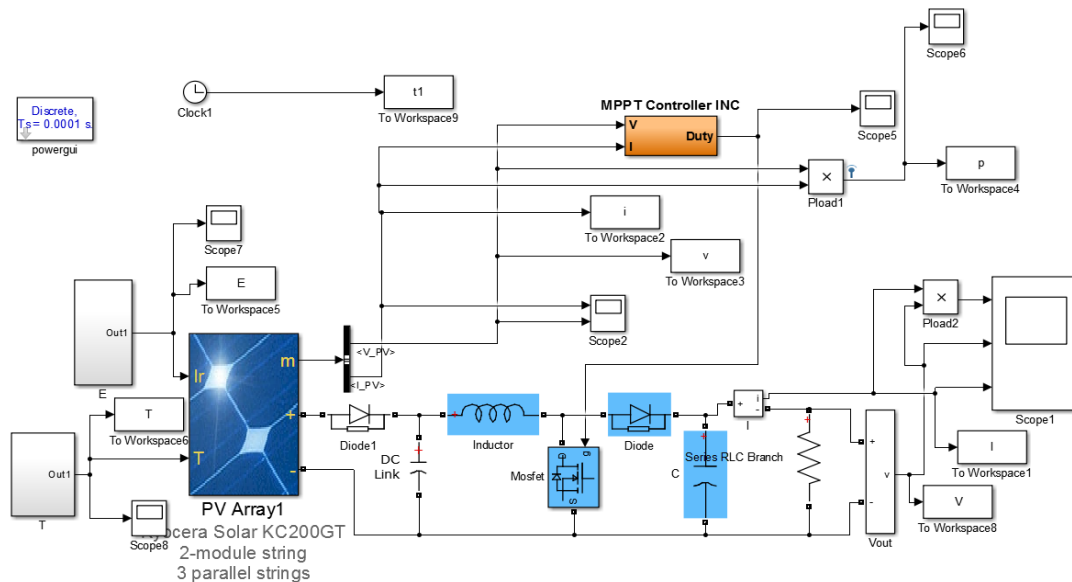


Figure II.14: Block diagram of a photovoltaic system equipped with MPPT.

- The characteristics used for the PV module are given in Table II.1

Number of cells in series per panel (Ns)	54
Maximum power (P_max)	200.143 W
Short Circuit Current (I_cc)	8.21 A
Open Circuit Voltage (v_co)	32.9 V
Current at MPP point (I_op)	7.61 A
Voltage at MPP Point (v_op)	26.3 V
Number of Panel in Series (Nps)	2
Number of panels in parallel (Npp)	3

Table II.1 :: Technical data sheet for KC200GT to STC conditions .

❖ The parameters of the Boost electric converter are given by the following table:

Parameter	Name	Value
L_i	Inductor of the converter	4 mH
C_i	Input Capacity	4700 uF
C_o	Output Capacity	470 UF
R	Resistance de charge	200Ω

Table II.2: Converter parameters.

➤ **Comment:**

The following figure shows the power as a function of voltage of a photovoltaic system (200w panel) controlled by a **PO** controller in a variable temperature and lighting.

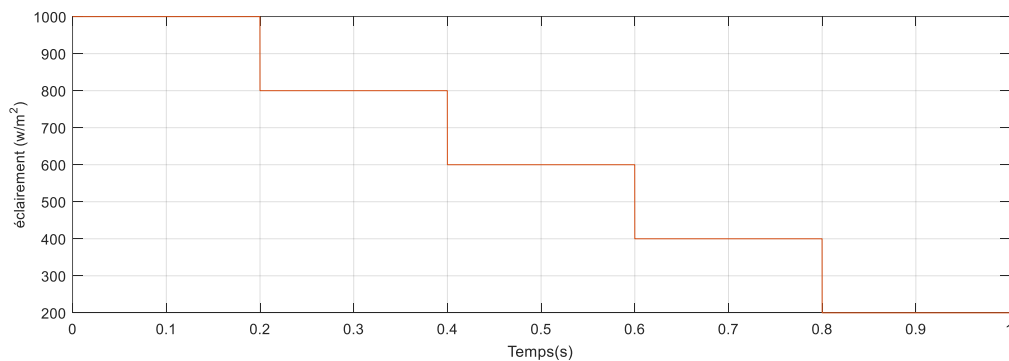


Figure II.15: Variation in illumination .

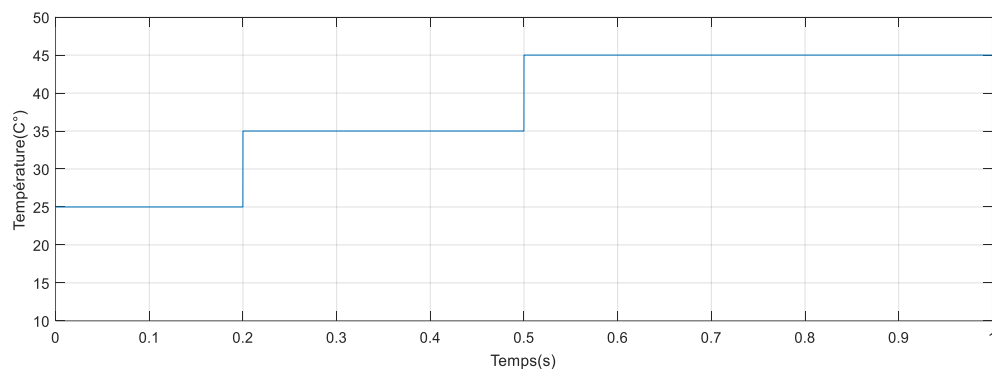


Figure II.16: Temperature variation.

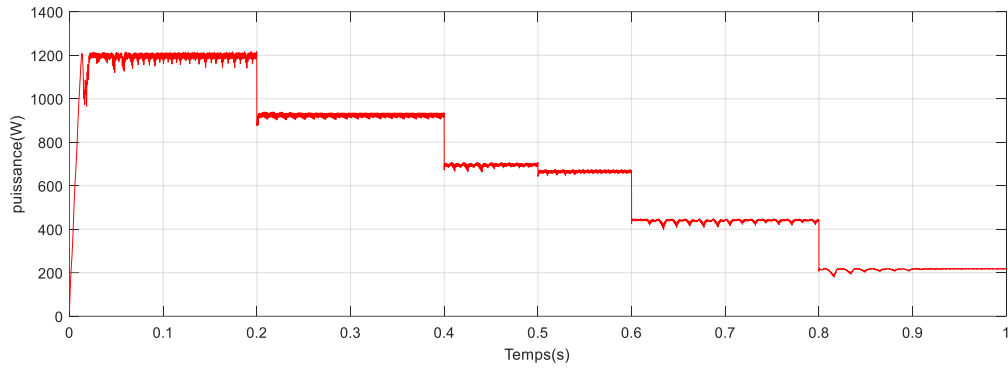


Figure II.17: Characteristics $P(t)$ of a PV system.

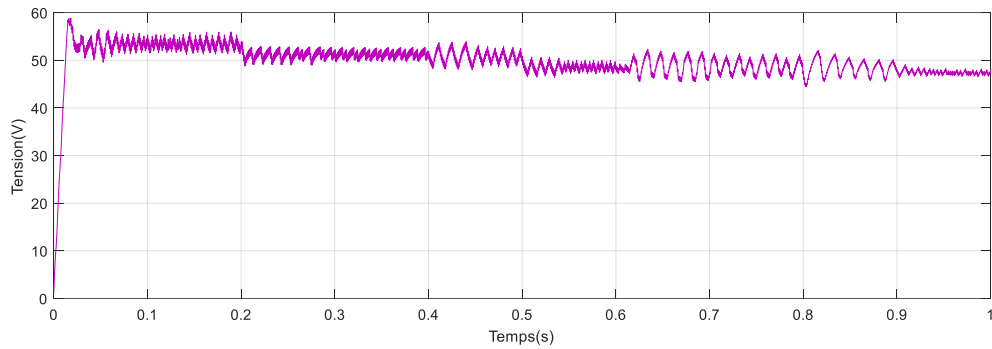


Figure II.18: Characteristics $v(t)$ of a PV system.

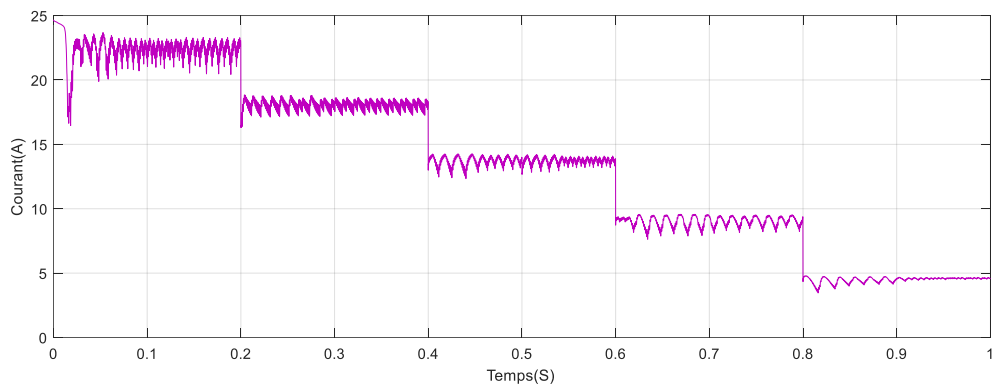


Figure II.19 : Characteristics $i(t)$ of a PV system.

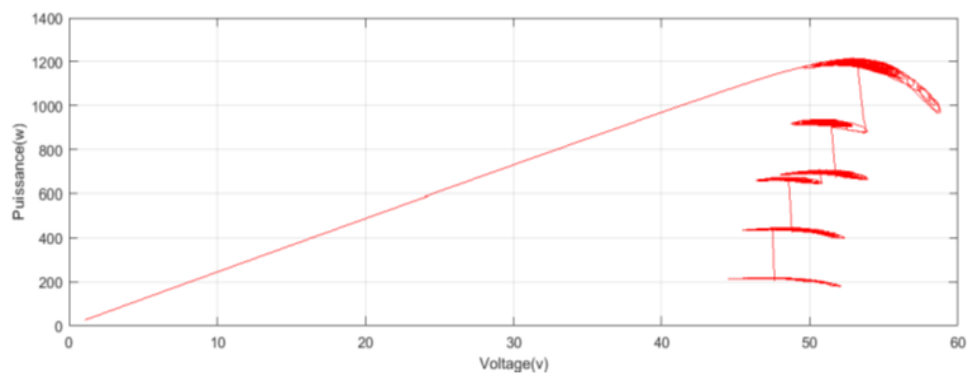


Figure II.20 : Characteristics $p(v)$ of a PV system.

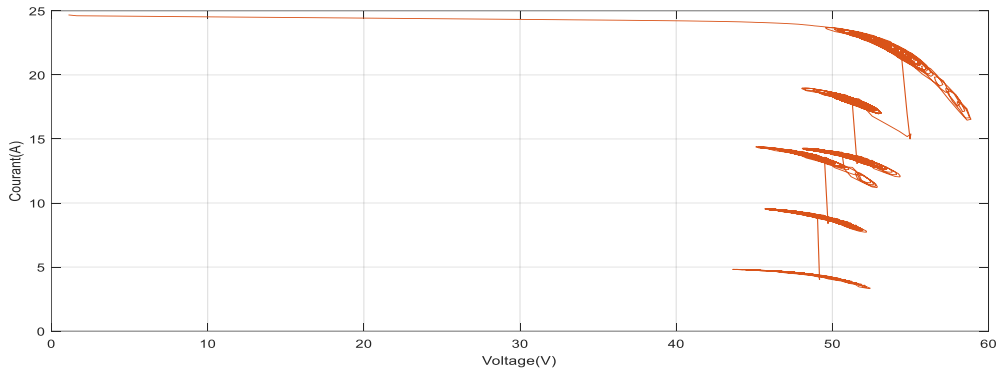


Figure II.21: Characteristics $i (v)$ of a PV system.

How on the figures:

Figure (2.20) shows the power-versus-time pace of a photovoltaic system controlled by a disturbance and observation (P&O) controller.

- ✓ in a variable temperature and illuminance, we notice that the power takes an oscillation time of (0.01s) to stabilize at the maximum value of the power (1200W).
- ✓ Figures (2.20), (2,21),(2,22) show the power speed and voltage as a function of time of a photovoltaic system controlled by an IC controller in a variable temperature and different illuminations:
- ✓ First, we subjected the system to a brightness variation $E=200, 400, 600, 800, 1000$ W/m^2 . At the time $t=0.2s$ with a variable temperature (25,35,45°C). Therefore, we see in the figures (2.20, 2.21), an increase in voltage which induces a decrease in power, the operating point of the system moves away from the MPP, after 0.01s. The control goes up the operating point and stabilizes it around the MPP with some oscillation that is caused by the control algorithm [39].

II.10 Conclusion:

In this chapter we have carried out a study by MPPT simulation by method the (P&O) method. Which based on controlled power reaction, this MPPT control directly uses the voltage and current of the photovoltaic panel to find the operating point corresponding to the maximum power.

Finally, the simulation results for the P&O algorithm of the overall system are built under Matlab-Simulink.

Chapter III

Control of a photovoltaic pumping system based on a DC motor

III.1 . Photovoltaic pumping systems:

Many people in rural areas of developing countries face major problems due to water deficit. These problems are especially accentuated in desert areas. The water deficit in drylands is a vital issue for people. The improvement of living conditions in these areas is linked to the search for adequate solutions to this problem. Photovoltaic (PV) pumping is the ideal solution for water supply wherever the electricity grid is absent. [40]

Currently, two photovoltaic pumping systems are in use, with and without batteries. The battery-free technology has some disadvantages, its main flaw is to have a water flow that depends on the amount of sunshine during the day. We are going to do a study with the addition of batteries in the photovoltaic pumping system.

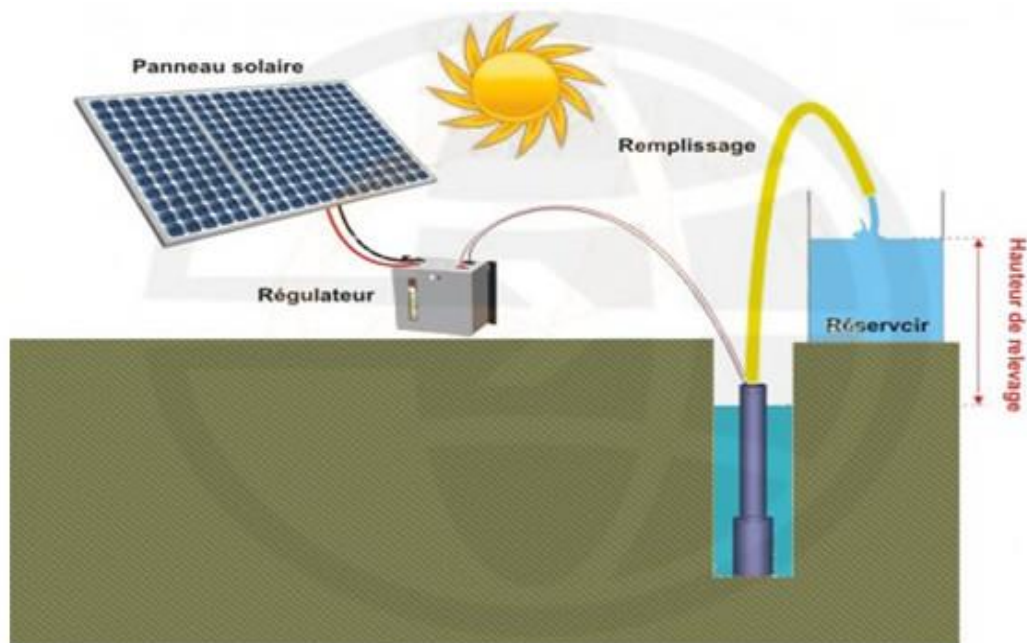


Figure. III.1: Photovoltaic pumping systems.

III.2. Modelling of a separately excited (Independent) MCC:

The modeling of the DC machine in the transient regime makes it possible to highlight certain phenomena that appear during the operation of the machine such as: starting, braking, armature reaction, switching, speed variation, etc.

Consider a constant-flux DC motor obtained by separate excitation. This type of excitation allows us to obtain a relatively simple speed control that is operated by action on the voltage of the armature.

III.3. Equation of the machine:

The modeling of the motor + load assembly is feasible from the basic equations of the DC machine and the fundamental relationship of dynamics. The electrical diagram of an independently excited MCC is as follows:

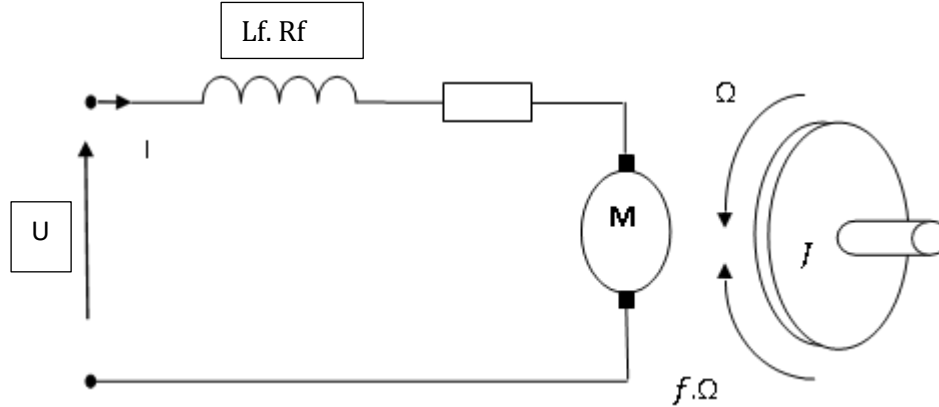


Figure. III.2 Electrical diagram of a separately excited MCC.

The index 'e' corresponds to 'excitation', the index 'a' corresponds to 'feeding'.

- Inductor equation:

$$U_e = R_e \times I_e + \frac{dI_e}{dt} \quad (\text{III. 1})$$

The index 'e' corresponds to 'excitation', the index 'a' corresponds to 'feeding'.

- Inductor equation:

$$\frac{dI_a}{dt} \times L_a I_a \times R_a U_a = + + E \quad (\text{III.2})$$

With Ω rotation speed in radians/second.

- Flow equation:

We perform a simple simulation where the flux is always a linear function of the excitation current and therefore the effects of saturation are neglected:

$$F_e = M_e \times I_e \quad (\text{III. 3})$$

- Equation du couple :

It is obtained from the electromagnetic power:

$$P_e = I_a \cdot E = I_a \cdot K \Omega \Phi = C_e \Omega \quad (\text{III.4})$$

This gives:

$$C_e = K. I_a. F \quad (\text{III.5})$$

- Mechanical equation:

$$C_e - C_r = J \frac{d\Omega}{dt} \quad (\text{III.6})$$

Where C_e is the electromagnetic torque, C_r the resisting torque imposed by the load, J the total moment of inertia (machine + driven load) and f the friction proportional to the rotational speed.

III.4.Pump Model:

The pump is an essential part of pumping systems. In our work we used a centrifugal pump. Its resistance torque C_r is given by the following equation:

$$C_r = k_r \cdot \omega^2 \quad (\text{III.7})$$

Where k_r is the coefficient of proportionality ($\text{Nms}^2 / \text{rad}^2$).

- The mechanical equation of the system is:

$$C_m - C_r = J \frac{d\omega}{dt} \quad (\text{III.8})$$

- Where J is the moment of inertia of the pump motor unit (kg/m^2).

Hysteresis running control

The realization of this technique, regulation by all or nothing, consists of accomplishing the following two steps:

- Compare the measured current with the reference current, which produces a control signal which will be the input signal applied to the hysteresis comparator.
- Fix a band in which the current can evolve. Reaching one of the limits causes the operation of the switches to change in such a way that the current does not exceed this limit and is directed towards the other.

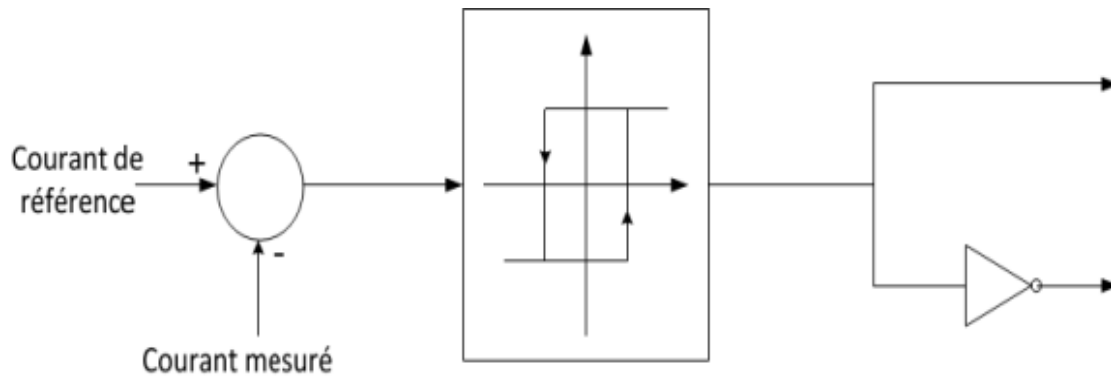


Figure III. 3 : Hysteresis control principle.

Cruise control

The speed control here is operated by a twelfth series type chopper equipped with a machine control. it must make it possible to transform the fixed voltage supplied by the first chopper to a continuously variable voltage

The speed control of a DC machine via a Pi regulator which generates the reference current is the last one regulated by a hysteresis regulator.

III.5. Simulation and results:

The simulation is performed using MATLAB/SimPowerSystem blocks as shown in Fig.III-9.

Basically, the electrical components (panel, converter, motor) are connected to each other by electrical ports representing the negative and positive terminals.

The two inputs to the system, and therefore to the PV panel, are temperature and irradiation Solar and the main output of the system happens to be the speed of the motor that joins then the inlet of the pump. The parameters of the model are available in the appendix.

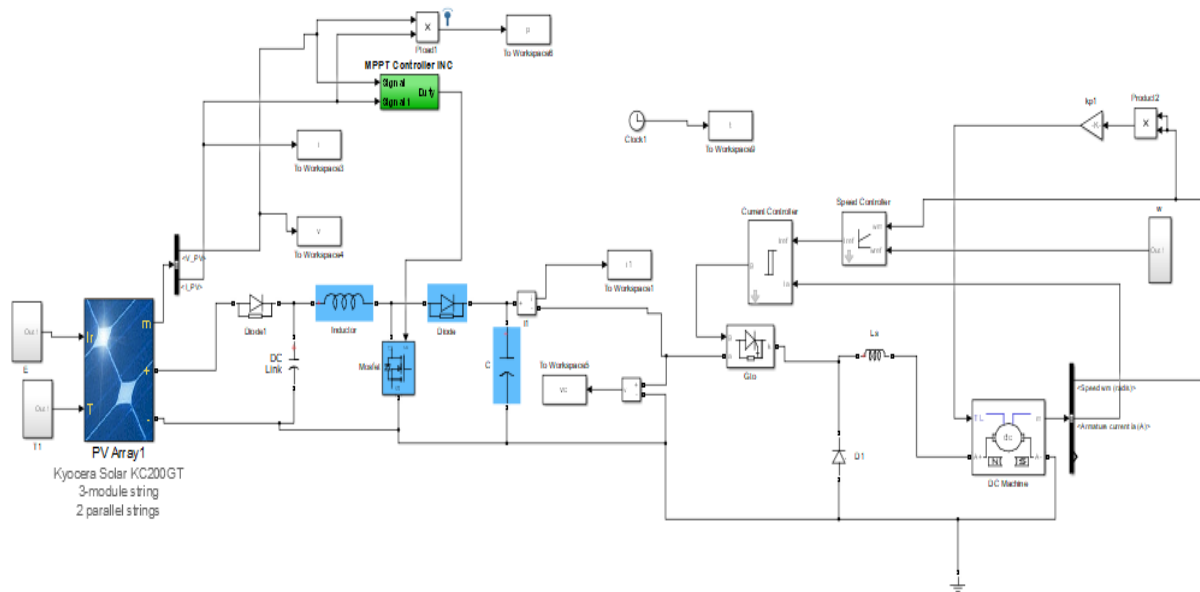


Figure. III.4 : Simulink Block of *DC Motor-pump group with PV*

To show the effectiveness of the control strategy studied, the ambient temperature and the solar insolation are varied as illustrated in Figure (III.5-6).

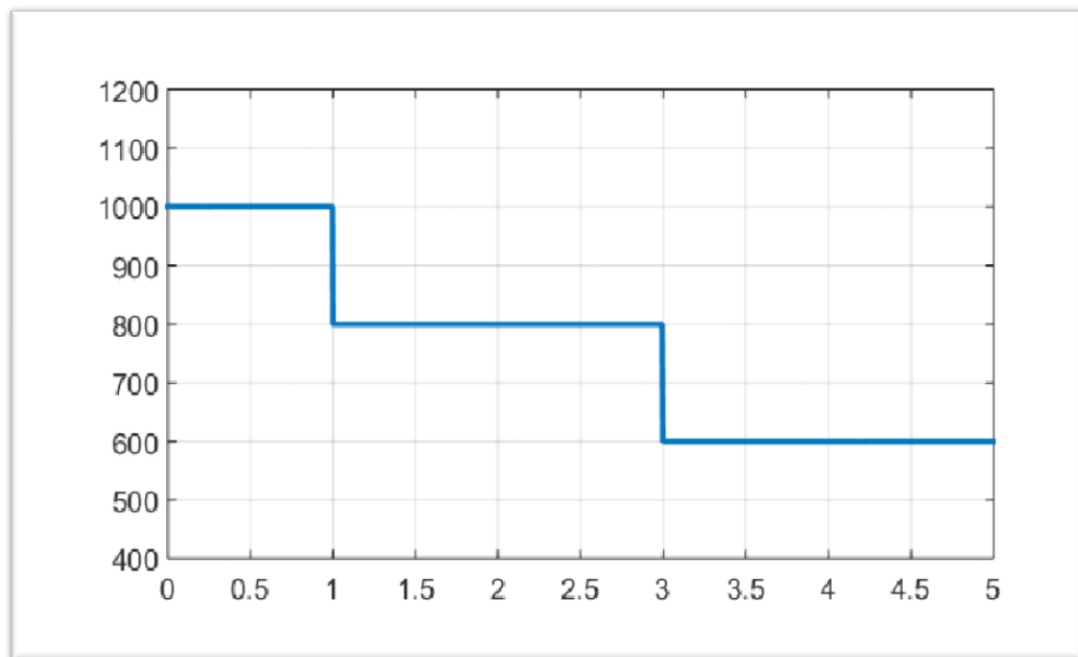


Figure. III.5: *Variation of illumination*

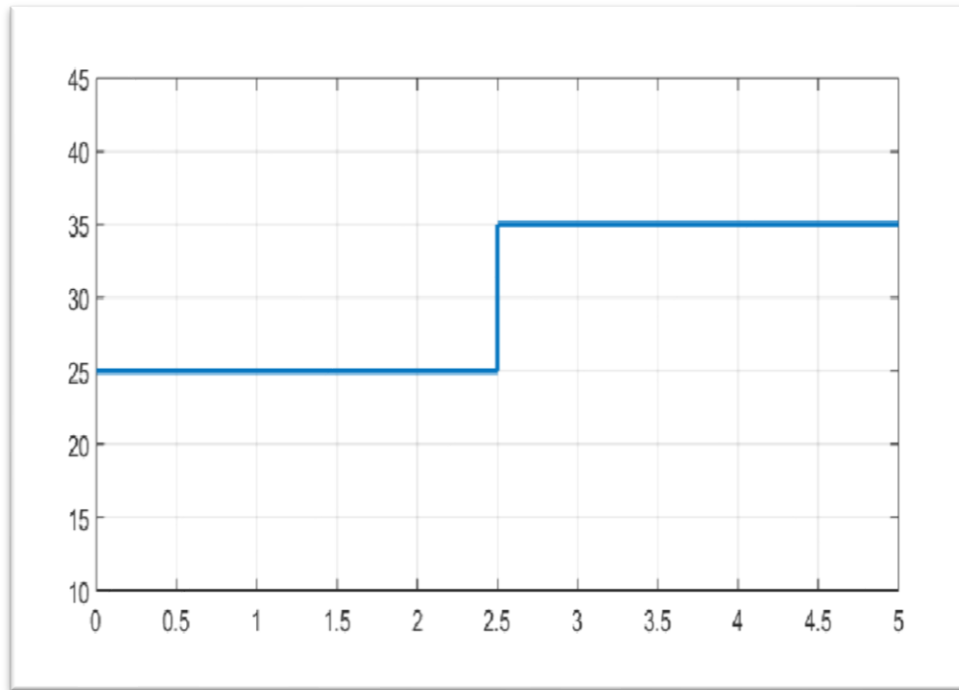


Figure. III.6: Solar panel temperature

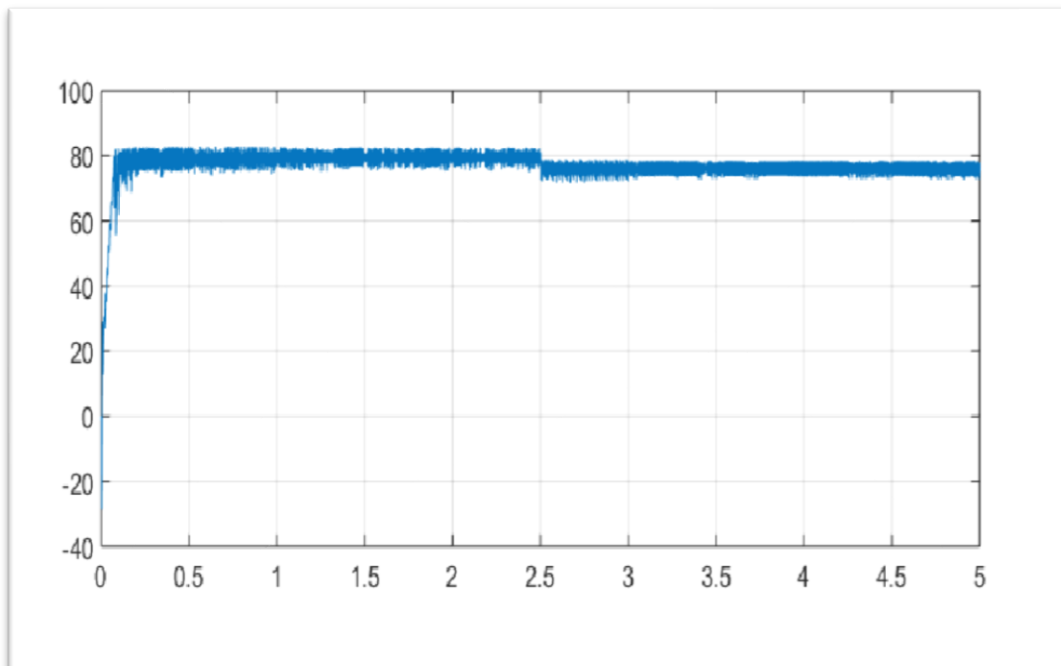


Figure. III.7: PV Voltage

The results of the simulations are shown by the following figures:

Despite a very fluctuating solar irradiation, the strategy is able to produce the maximum power (a graph of the power of the PV panel is available in chapter 2)

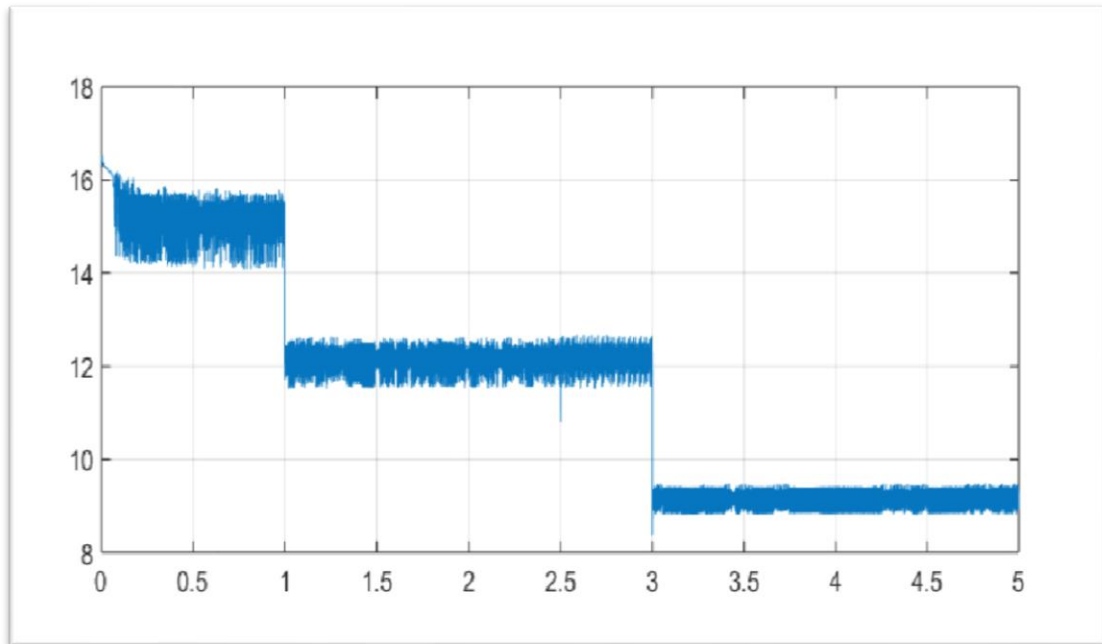


Figure. III.8 : The Power of the GPV for variable illuminance .

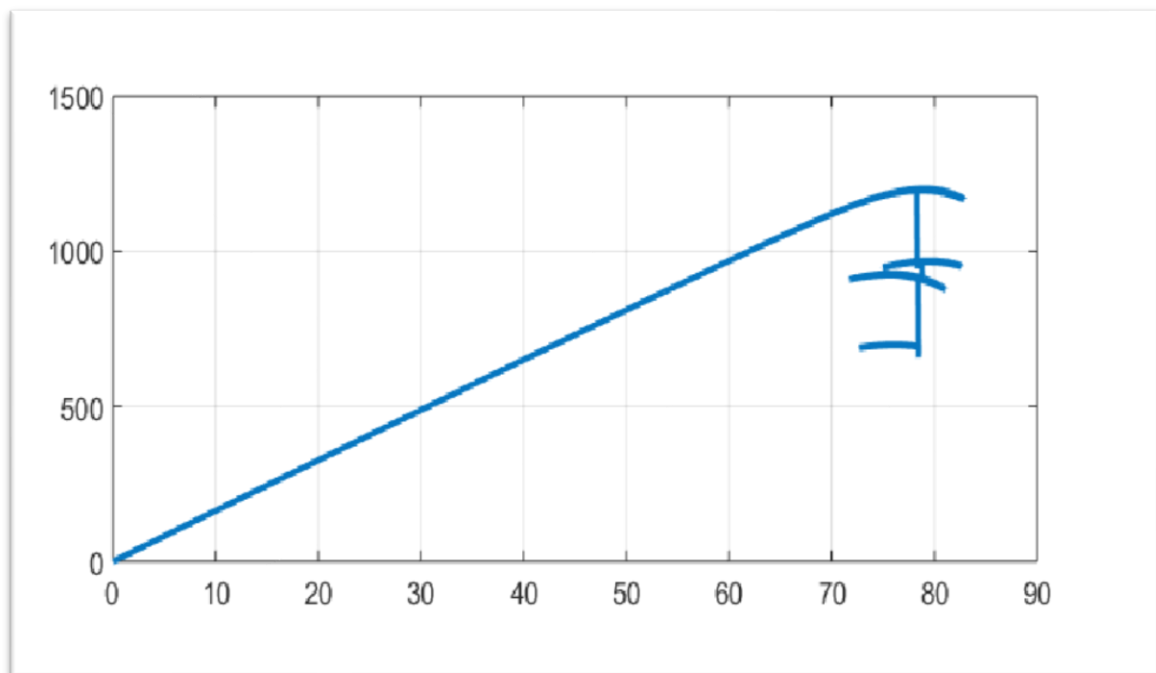


Figure. III.9 : The Power of the GPV as a function of the voltage.

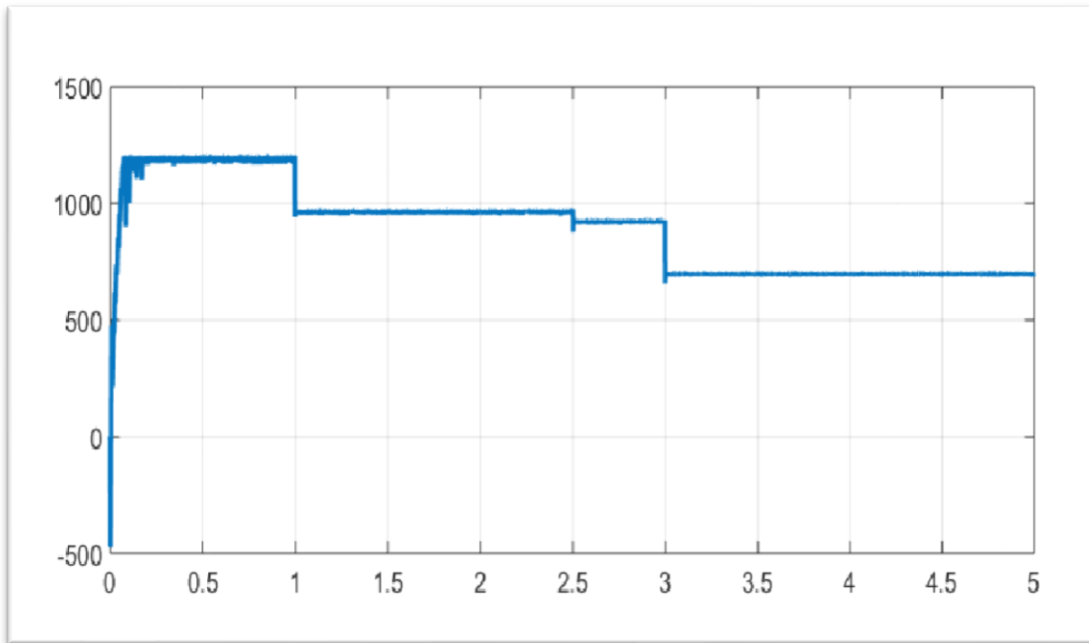


Figure. III.10: The Power of the GPV.

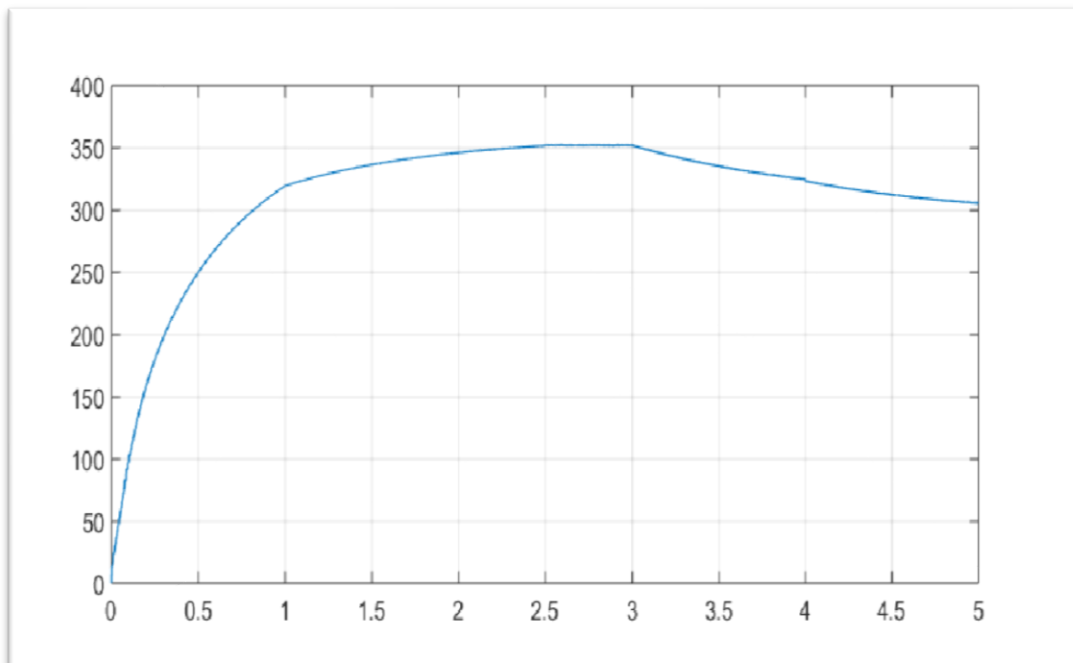


Figure. III.11: The Tension of MCC.

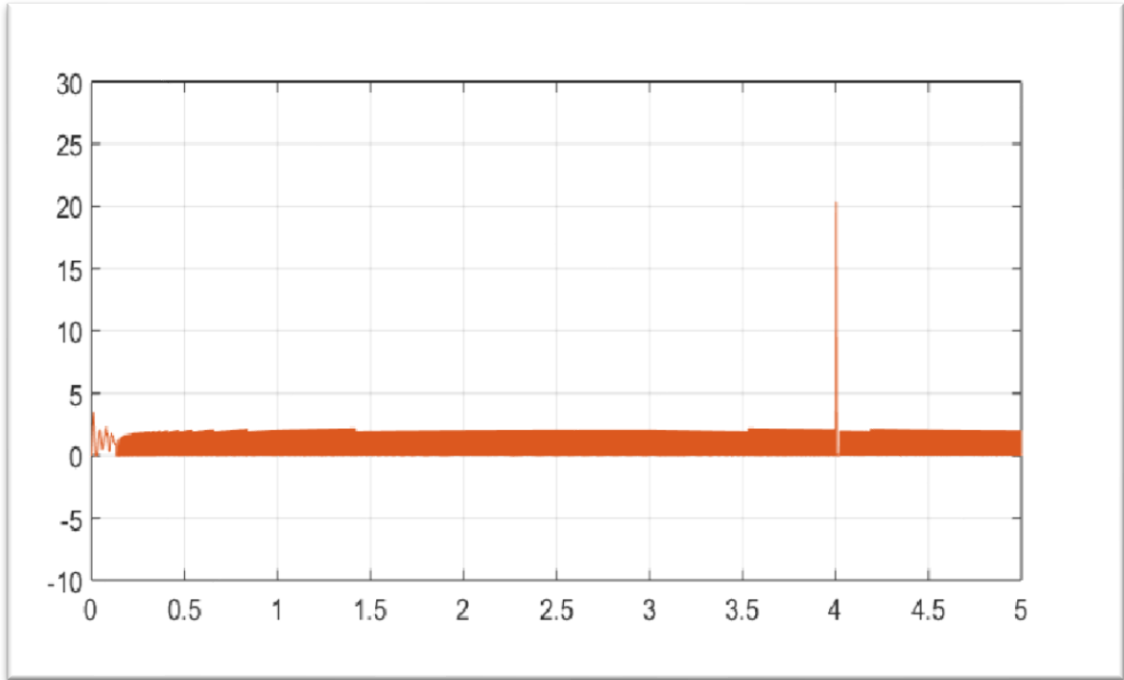


Figure. III.12: The MCC current..

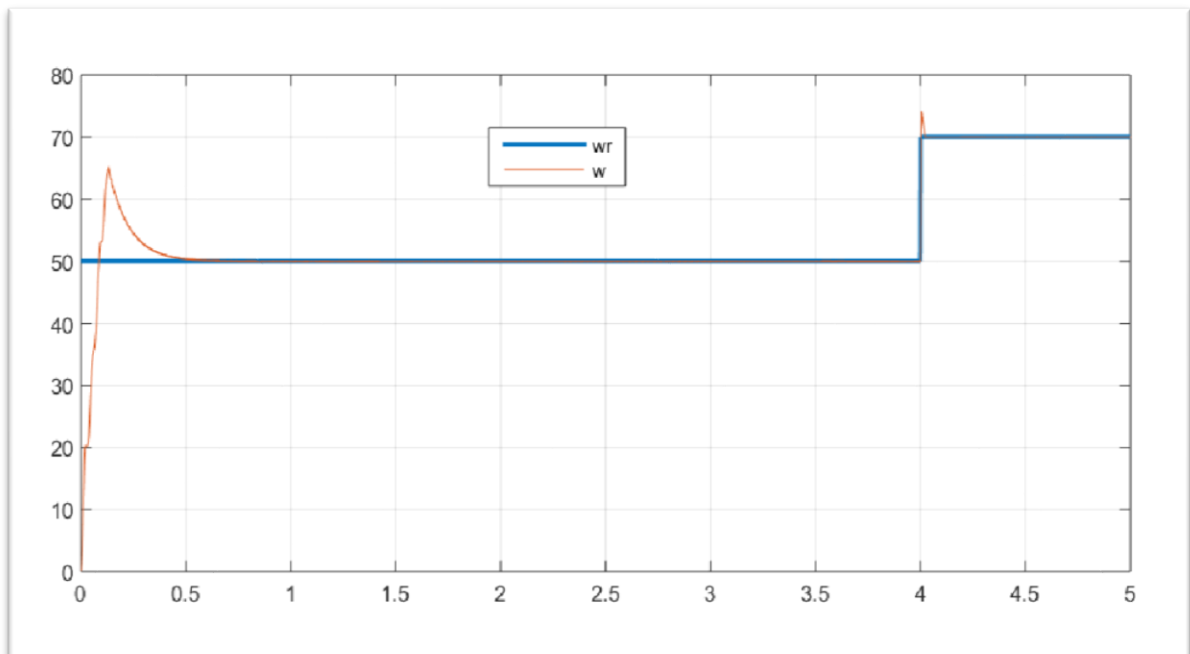


Figure. III.13: variation of the engine rotation speed.

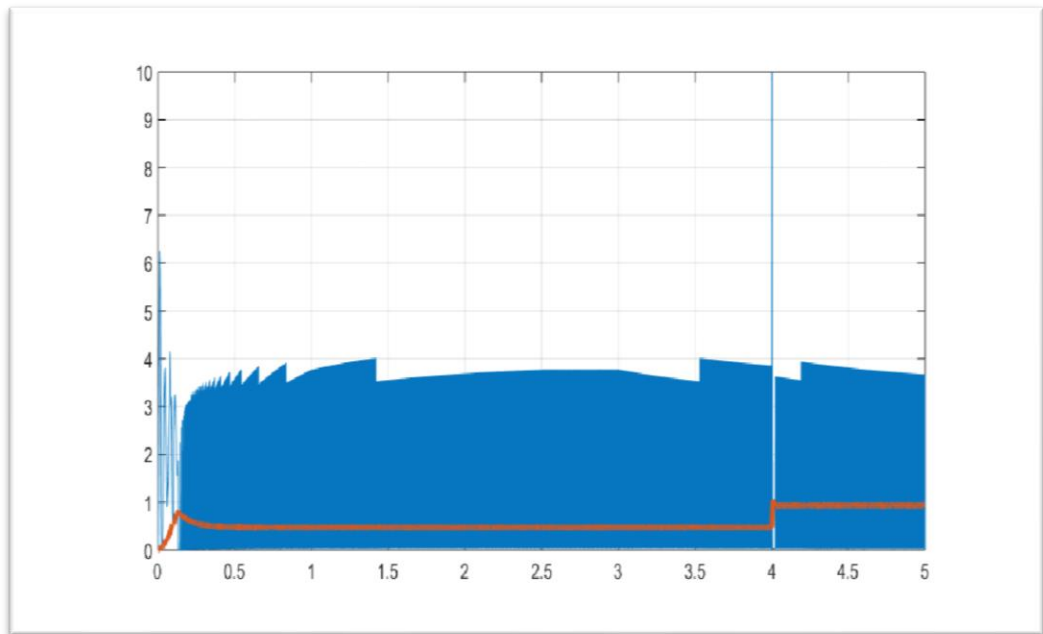


Figure. III.14: The MCC Couple.

Interpretation:

The variation of illuminance and temperature as a function of time does not influence the speed of the motor, which depends on its reference value

For the velocity we have an excellent convergence towards the reference value Figure (II.14) shows the velocity response of the MCC with error correction

An increase in temperature beyond the optimal temperature leads to a decrease in the power and voltage of the photovoltaic panel.

It is found that the voltage and speed of the motor vary around their acceptable values, respectively. As a result, it can be concluded that the approach presented ensures a smooth functioning of the PV pumping system.

We notice that for low illuminance values and high temperature value, the operating points deviate from the optimal power. and the system then works bine.et the engine runs in normal mode.

The speed of the maximum power extracted from the photovoltaic array and the stator current of the motor are shown in Figure (III.14), the point of maximum power moves to reach the new corresponding maximum point.

The simulation results obtained showed its robustness in both transient and steady conditions. For a sudden change in illuminance, a better response time and low oscillation were

obtained. As far as the permanent regime is concerned, in the end this approach has given acceptable results.

III. 6: Conclusion

The aim of this work is the study of the speed control of a DC motor in a water pumping system with solar energy.

In this last chapter, we have validated the complete pumping chain by simulation. Composed of a DC motor and centrifugal pump, via a DC/DC converter of the Boost type. This led us to conclude that:

The maximum power is obtained cancels out the effects of disturbances caused by variations in environmental conditions, and the regulating speed of the permanent magnet DC motor powered by photovoltaic solar panels can be controlled.

Overall conclusion

Overall conclusion:

The objective of this thesis was to model and control a photovoltaic pumping system for water pumping. The proposed system consists of: a photovoltaic generator controlled by an MPPT algorithm to obtain the maximum power point, a static converter and a DC motor pump unit.

In this context, the basic principles of photovoltaic conversion followed by modeling and simulation of a photovoltaic panel under the MATLAB/Simulink environment is present. With the MPPT technique, the system operates at its maximum power.

The behavior of the solar pumping system will be analyzed with simulations.

The complete Agricultural pumping system built using Matlab/Simulink - SimPowerSystems and tested under various operating conditions. Simulation has simplicity, low cost, and the possibility of good performance.

The results are very satisfactory. Even for low illuminance values and high temperature value, the motor operates in nominal mode.

Références bibliographiques :

- [1] **B . Abdelbacet , S . Benyoucef**, «étude technico économique d'un système photovoltaïque en site isolé», Mémoire de Magister, UNIVERSITE MOHAMED BOUDIAF - M'SILA 2018.
- [2] <https://opera-energie.com/energie-solaire>
- [3] **Z . Asma** «Etude par simulation du fonctionnement d'un système photovoltaïque menu d'une commande MPPT» , Université Abou BekrBelkaïd – Tlemcen 2016
- [4] **B . Houssam eddine A.Walid** «Commande floue pour l'optimisation de la puissance d'un générateur photovoltaïque»; Mémoire de Magister , UNIVERSITE MOHAMED BOUDIAF - M'SILA 2019 .
- [5] **Mr BAILEK Nadiem** « Étude et Modélisation du Flux Solaire globale sur surface inclinée dans la région de Touat » Thèse de Doctorat , UNIVERSITE DJILLALI LIABES SIDI BEL ABBES 2018 .
- [6] **Ben Khaled Abdallah , Ayad Mustapha Fawzi** « Commande robuste du système PV par les algorithmes MPPT » , Mémoire de Magister , UNIVERSITE MOHAMED BOUDIAF - M'SILA 2021.
- [7] **J. Royer ; T .Djiako ;E. Schiller ; B . Sada Sy** « LE POMPAGE PHOTOVOLTAÏQUE» livre »;Université d'Ottawa TJ912.P65 1998
1. [8] **Ben Khaled Abdallah ; Ayad Mustapha Fawzi** «Commande robuste du système PV par les algorithmes MPPT» Mémoire de Magister , UNIVERSITE MOHAMED BOUDIAF - M'SILA, 2021 .
2. [9] **A. Ould Mohamed Yahya¹, A. Ould Mahmoud¹ et I. Youm^{2,3}** «Etude et modélisation d'un générateur photovoltaïque», revue des energies renouvelables vol. 11 n°3 sénégal, 2008
- [10] **M. Z. F.Z. Zerhouni**, «Optimisation d'un système à énergie verte avec validation pratique» Revue des Energies Renouvelables, vol. 11 , no. N°1, p. 41–49, 2008.
- [11] **M. SLAMA Fateh**, «Modélisation d'un système multi générateurs photovoltaïques interconnectés au réseau électrique» Mémoire de Magister , UNIVERSITE FERHAT ABBAS - SETIF, 2012 .
- [12] **Cedric Cabal** , «Optimisation énergétique de l'étage d'adaptation électronique dédié à la conversion photovoltaïque » Université Paul Sabatier – Toulouse III, 2008. Français.

[13] **Angel Cid Pastor** , « Conception et réalisation de modules photovoltaïques

electroniques » INSA de Toulouse, 2006. Français

[14] **Daniel Depernet, Julian Vernier, Pierre-Alexis Gril** , « Caractérisation de panneaux photovoltaïques par mesured'impédance » Université de Lorraine [UL], Jul 2018, Nancy, France

[15] **M. SLAMA Fateh**, «Modélisation d'un système multi générateurs photovoltaïques interconnectés au réseau électrique» Mémoire de Magister , UNIVERSITE FERHAT ABBAS - SETIF, 2012

[16] **Y.VESCHETTI**. «Modélisation caractérisation et réalisation de nouvelles structures photovoltaïque sue substrat de silicium mince». Thèse de Doctorat Louis Pasteur Strasbourg,

2005

[17] **S.GUITOUNI**, «Elaboration et étude de structures à base de couches minces de ZnO et

de chalcogénures (CIS, CZTS) pour des Applications Photovoltaïques», Thèse de Doctorat,

Université des frères Mentouri–constantine1, 2017.

[18] **BENDJEBBAR Kamel Eddine**, «Amélioration des rendements des cellules photovoltaïques à filière silicium», Thèse de Doctorat ; Université des Sciences et Techniques d'Oran Mohamed Boudiaf

[19] **A. Azi**, «Contribution au développement d'un outil d'aide aux performances diagnostic des MPPT dans la chaîne de conversion photovoltaïque », Mémoire magister, Université de M'sila, 2014.

[20] **M. Calais, J. Myrzik, T. Spooner, and V. G. Agelidis**, « Inverters for single-phase grid connected photovoltaic systems—An overview », in Proc. IEEE PESC'02, vol. 2, pp. 1995–2000,2002.

[21] **H.Haeberlin**, « Evolution of inverters for grid connected PV-systems from 1989 to 2000 »,in Proc. 17th Eur. Photovoltaic Solar Energy Conf. ,pp. 426–430.Munich, Germany, Oct. 22–26, 2001.

[22] **FERRAH FATEH**, «Etude et simulation d'un étage mppt pour un système à énergie renouvelable », Mémoire de Master, Université Larbi ben M'Hidi– Oum El Bouaghi. 2013

[23] **N. Nobuyoshi and I. Takayoshi**, «A Control Method to Charge Series-Connected Ultraelectric Double-Layer Capacitors Suitable for Photovoltaic

Generation Systems Combining MPPT Control Method», IEEE Transactions on Industrial Electronics, Vol. 54, N°1, pp. 374 - 383, 2007

[24] **K. Khouzam**, «Optimum Load Matching in Direct-Coupled Photovoltaic Power Systems Application to Resistive Loads», PES 1990 WM215-4, IEEE Transactions on Energy Conversion, EC-5, N°2, pp. 265 – 271, 1990.

[25] **P. Izzo**, «Etude d'un Circuit Electronique et Algorithmique Destiné à la Gestion de Systèmes Autonomes de Production d'Energie Photovoltaïque», Thèse de Doctorat, Université de Montpellier II, Décembre 2002

[26] **J. Appelbaum and M.S. Sarma**, «The Operation of Permanent Magnet DC Motors Powered by a Common Source of Solar Cells», IEEE Transactions on Energy Conversion, Vol. 4, N°4, pp. 635 - 642, 1989

[27] **AHMADI ISMAIL**, «Etude et simulation d'un système de pompage d'eau couplé à un générateur photovoltaïque», Mémoire de Master, Université Larbi ben M'Hidi– Oum El Bouaghi. 2013.

[28] **YAAKOUB BENYAHIA**, «Modélisation et simulation d'un système photovoltaïque adapté par une commande mppt », Mémoire de Master, Université Larbi ben M'Hidi– Oum El Bouaghi. 2013

[29] **A.Bouden**, « Analyse optimisée de système de pompage photovoltaïque », Thèse de Magister, Université Mentouri, Constantine, 2008.

[30] **G.MedYacine, D.belkacem, D.akram**, « modélisation et commande d'un système PV connecte au réseau électrique utilisant DSTATCOM. » , Mémoire Master, Université KasdiMerbah Ouargla,2020

[31] **Z. Bendjellouli** «Contribution a la modélisation d'une cellule solaire», Mémoire de

magister université de bachar, 2009.

[32] **C. CABAL** «Optimisation énergétique de l'étage d'adaptation électronique dédié à la

conversion photovoltaïque », Thèse de doctorat université de Toulouse III ,2008.

[33] **MLLE BENHADDOUCHE NESRINE FATIMA** «La commande d'un système

photovoltaïque d'un satellite» Thèse de master université tlemcen 2013/2014.

[34] **Abdelmalik Zorig**, «Modélisation et commande d'un système de production d'énergie photovoltaïque couplé au réseau triphasé », Mémoire de master, Université de Msila, 2011.

- [35] **Cédric Cabal**, «Optimisation énergétique de l'étage d'adaptation électronique dédié à la conversion photovoltaïque», université Toulouse III-Paul Sabatier, Thèse de doctorat, 2008.
- [36] **B. Boudjelel, T. Benslimane**, «Open-Switch Fault-Tolerant Control of Power Converter in a Grid-Connected Photovoltaic System», International Journal of Power Electronics and Drive System (IJPEDS), Vol. 7, No. 4, pp. 1294-1308, December 2016.
- [37] **Hamidouche Macylia**, «Etude d'un System Photovoltaïque», Mémoire de master, Université A.MIRA de Bejaïa, 2016.
- [38] **Belarbi M.Mustapha**, «Contribution à l'étude d'un générateur solaire pour site autonome», Thèse de Doctorat, Université Oran Mohammed Boudiaf, 2015.
- [39] **A. HADJ ARAB, M. BENGHANEM et A. GHARBI**« Dimensionnement de Systèmes de Pompage Photovoltaïque» Revue des Energies Renouvelables. Vol.8, pp (19 – 26), 2005.
- [40] **A.Bouden**, « Analyse optimisée de système de pompage photovoltaïque », Thèse de Magister, Université Mentouri, Constantine, 2011