People's Democratic Republic of Algeria Ministry of Higher Education and Scientific Research

Chahid Hamma Lakhdar University of El-Oued

Faculty of Science and Technology

Graduation Thesis

In order to obtain the diploma of

ACADEMIC MASTER's DEGREE

Domain: Science and Technology

Course: Mechanical Engineering

Specialty: Electromechanics

Theme

Study and design of a micro energy source electrical for use in desert areas

Directed by :

- ✓ Dr. Laouamer mosbah

Directed by:

- ✓ Azeb chikh yakoub
- ✓ Ben Amara Nacer eddine
- ✓ Ahmima elhabib

Defended- May 2025

Thanks

In the name of Allah, the All-Merciful, the All-Merciful

Praise is to **Allah** the only one and peace and blessings be upon him who has no Messenger after him, and upon his family, his companions and all those who follow his path until the Day of Resurrection.

I would like to express my deep gratitude to Mr.
Dr. Al-Awamer Misbah, Teacher at the Chahid Hamma Lakhdar University of El-Oued, for his valuable advice, guidance as well as for the trust and help he gave me to carry out this work.

I would also like to thank my parents, all the members of my family, my brothers and my dear sisters.

My thanks also go to my friends, colleagues and teachers.

DEDICATIONS

During this search, we faced many challenges and obstacles, but thanks to God in the first place, and then with perseverance and determination, we were able to overcome them. We express our deep gratitude to our parents, brothers, sisters and friends, who have been a true support throughout this academic journey. Nor can we forget our dear teachers, who have played a major role in guiding us, supporting us and providing us with valuable information. We dedicate this modest work to you, praying to Almighty God to bless your lives, to grant you health and well-being, and to reward you generously.

SOMMAIRE

List of Figures

List of TABLE

Abstract

This thesis presents a comprehensive technical study and design of a micro electrical energy system tailored for remote desert regions, where access to conventional power grids is limited or nonexistent. The work begins with a classification and evaluation of renewable energy sources suitable for harsh desert conditions, emphasizing solar energy as the most viable and sustainable option due to its high irradiance and wide availability in such environments.

A design has also been proposed of an autonomous photovoltaic (PV) energy system is proposed. The system components — including solar panels, converters, batteries, and control units — are selected based on environmental constraints such as extreme temperatures, dust, and fluctuating irradiance levels.

The final focuses on the intelligent simulation of the designed system using MATLAB/Simulink. Multiple MPPT (Maximum Power Point Tracking) algorithms were implemented, with a focus on neural network-based control. This method demonstrated superior performance in terms of efficiency, fast convergence, and adaptability to environmental changes, making it ideal for desert applications. The results confirm that the integration of artificial intelligence, especially through ANN-based MPPT, significantly enhances system reliability, energy yield, and autonomous operation.

Ultimately, this work provides a robust framework for designing and optimizing micro-energy systems in desert environments, contributing to sustainable energy development in isolated areas.

Keywords :

Solar Energy - Desert Areas - Photovoltaic System - Renewable Energies - MPPT (Maximum Power Point Tracking) - Artificial Neural Networks (ANNMATLAB/Simulink Simulation - Sustainable Energy

résumé

Cette thèse présente une étude technique complète et la conception d'un microsystème d'énergie électrique adapté aux régions désertiques reculées, où l'accès aux réseaux électriques conventionnels est limité, voire inexistant. Le travail commence par une classification et une évaluation des sources d'énergie renouvelables adaptées aux conditions désertiques difficiles, soulignant que l'énergie solaire est l'option la plus viable et la plus durable en raison de son irradiance élevée et de sa grande disponibilité dans ces environnements.

Une conception d'un système d'énergie photovoltaïque (PV) autonome est proposée. Les composants du système – panneaux solaires, convertisseurs, batteries et unités de contrôle – sont sélectionnés en fonction des contraintes environnementales telles que les températures extrêmes, la poussière et les fluctuations de l'irradiance.

Le dernier chapitre se concentre sur la simulation intelligente du système conçu à l'aide de MATLAB/Simulink. Plusieurs algorithmes MPPT (Maximum Power Point Tracking) ont été mis en œuvre, en mettant l'accent sur le contrôle par réseau neuronal. Cette méthode a démontré des performances supérieures en termes d'efficacité, de convergence rapide et d'adaptabilité aux changements environnementaux, ce qui la rend idéale pour les applications désertiques. Les résultats confirment que l'intégration de l'intelligence artificielle, notamment via le MPPT basé sur les ANN, améliore considérablement la fiabilité du système, le rendement énergétique et le fonctionnement autonome.

En fin de, ces travaux fournissent un cadre robuste pour la conception et l'optimisation de micro-systèmes énergétiques en milieu désertique, contribuant ainsi au développement énergétique durable dans les zones isolées.

Mots-clés

Énergie solaire - Zones désertiques - Système photovoltaïque - Énergies renouvelables - MPPT (Suivi du point de puissance maximale) - Réseaux de neurones artificiels (ANN) - Simulation MATLAB/Simulink - Énergie durable

ملخص

تتناول هذه المذكرة دراسة تقنية شاملة وتصميم نظام طاقة كهربائية مصغر موجه خصيصًا للمناطق الصحراوية المعزولة، حيث يصعب توفر شبكات الكهرباء التقليدية. تبدأ الدراسة بتحليل وتصنيف مصادر الطاقات المتجددة المناسبة للظروف الصحراوية القاسية، وقد تبيّن أن الطاقة الشمسية تمثل الخيار الأنسب والأكثر استدامة نظرًا لتوفر الإشعاع الشمسي بكثرة في هذه المناطق.

حيث تم اقتراح تصميم دقيق لنظام طاقة كهروضوئي مستقل، و تم اختيار مكوناته (الألواح الشمسية، المحولات، البطاريات، ووحدات التحكم) بما يتماشى مع القيود البيئية مثل درجات الحرارة المرتفعة، الغبار، وتغيرات الإشعاع الشمسي.

وفي الأخير، فقد تم إجراء محاكاة ذكية للنظام المصمم باستخدام بيئة MATLAB/Simulink ، حيث تم دمج عدة خوارزميات لتتبع نقطة القدرة القصوى(MPPT) ، مع التركيز على الخوارزمية المعتمدة على الشبكات العصبية الاصطناعية (ANN) وقد أظهرت هذه الطريقة أداءً عاليًا من حيث الكفاءة، وسرعة الاستجابة، والقدرة على التكيف مع تغيرات الظروف البيئية، مما يجعلها مثالية للتطبيقات في المناطق الصحراوية.

في الختام، توفّر هذه المذكرة إطارًا هندسيًا وتقنيًا متكاملاً لتصميم وتحسين أنظمة الطاقة المصغرة المستقلة في البيئات الصحراوية، مساهمة بذلك في تطوير حلول طاقوية مستدامة للمناطق النائية.

الكلمات المفتاحية :

الطاقة الشمسية، المناطق الصحراوية، نظام كهروضوئي، الطاقات المتجددة، MPPT، الشبكات العصبية الاصطناعية (ANN)، محاكاةMATLAB/Simulink ،الطاقة المستدامة

General Introduction

General Introduction:

In a global context marked by the scarcity of fossil energy resources, the increasing demand for electricity, and the need to reduce environmental impact, the use of renewable energy has emerged as a sustainable and strategic alternative. This need becomes even more pressing in isolated and hard-to-reach areas, such as desert regions, where extending conventional electrical grids is often economically and technically unfeasible.

Algeria, with its vast Saharan territory enjoying exceptional sunlight and favorable climatic conditions, offers an ideal setting for the development of decentralized, clean energy solutions tailored to the local environment. Among these solutions, the micro power source — often combining photovoltaic, wind, or hybrid technologies — provides an effective response to the basic energy needs in these remote areas.

The objective of this research is to study and design an autonomous micro power source optimized for the extreme environmental conditions of the desert. This includes analyzing specific energy needs, selecting appropriate technologies, modeling the proposed system, and evaluating its performance in terms of reliability, efficiency, and cost.

Through this study, we aim to demonstrate the technical and economic feasibility of such a solution, contributing to the energy transition and improving the living conditions of populations residing in arid and remote regions.

CHAPTER I: TYPES OF RENEWABLE ENERGIES USED IN DESERT AREAS

I.1 Introduction:

Desert areas face significant challenges in energy supply due to their geographic remoteness from production centers and electrical grids, as well as extreme climatic conditions such as high temperatures, strong winds, and the presence of sand. With the growing demand for energy, it has become essential to seek sustainable and efficient solutions that ensure a stable supply while reducing dependence on fossil fuels and preserving the environment.

In this context, renewable energies emerge as a strategic alternative, particularly in desert regions that benefit from some of the highest levels of sunlight in the world, along with vast areas of land available for the installation of energy equipment. Wind energy and biomass, though limited, also offer interesting prospects in certain specific areas.

This chapter aims to provide a technical and comparative overview of the main types of renewable energy that can be harnessed in desert environments, focusing on their advantages, constraints, and the practical applications already implemented or planned in Algeria or other countries with similar climates and geography.

The analysis will specifically focus on solar energy in its various forms, wind energy, geothermal energy, and biomass, while emphasizing the role of these resources in promoting sustainable development in remote desert areas.

I.2. Definition of Renewable Energies:

Renewable energies are energies that can be naturally renewed or regenerated. Therefore, they can be used without limit over time, while fossil energies come from reserves that are depleting. There are five main families of renewable energies. In the order of their current exploitation, they are:

- Solar energy
- Wind energy
- Hydropower (hydroelectricity)
- Biomass (including firewood, biogas, etc.)
- Geothermal energy

When considering the entire use of wood for heating and cooking, it is this, and thus biomass, that is the most important renewable energy. However, for electricity production, hydropower is by far the most widely used renewable energy. [1].

.

Figure I.01:Different Types of Renewable Energies

I-3. Different Types of Renewable Energies Used in Desert Areas:

In the current context of the energy transition, desert areas represent a strong potential for the development of renewable energies. Thanks to their extreme and stable climatic conditions, they offer an optimal environment for the exploitation of clean and sustainable energy sources.

The types of renewable energies present in desert regions are :

1. Solar energy.
2. Wind energy.
3. Biomass.

I.3.1. Solar Energy

Solar energy is a form of renewable energy that comes from solar radiation. It allows the production of electricity either through photovoltaic panels or solar thermal power plants by capturing sunlight. This energy can be exploited on a large scale in solar farms or on a small scale by individuals. It is clean, emits no greenhouse gases, and uses a free, inexhaustible resource, particularly abundant in desert areas, where sunlight is intense and constant throughout the year. [2] There are three types

I.3.1.1 Photovoltaic Solar Energy

I.3.1.1.1 Definition

Photovoltaic solar energy comes from the conversion of sunlight into electricity within semiconductor materials such as silicon or materials coated with a thin metallic layer. These photosensitive materials have the property of releasing their electrons under the influence of external energy. This is the photovoltaic effect. The energy is provided by photons (components of light) that strike the electrons and free them, generating an electric current. This direct current of micro power, measured in peak watts (WC), can be converted into alternating current using an inverter.

The electricity produced is available in the form of direct electricity or stored in batteries (decentralized electrical energy) or injected into the grid.

A photovoltaic solar generator consists of photovoltaic modules, which are themselves made up of photovoltaic cells connected together.

The performance of a photovoltaic system depends on the orientation of the solar panels and the sunlight zones in which you are located.

Figure I.01: Photovoltaic Module

I.3.1.1.2 Operating Principle

The photovoltaic effect was discovered by the French physicist BECQUEREL as early as 1839. The photovoltaic effect allows for the direct conversion of the light energy from solar rays (photons) into electricity (Volts) through the production and transport of positive and negative electric charges within a semiconductor material under the influence of light.

This material consists of two parts, one with an excess of electrons and the other with a deficiency of electrons, known respectively as n-doped and p-doped. When the first part comes into contact with the second, the excess electrons in the n-type material diffuse into the p-type material.

The initially n-doped area becomes positively charged, and the initially p-doped area becomes negatively charged. Therefore, an electric field is created between them, which tends to push the electrons towards the n area and the holes towards the p area. [3]

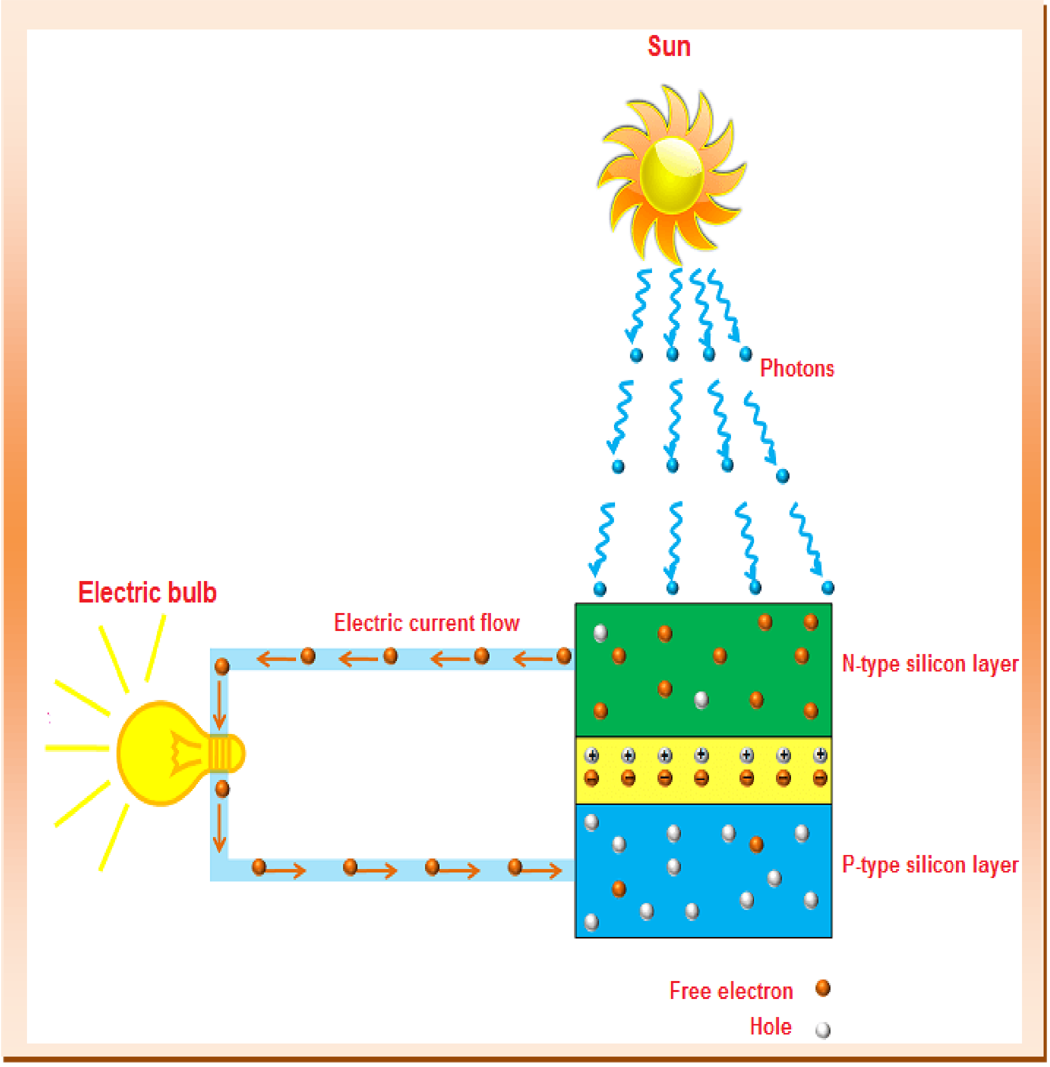

Figure I.03: Photovoltaic Effect

Thus, this principle involves the collision of incident photons (light flux) with free electrons and valence electrons, transferring energy ($h\nu$) to them. [4]

ϖ If this energy is greater than or equal to the bandgap energy of the semiconduct (Eg = EC - EV), the electron moves from the valence band to the conduction band, leaving a hole behind. This leads to the creation of electron-hole pairs at different points of the junction. Therefore, any minority carrier near the junction has a very high probability of crossing it, while the junction primarily opposes the passage of majority carriers (Figure 4).

ϖ If the photons have energy much higher than Eg, they move from the valence band to an unstable level in the conduction band. The excess energy will be transferred as phonons in the crystal lattice, then lost as heat, and the electron will settle at a stable level in the conduction band.

ϖ If the photons have energy lower than Eg, they will not be absorbed, and their energy will not contribute to the photovoltaic conversion.

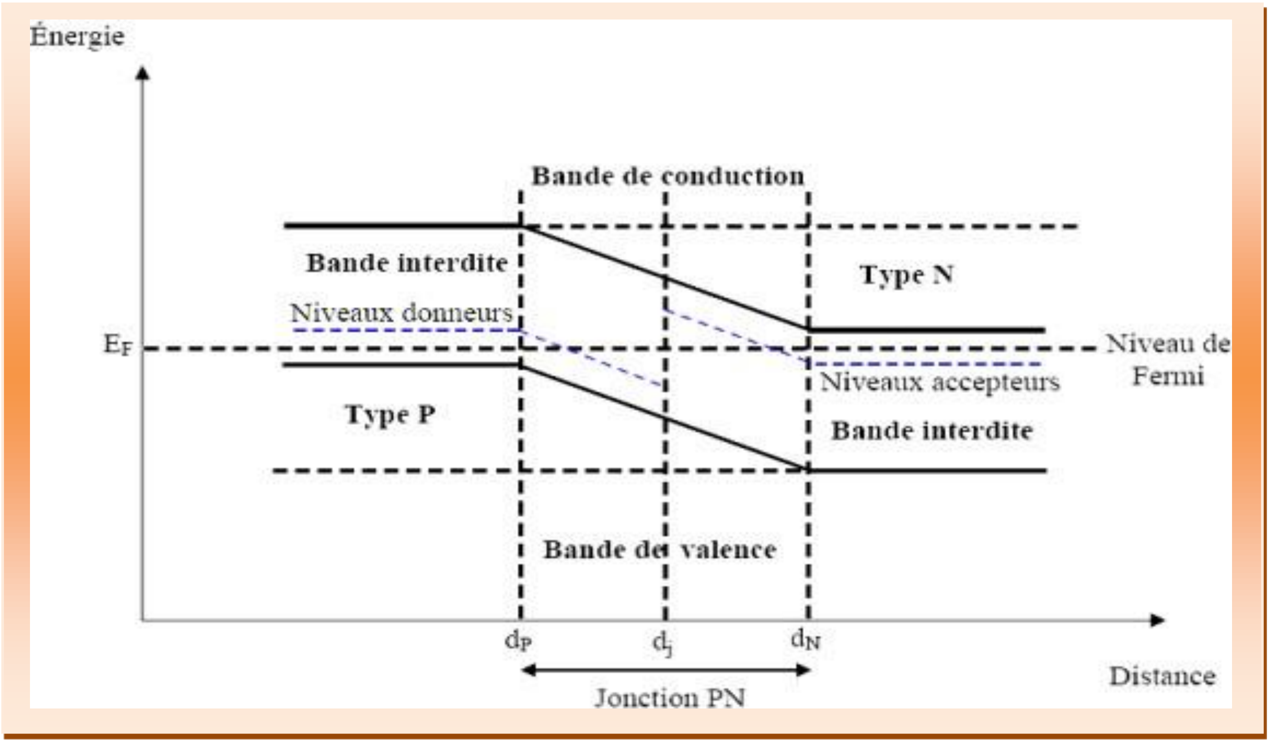

Figure I.04: Energy band diagrams near the junction

I.3.1.2 Solar Thermal Energy

It is radically different from photovoltaic solar energy, as it produces heat from infrared solar radiation to heat water or air. In this case, thermal collectors are used, which involve a completely different technology.

In common terms, these are "solar water heaters" or "hot air collectors."

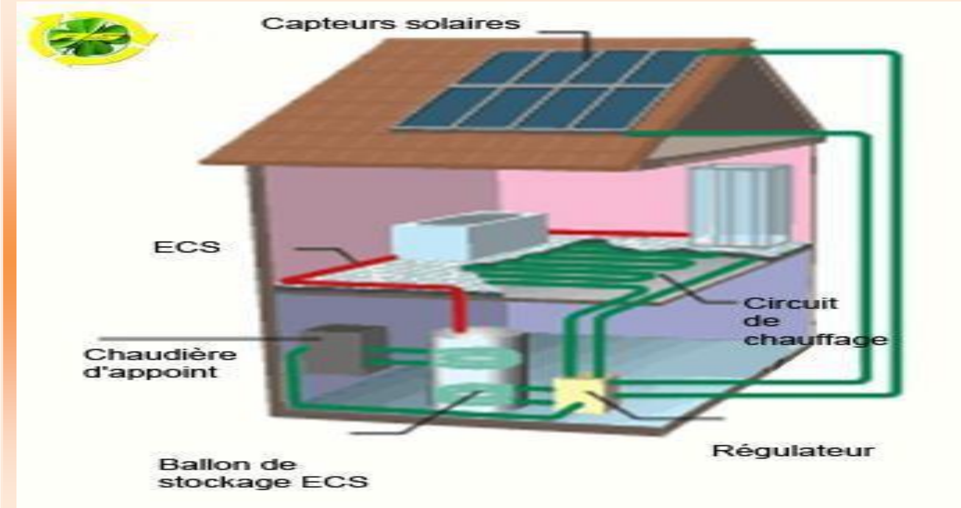

Figure I.05: Solar Water Heater

I.3.1.3 Thermodynamic Solar Energy

There is also what is called thermodynamic solar energy, which operates on the principle of concentrating solar rays using curved mirrors, focusing them onto a focal point placed on a tower that stores the heat, which is then released in mechanical form using a steam turbine, for example.

Figure I.06 : Solar Tower

I.3.1.4 The pros and cons of Solar energy in desert areas

I.3.1.4 .1 Benefits :

1. Very high solar radiation (> 3000 h/year).
2. Systems that are simple to install and maintain (few moving parts).
3. Solution suitable for remote (off-grid) areas.
4. Easy scalability (modular systems).
5. Low long-term operating costs.
6. Compatible with hybrid systems (solar + diesel + batteries).

I.3.1.4 .2 Disadvantages :

1. Dust/sand build-up reduces yield.
2. High temperatures decrease the efficiency of the panels.
3. Expensive storage (lithium batteries, regular maintenance).
4. No production at night (need for storage or hybridization).
5. Need for large areas for large-scale projects.
6. Local environmental impacts (shading, microclimate).

I.3.2. Geothermal energy

I.3.2.1 Definition

Geothermal energy is a renewable energy source that relies on harnessing heat contained in the depths of the earth's crust to produce heat or electricity [4] Today, it is a form of clean energy that is expanding technically and economically.

The Earth's crust is divided, thermally, into stable areas with low geothermal fluxes and unstable areas with high heat flux. These geological contrasts make it possible to classify the types of geothermal energy according to the depth of the source and its temperature.

This energy is used in many applications, including heating and power generation. It is also a reliable and promising solution in remote and desert regions, due to the stability of geological conditions and its independence from climatic factors.

Its main types are as follows:

1. High-energy geothermal energy.
2. Low-energy geothermal energy.
3. Very low energy geothermal energy.

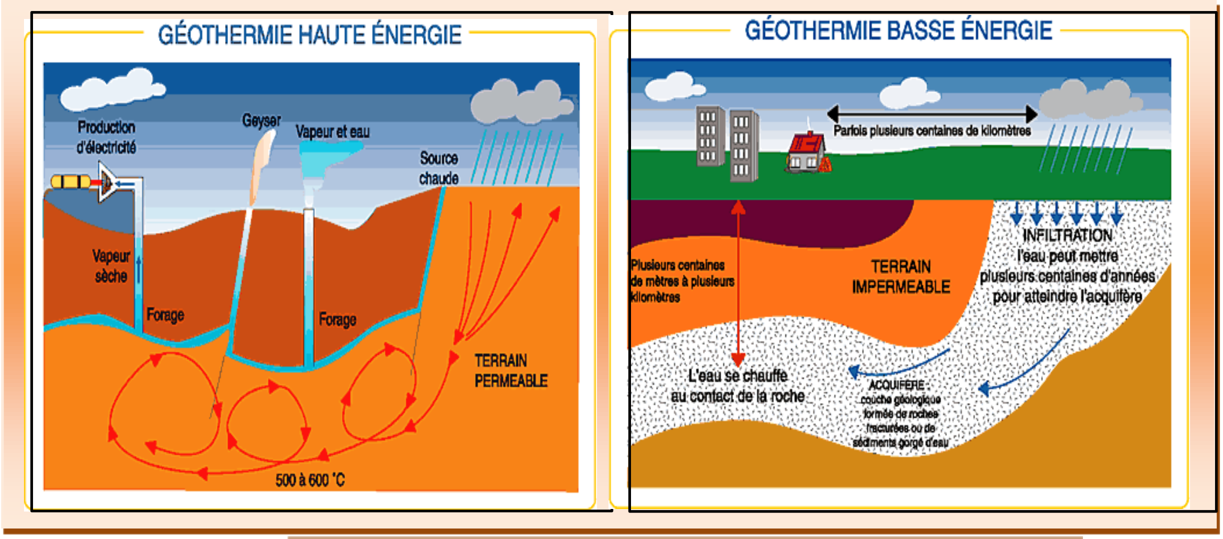

Figure I.07:Low-energy geothermal energy

I.3.2.2 The operating principle of geothermal energy

The principle is to extract geothermal energy from the ground for use in the form of heating or conversion into electricity. In the deeper layers, the Earth's heat is produced by the natural radioactivity of the rocks that make up the Earth's crust: this is the nuclear energy produced by the decomposition of natural matter, uranium, thorium and potassium. This energy can be used either as electricity or as heat and each type is characterized by its multiple technologies and applications, depending on demand and needs.

Nappe phréatique a puis de 100°C → Water infiltration → Steam → Electricity

Figure I.08:Geothermal system

I.3.2.3 The pros and cons of Geothermal energy in desert areas

I.3.2.3.1 Benefits :

1. 24-hour stable power source (base load).
2. Low maintenance after installation.
3. Nearly zero CO_2 emissions.
4. Direct use possible for heating or cooling.
5. Long service life of the systems (> 30 years).
6. Reduction of dependence on fossil fuels.

I.3.2.3.2 Dis advantages :

1. Limited geothermal resources in desert regions.
2. Very high initial costs (deep drilling, geological studies).
3. Low but present seismic risks.
4. Heavy reliance on accurate geophysical data.
5. Advanced technologies required (pumps, exchangers).
6. Risks of contamination of groundwater.

I.3.3. Wind energy

I.3.3.1 Definition

In desert areas, wind energy is used to generate electricity, taking advantage of the steady winds that characterize these vast open spaces. The transformation of wind energy into electrical energy is based on wind turbines composed of a mechanical part and an electrical part. The mechanical section captures the kinetic energy of the wind and converts it into rotational mechanical energy. This is then transmitted, usually via a gear system (gearbox), to an electric generator. The latter ensures the final conversion into electrical energy, which is particularly useful for supplying isolated desert regions, which often lack a conventional electricity grid.

I.3.3.2 How a wind turbine works

A wind turbine, more commonly known as a "wind turbine", is used. Its operation is simple and inspired by windmills. The machine consists of three blades (usually carried by a hub constituting the rotor and installed at the top of a vertical mast). This assembly is fixed by a basket that houses a generator. An electric motor allows the rotor to be oriented so that it is always facing the wind. Blades are used to transform the kinetic energy of the wind (energy that a body possesses due to its movement) into mechanical energy (mechanical movement of the blades). The wind causes the blades to rotate between 10 and 25 revolutions per minute. The speed at which the blades rotate depends on their size: the larger they are, the slower they rotate. The generator transforms mechanical energy into electrical energy. Most generators need to run at high speeds (1,000 to 2,000 revolutions per minute) to generate electricity. It is therefore first necessary that the mechanical energy of the blades passes through a gearbox whose role is to accelerate the movement of the slow transmission shaft, coupled to the blades, to the fast shaft coupled to the generator. The electricity produced by the generator has a voltage of about 690 volts. As it cannot be used directly, it is treated with a converter and its voltage is increased to 20000 volts. It is then injected into the electricity grid and can be distributed to consumers. .

I.3.3.3 Main components of a wind turbine

There are many possible configurations of wind turbines that can have significant differences due to their multiple types. However, the "classic" wind turbine is usually made up of three main components.

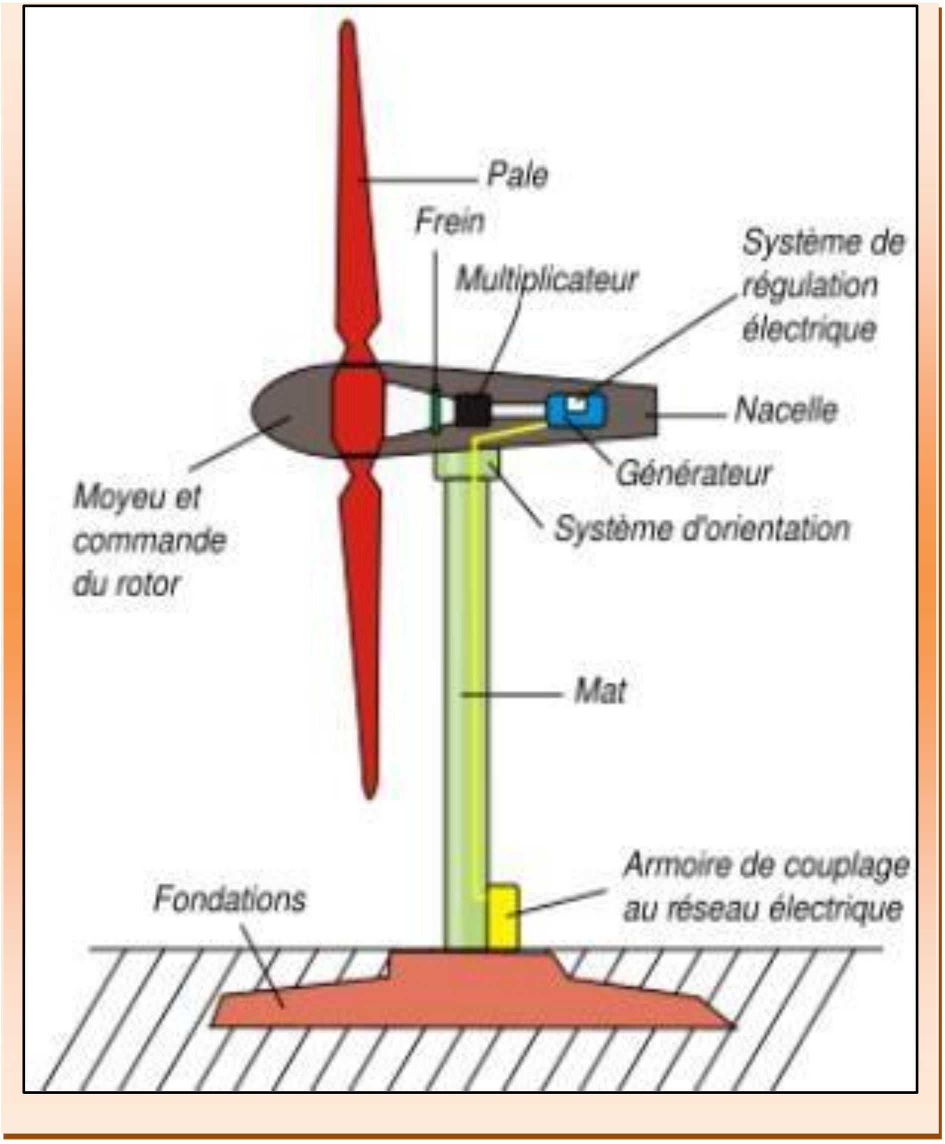

Figure I.09: General structure of a wind turbine

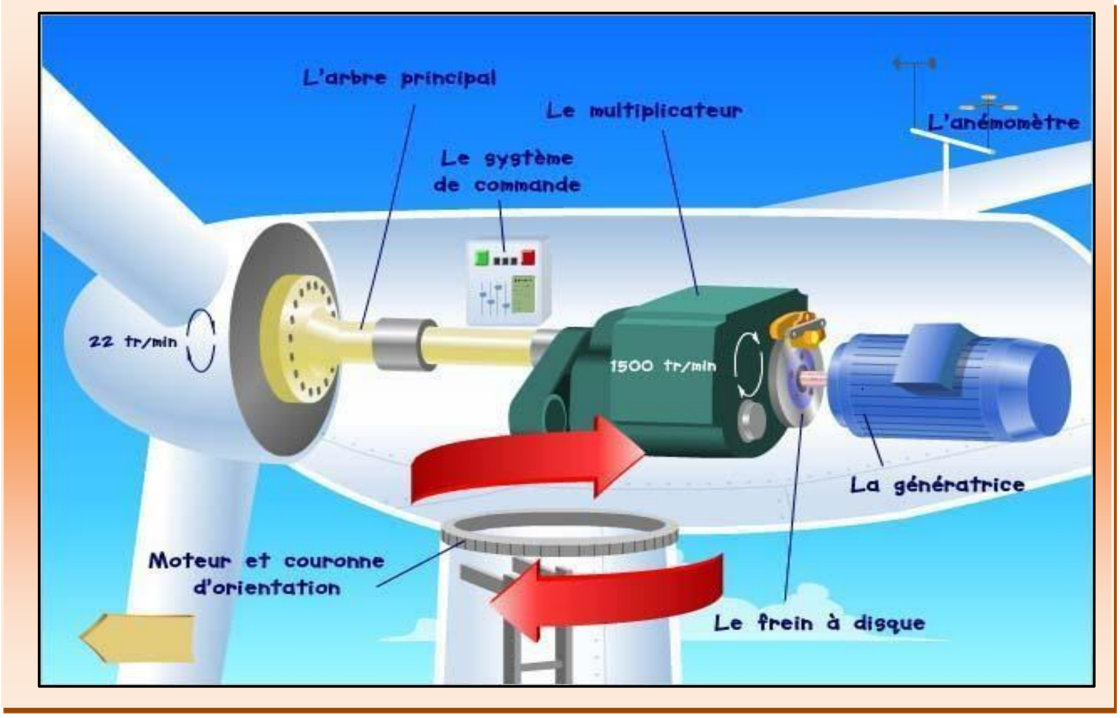

Figure I.10:Exploded view of a wind turbine

❖ The mast, often a steel tube or wire mesh, should be as high as possible to avoid disturbances near the ground. Thus, the amount of materials used is a significant cost and the weight must be limited. (Example: NORDEX N90 2.3 MW wind turbine: diameter 90 m, mast height 80 m).

❖ The nacelle is made up of all the mechanical elements that connect the wind turbine to the generator: slow and fast shafts, bearings, multiples. Disc brakes, different from aerodynamic brakes, which automatically stop the system in the event of an overload. The generator is usually a synchronous or asynchronous machine and hydraulic or electrical systems to guide the blades (pneumatic brakes) and conveyors (needed to maintain the area where the air generator protrudes perpendicular to the direction of the wind).

❖ The rotor, which consists of the blades collected in its center. For wind turbines dedicated to electricity generation, the three-bladed rotor (the Danish concept) is the most popular because it is characterized by a good compromise between cost, vibration behavior, visual pollution and noise.

❖ Fixed speed rotors are configured with a blade guidance system that makes it easier to operate the generator (usually an asynchronous squirrel cage machine) in the vicinity of the synchronization and that it is directly connected to the precision electronic force.

❖ Variable speed rotors are often cheaper because the blade orientation device is simplified. However, an electronic electrical interface is required between the generator and the grid or load.

❖ The blades are mainly characterized by their reliable engineering in aerodynamic performance and the materials they manufacture (currently, composite materials such as glass fibers and the latest carbon fibers are very useful.

Wind engines used to capture wind energy can be classified into two distinct categories:

- ✓ Machines with a horizontal axis.
- ✓ Vertical axis machines

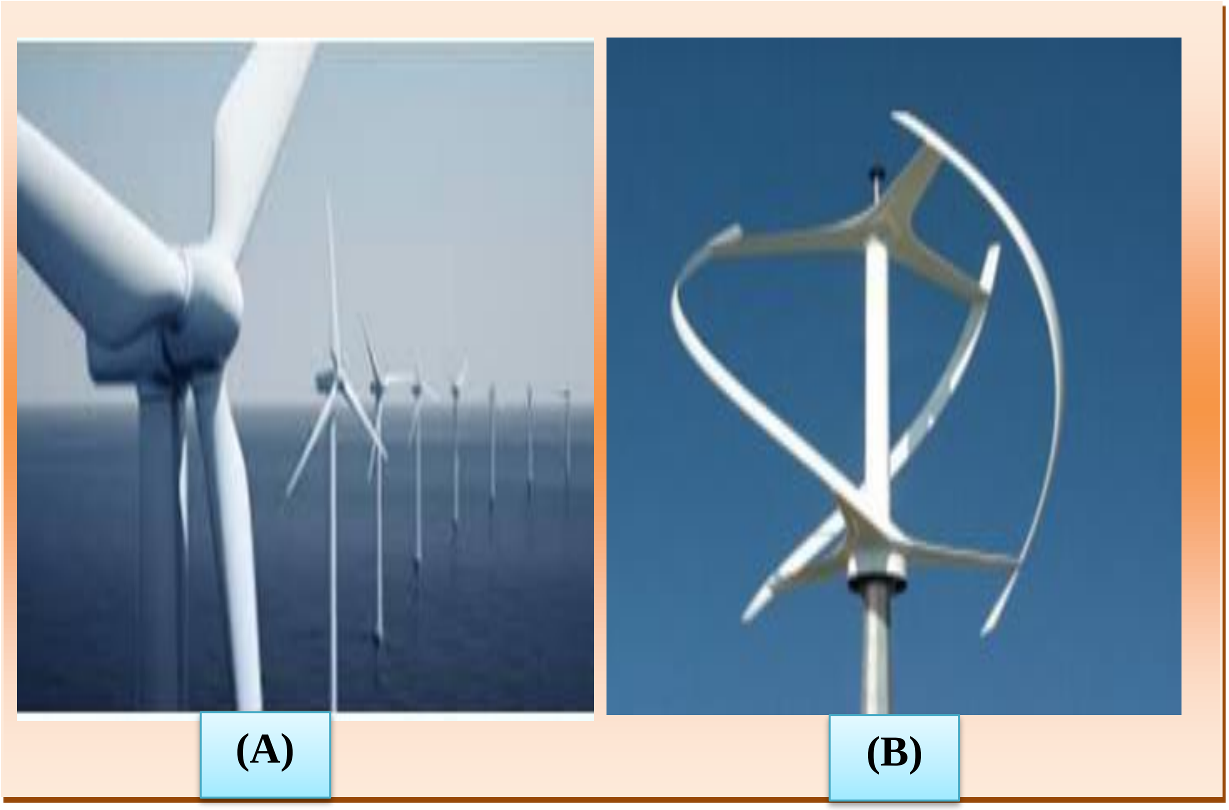

Figure I.11:Wind turbine with horizontal axis (A); Vertical axis wind turbine (B)

I.3.3.4 The pros and cons of wind energy

The development of wind energy is closely linked to the benefits it presents. However, it also has somedrawbacks, especially in specific contexts like desert areas.

I.3.3.4.1 Benefits

1. Does not produce polluting emissions.
2. Dismantled without permanent environmental impact.
3. Easy to install in remote areas.
4. Creates local jobs.
5. Stable winds in some desert regions (e.g. Adrar).
6. Does not require water for cooling.

I.3.3.4.2 Disadvantages

1. Unstable production due to wind variability.
2. Difficult maintenance because of the sand and heat.
3. Erosion of components due to sandstorms.
4. Reduced efficiency of turbines at high temperatures.
5. Negative visual impact on the landscape.
6. Risk to migratory birds.

I.3.4. Energy Bioenergy

I.3.4.1 Definition

Bioenergy refers to energy derived from biomass, i.e. all organic matter of plant, animal or residual origin (such as agricultural waste). All definitions converge on one essential point: bioenergy comes from the transformation of solar energy captured by living organisms, directly or indirectly, into organic matter that can be used for energy purposes.

In desert areas, although the biomass resource is naturally limited due to the low density of vegetation, some forms of bioenergy can be valued locally. For example, agricultural residues in oases, such as date palm leaves and pits, can be turned into biofuels or used for heat generation. This is an interesting opportunity to strengthen the energy autonomy of isolated rural communities, while recovering organic waste available on site.

I.3.4.2 Biomass

Biomass refers to all organic matter that can be used as energy. Organic matter can be both plant materials (food residues, wood, leaves, etc.) and animal materials (animal carcasses, living soil beings).

I.3.4.3 The pros and cons of energy Bioenergy

I.3.4.3.1 Benefits of Bioenergy

1. Use of local organic waste (agricultural waste, palm trees, manure, etc.).
2. Reduction of agricultural waste in the oases.
3. Small-scale energy production adapted to remote areas.
4. Creation of local jobs (collection, treatment, maintenance).
5. Reduction of greenhouse gas emissions compared to fossil fuels.
6. Renewable and potentially continuous source of energy depending on the resource.

I.3.4.3.2 Disadvantages of bioenergy

1. Water needs for certain processes (anaerobic digestion), which is difficult to guarantee in the desert.
2. Limited energy yield compared to solar or wind.
3. Challenging biomass collection and transportation logistics in remote areas.
4. Low biomass resources in very arid areas.
5. Technical maintenance for biogas systems can be complex.
6. Risk of pollutant emissions if combustion is poorly controlled.

I.3.5. Hybrid Energy

Hybrid energy systems combine two or more sources of energy—often renewable ones—to generate electricity or power systems more efficiently and reliably.

These systems are especially crucial in areas where depending on a single energy source is not viable due to environmental variability or the lack of connection to the main electrical grid [5]

I.3.5.1 Typical Combinations (Solar + Wind, etc.)

Some of the most common hybrid combinations include :

- Solar energy + Wind energy
- Solar energy + Diesel generator.
- Solar energy + Battery storage

These combinations allow the system to offset low production from one source with power from the other. For instance, sunlight is most available during the day, while wind is typically stronger at night—providing a balanced supply of energy throughout the day [6]

I.3.5.2 Advantages in Desert Areas

Desert environments are perfect for hybrid energy systems because :

- They offer strong solar and wind resources
- They often lack centralized power grids
- Hybrid systems provide sustainable, long-term energy solutions

For example, in the Sahara Desert, hybrid systems are used to power remote villages and communication centers, reducing the need for fossil fuels. They also help in reducing carbon emissions and minimizing environmental impact [7].[8]

I.4. Renewable Energy Assessment in Algeria:

The renewable energy potential in Algeria is the largest in North Africa. The renewable energy market is promising and the promotion of renewable energy is one of the pillars of the country's energy and environmental policy. Among the objectives that the public authorities are trying to set themselves, the local market must reach 500 megawatts by 2010, bringing electricity produced from renewable energies to 5% of the total electricity produced .

I.4.1 Solar potential

Due to its strategic location, Algeria has the largest solar energy depot in the Mediterranean basin. The average duration of sunshine on Algerian territory exceeds 2,000 hours per year and reaches about 3,500 hours of sunshine in the Great Desert of Algeria. The total energy received is estimated at 169,400 TWh/year, i.e. 5000 times the country's annual electricity consumption

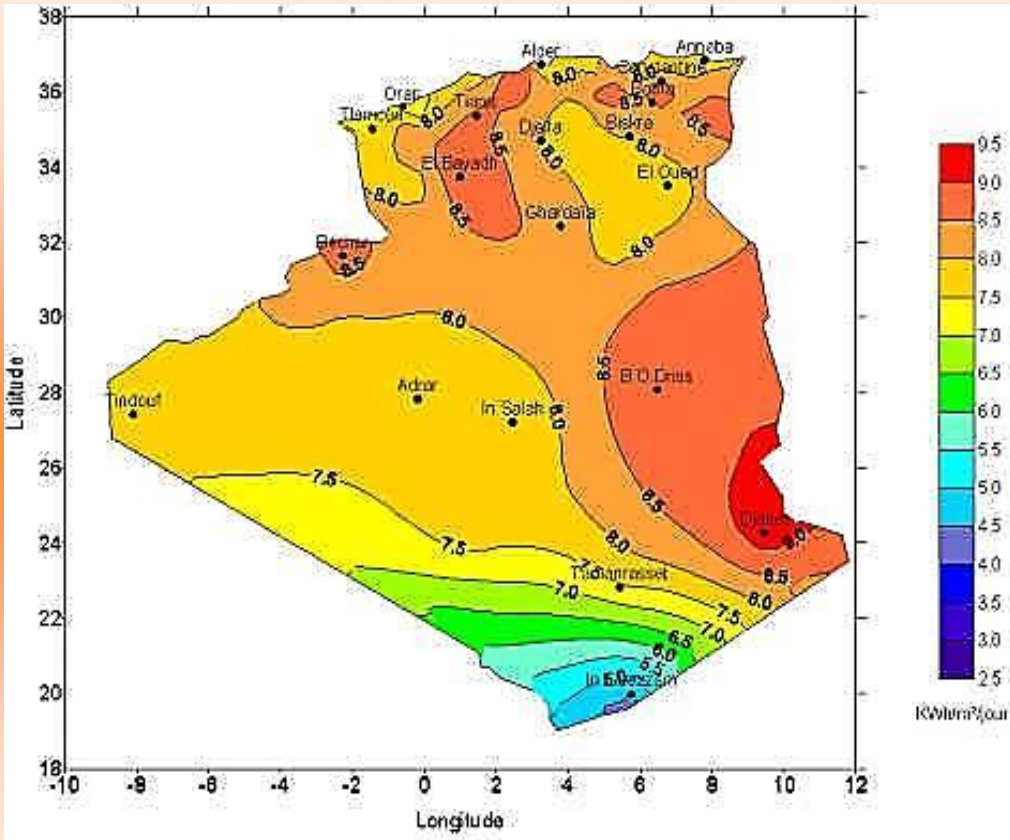

Figure I.12:Map of irradiation in Algeria (month of July)

I.4.2 Wind potential

Wind potentials diverge depending on the geographical location. Thus, in northern Algeria, the wind potential is characterized by a moderate average wind speed (1 to 4/s) with small

climates around the cities of Oran, Annaba, in the highlands and also in Biskra. This energy potential is well suited to pumping water, especially at higher altitudes. In the south, the average wind speed exceeds 4m/s, especially in the southwest, with winds exceeding 6m/s in the Adrar region

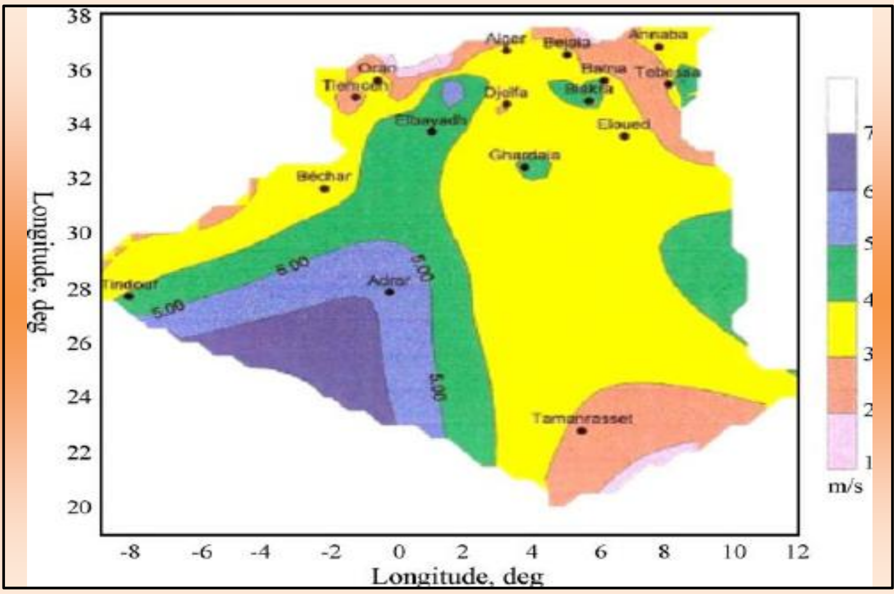

Figure I.2:Wind map n Algeria

I.4.3 Geothermal energies

The Saharan regions of Algeria are among the most promising sites for the exploitation of geothermal energy, due to their favourable geological and thermal characteristics. Studies have revealed the presence of high-temperature geothermal springs in several desert areas, including Biskra, where temperatures can reach up to 118°C, making this region one of the hottest spots with high geothermal potential.

Other regions such as Ouargla, Béchar and El Menia also show strong indications of high thermal gradients, sometimes exceeding 5 °C per 100 meters. These areas are of strategic importance due to their large spaces and low population density, which facilitates drilling and exploitation operations with minimal environmental impact. The use of geothermal energy in these regions provides a sustainable and clean source of energy, for example for electricity generation or for heating and cooling applications in the industrial and agricultural sectors. This is part of Algeria's strategy to diversify its energy sources and reduce its dependence.

I.5. Comparative table of energy sources:

Criterion	Solar ☀	Aeolian 🌬	Hybrid ♻
Available Resource	Very strong	Variable	Optimal
Installation cost	Moderate	High	Higher
Maintenance	Average	Complex	Average
Production continuity	Not	Variable	Yes
Ideal for desert areas	Yes	Depending on the wind	Recommended

Table I.1: Choice of the type of energy source (solar, wind, hybrid)

I.6. Conclusion:

Desert areas, although faced with extreme conditions, represent a favourable terrain for the exploitation of renewable energies, in particular solar energy thanks to exceptional sunshine. Among the available sources, photovoltaic energy is the most suitable, both technically and economically. However, energy diversification through the integration of hybrid systems (solar-diesel), the development of microgrids, as well as the improvement of storage technologies, are essential to ensure a sustainable and reliable energy supply in these remote regions. In this to fossil fuels.

Chapter II : Study and design of an electrical power source for desert areas

II.1 Introduction

Desert areas are characterized by extreme climatic conditions, low population density and limited access to basic infrastructure, including energy. The absence or inadequacy of a reliable power supply is a major obstacle to the socio-economic development of these regions. However, these areas benefit from strong sunlight, which makes them ideal candidates for the exploitation of renewable energies, especially solar energy.

The aim of this chapter is to analyse the typical energy needs of desert areas and to propose a suitable, sustainable and autonomous solution for electricity production. The study will focus on the available technologies, the specific constraints of the desert environment and the design criteria for an efficient energy system. Emphasis will be placed on the use of local resources, ease of maintenance and the resilience of systems to harsh climatic conditions.

II.2 Environmental and technical specificities of desert areas

II.2.1 Environmental specificities

1. **Temperature extremes**: Desert areas experience significant temperature variations, with temperatures often exceeding 45–50 °C during the day and dropping sharply at night.
2. **Rare precipitation**: Less than 250 mm of rain per year, sometimes none for several years.
3. **Sandy and poor soil**: Low organic matter content, very permeable, prone to wind erosion.
4. **Sparse vegetation**: Composed mainly of xerophilous (drought-tolerant) plants.
5. **Wind and dune movement**: Strong winds cause sandstorms and constant dune movement.
6. **Limited water resources**: Groundwater is deep, often salty, and difficult to access.

II.2.2 Technical specifications

1. **Extreme climate design**: Use of heat-insulating materials, natural ventilation, sand protection.
2. **Infrastructure that is resistant to the elements**: Roads, homes and networks must withstand sandstorms, abrasion and temperature variations.
3. **Harnessing solar energy**: Very strong sunlight (up to 3500 h/year), ideal for solar projects.
4. **Water management**: Techniques such as desalination, deep drilling and water harvesting are essential.
5. **Difficult to transport** : Tracks can be buried under sand, requiring regular maintenance.

Figure II.01 : Spécificités environnementales et techniques des zones désertiques

II.3. Choice of type of energy source (solar, wind, hybrid)

The choice of the type of energy source in desert regions is a strategic choice, depending on the available natural resources and local energy needs. Three types of sources are generally considered :

II.3. 1 Solar energy

II.3.1.1 Advantages: Very high sunshine (more than 3000 h/year), low maintenance cost, easy to install in remote areas.

II.3. 1.2 Disadvantages: Dust accumulation, production interrupted at night, need for battery storage.

II.3.2 Wind energy

II.3. 2.1 Advantages: Possible operation at night, complementarity with solar energy.

II.3. 2.2 Cons: Wind variability, more complex maintenance, higher installation costs.

II.3.3 Hybrid system (solar + wind + storage)

II.3. 3.1 Advantages : Continuous production, better stability, optimal solution for remote villages.

II.3. 3.2 Cons: High upfront cost, more complex technical management.

➤**Recommendation** : In desert areas, the hybrid system is the most reliable, ensuring stable production thanks to the complementarity of solar and wind resources.

II.4 Sizing of the energy system

The dimensioning of an energy system is a fundamental step in the design of renewable energy installations. It aims to ensure a balance between energy demand and production capacity, while ensuring optimal efficiency in terms of cost and performance. This is especially crucial in remote or desert areas, where access to the national electricity grid is often non-existent or difficult [9].

The sizing process is based on several parameters: the nature of the system (solar, wind, hybrid), the local resources available, the consumption profile, and the climatic conditions. It requires accurate collection of load data, estimation of energy requirements, and proper selection of system components [10] .

II.4.1 Estimating energy demand

This step consists of identifying all the electrical equipment on the site (lighting, pumps, refrigerators, etc.), noting the nominal power (in watts) and the daily duration of use (in hours). The daily energy consumption is then calculated according to the formula:

$$E_J = \sum (t_i \times P_i) \quad \text{(II 1)}$$

where:

- P_i: Power of the device *i* (en W),
- t_i : Daily use time (en h).

It is recommended to add a safety margin (between 20 and 30%) to compensate for losses in the system (cables, converters, batteries) [11]

II.4.2 Selecting System Components

II.4.2.1 Photovoltaic (PV) panels

The total power required for the solar panels depends on the daily energy consumption and the average solar irradiation of the site. An approximation can be expressed by:

$$P_{PV} = \frac{E_J \times 1.3}{H_{solaire}} \quad \text{(II 2)}$$

where:

- H_{solar} : average daily solar irradiation (kWh/m²/jour),
- 1.3 : Loss Factor (**Université de Perpignan, 2019**).

II.4.2.2 Batteries de stockage

The batteries ensure continuity of power in the absence of sunlight. Their capacity is calculated according to:

$$C = \frac{E_{autonomie}}{V \times DOD} \quad \text{(II 3)}$$

où :

- C : Ampere-hour capacity (Ah),
- V : System voltage (12 V, 24 V...),
- DoD : depth of discharge (usually between 0.5 et 0.8).

II.4.2.3 Inverter

The inverter converts the direct current (DC) produced by the panels or batteries into alternating current (AC). It must be chosen according to :

- la puissance totale en AC requise,
- la nature des charges (résistives ou inductives),
- la capacité à supporter les pics de puissance lors des démarrages.

II.5. Electrical Source Modeling

Electrical modeling of the source is an essential step in the analysis of the energy behavior of a system based on renewable energies. It aims to represent the source (such as a photovoltaic panel) using an equivalent electrical model to simulate its operation under different climatic and load conditions (**Université de Boumerdès, 2020**).

In the case of a photovoltaic source, the one-diode model is generally adopted, which incorporates the main electrical characteristics of the panel such as:

$$I = I_{ph} - I_0\left[exp\left(\frac{V_s + I \times R}{V_t}\right) - 1\right] \quad \text{(II 4)}$$

- I_{sc} : the short-circuit current,
- V_{oc} : the open-circuit voltage,
- R_s : the series resistor ,
- R_{sh} : parallel resistance,
- I_0 : the saturation current of the junction .

The equation of the current-voltage characteristic of the PV module can be formulated as follows:

where :

$$I = I_0\left(e^{\frac{V}{V_t \times n}} - 1\right) - I_{ph} \quad \text{(II 5)}$$

- I : output current (A),
- V : voltage across the module (V),
- I_{ph} : courant photo-généré (A),
- n : quality factor (usually between 1 and 2),
- V_t : thermal tension.

This model allows to accurately simulate the behavior of the PV generator in a real environment, taking into account internal losses and temperature and irradiance conditions [12].

II.6 Energy storage systems (batteries, supercapacitors)

Energy storage systems play a fundamental role in renewable energy installations, especially in isolated environments where the availability of the primary source (such as the sun or wind) is intermittent. These systems help to ensure a balance between production and consumption, by storing excess energy for deferred use [13].

II.6.1 The most common technologies are:

II.6.1.1 Electrochemical batteries

Mainly lead-acid or lithium-ion. They offer a suitable energy density and wide commercial availability. Their modeling includes parameters such as capacitance (Ah), depth of discharge (DoD), charging efficiency, and lifetime.

II.6.1.2 Supercapacitors

Although they have a low energy density, they are distinguished by their high power, very short charge/discharge time, and exceptional service life. They are often used in addition to batteries to absorb fast charging peaks.

The choice between batteries and supercapacitors therefore depends on the application, the charging profile, the energy management strategy, as well as the economic and climatic constraints (**Université de Biskra, 2021**).

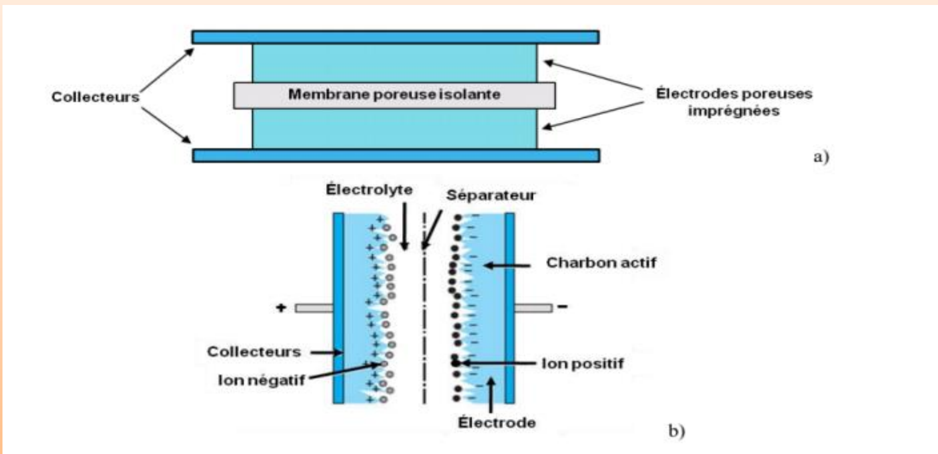

***Figure II .02 :* Constituyion of a super capacitor**

II.7. Control and regulation systems

Control and regulation systems play a fundamental role in optimizing the performance of a hybrid energy system.

They not only ensure the stability of the system but also enable the intelligent management of energy flow between different sources (photovoltaic, battery, supercapacitor) and loads [14] .

In the case of a standalone solar system, the MPPT (Maximum Power Point Tracking) controller is essential to extract the maximum power from the photovoltaic generator according to variations in solar irradiation and temperature. The most commonly used method is Perturb and Observe (P&O) due to its simplicity of implementation and real-time efficiency.

A DC/DC voltage regulator is then integrated to match the voltage from the panel to that of the battery or load, while also providing protection against overvoltage and overcurrent. Moreover, an Energy Management System (EMS) is often used to decide, in real time, the optimal operating mode—charging, discharging, or standby—based on demand and state of charge.

Finally, for systems that include DC/AC converters (inverters), Field Oriented Control (FOC) or Sinusoidal Pulse Width Modulation (SPWM) is frequently employed to ensure a stable sinusoidal output suitable for AC loads.

The integration of these control strategies into a simulation environment such as MATLAB/Simulink allows for testing various control logics and predicting the overall performance of the system [15].

II.8. System simulation using MATLAB/Simulink

Numerical simulation is a crucial step in validating an autonomous energy system designed for desert environments. It enables the assessment of overall system performance, the prediction of potential failures, and the optimization of energy management strategies [16]

In this study, **MATLAB/Simulink** was used to model and simulate the various components of the system, including:

- **The photovoltaic generator (PV)**, modeled using the current-voltage (I-V) equation under variable irradiance and temperature conditions;
- **The DC/DC converter**, equipped with an **MPPT algorithm (Perturb & Observe)** to track the maximum power point;
- **The energy storage system** (batteries and/or supercapacitors), used to store surplus energy or supply it during deficits;

- **The DC/AC inverter**, which converts the DC power into AC to supply variable loads;
- **A variable load profile**, simulating realistic energy consumption throughout the day.

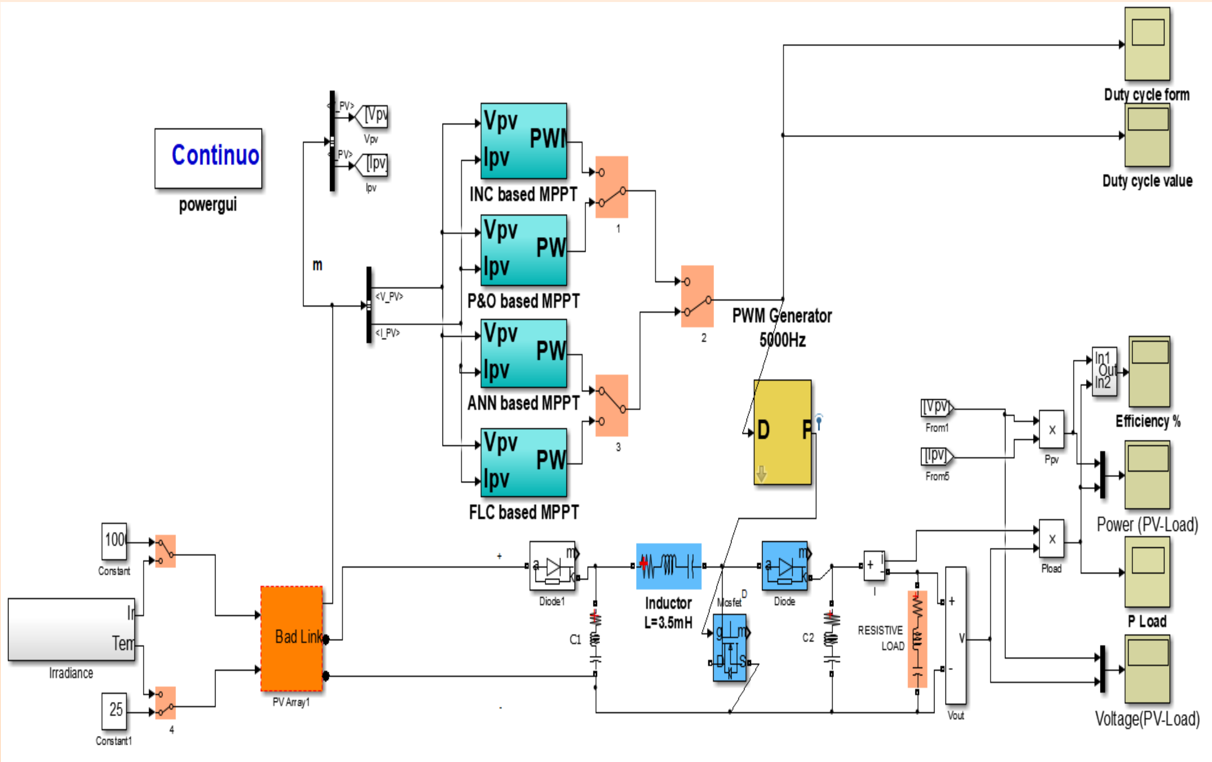

Figure II.03 : Block diagram of the hybrid photovoltaic energy system simulated under MATLAB/Simulink

The simulated model in Simulink is illustrated in the following schematic :Simulation: results demonstrated the system's ability to provide stable output, regulate voltage, monitor the battery state of charge (SOC), and maintain the DC bus voltage within acceptable limits. These results provide a solid reference for the next phase, where intelligent control strategies based on artificial intelligence will be implemented to enhance system performance.

II.9 Conclusion:

In this chapter, the technical and environmental aspects specific to desert areas, which pose unique challenge for designing electrical energy sources, were addressed. By studying and analyzing the characteristics of these regions, the most suitable system (solar, wind, or hybrid) was selected, and its sizing was determined based on an accurate estimation of energy demand. We also covered the selection of key system components such as solar panels, batteries, and inverters, along with the electrical modeling and the design of energy storage and control systems necessary to ensure energy continuity and efficiency.

Although this design provides a sustainable and appropriate energy solution for desert conditions, ongoing challenges related to environmental variability, load fluctuations, and the need to maintain high system efficiency highlight the necessity for more advanced and intelligent solutions.

Therefore, Chapter Three represents a progressive step towards the design of autonomous solar energy systems relying on artificial intelligence. This approach enables intelligent monitoring and analysis of system performance, as well as optimal control of operation and maintenance. The use of AI techniques significantly contributes to enhancing reliability, reducing operational costs, and adapting to the complex environmental changes characteristic of desert areas.

Consequently, the next chapter will explore the **"Intelligent Design and Optimal Monitoring of an Autonomous Solar System for Desert Areas Using Artificial Intelligence,"** combining advances in energy engineering with state-of-the-art AI technologies to achieve a fully integrated and sustainable energy system.

CHAPTER III: SIMULATION OF AUTONOMOUS PHOTOVOLTAIC SYSTEMS IN DESERT AREAS USING ARTIFICIAL INTELLIGENCE VIA NEURAL NETWORK–BASED MPPT CONTROL

III.1 Introduction:

In desert environments, solar irradiation is abundant, making solar energy a highly promising resource. However, extreme climatic conditions and rapid temperature fluctuations present significant challenges for the efficient operation of autonomous solar systems. To overcome these issues, this chapter focuses on the intelligent design and optimal monitoring of an autonomous solar system that integrates advanced Maximum Power Point Tracking (MPPT) techniques along with artificial intelligence (AI) algorithms.

The use of AI enables the system to dynamically adapt to changing environmental conditions, optimize energy harvesting, and improve overall system reliability. Such smart systems can predict and respond to variations in solar irradiance, temperature, dust accumulation, and other desert-specific factors, thereby enhancing performance and extending the lifespan of the equipment [17] [18].

This chapter will also present the design of the solar modules, initial sizing of components such as batteries and inverters, and the overall system architecture. Furthermore, it will analyze climatic variables relevant to desert regions, which serve as inputs to predictive models critical for intelligent system operation.

III.2 Description of the Proposed Autonomous Solar System

III.2.1 Selection of PV Modules Suitable for Desert Environments

In desert regions, solar panels must be capable of withstanding extreme temperatures, intense solar radiation, and airborne dust. Mon crystalline PV modules are generally preferred due to their higher efficiency and reliability in hot and harsh climates. These modules should also be equipped with anti-reflective coatings and corrosion-resistant frames to improve durability in sandy environments [19]

III.2.2 Initial System Sizing (Panels, Batteries, Inverter)

The sizing process starts with estimating the daily energy demand and matching it with solar availability in the region. The number of panels is determined based on solar irradiance and load requirements. Battery capacity is calculated to store excess energy for use at night or during cloudy days. An inverter is selected based on the overall power demand, converting DC power to AC for local usage [20].

III.2.3 Overall Architecture of the Solar System

The system is composed of interconnected photovoltaic panels (series and/or parallel), an MPPT charge controller to maximize output, batteries for energy storage (e.g., lithium-ion or AGM), and an inverter. Additionally, environmental sensors monitor solar radiation, temperature, and dust levels. An intelligent control unit powered by artificial intelligence ensures adaptive optimization and predictive maintenance under variable desert conditions

III.3 Choosing the right photovoltaic modules for the desert

Desert regions pose significant challenges for photovoltaic (PV) systems due to high ambient temperatures, dust accumulation, and large diurnal temperature fluctuations. Selecting appropriate PV modules for such harsh environments is essential to ensure reliable and efficient energy production.[21]

One of the key parameters in module selection is the **temperature coefficient of power**, which should be low (preferably below -0.35%/°C) to minimize performance loss under high temperatures. High-efficiency **monocrystalline technologies** such as PERC, TOPC on, and Heterojunction (HJT) are often recommended for their superior performance and thermal stability in hot climates

Another critical aspect is the **dust and sand resistance** of the modules. Anti-soiling coatings on the glass surface can significantly reduce dust accumulation, improving energy yield and reducing cleaning frequency. Modules installed in desert conditions should also feature a **durable frame** with high mechanical resistance and comply with certifications such as **IEC 61215** for environmental reliability and **IEC 61701** for corrosion resistance due to humidity and salt mist exposure.[22]

Furthermore, it is advisable to choose modules with a low **Nominal Operating Cell Temperature (NOCT)**—ideally below 45°C—to maintain high performance throughout the day. Modules with power ratings above 450W are preferred to maximize area efficiency and reduce the number of panels needed for a given capacity.[23][24]

III.4 Simulation of the photovoltaic system:

Figure (17) shows the Matlab Simulink diagram of a photovoltaic system with MPPT control (P&O), composed of a PV module and an MPPT controlled chopper that has pinpointed the output voltage and current of the module.

Characteristic	Specification
Number of cells (Ns)	36
Maximum power, Pmax	60 W
Voltage at Pmax, Vmpp	17.1 V
Current at Pmax, Impp	3.5 A
Minimum guaranteed power	58 W
Short-circuit current, Isc	3.8 A
Open-circuit voltage, Voc	21.1 V
Temperature coefficient of Voc	-80±10Mv/°C
Temperature coefficient of Isc	0.065±0.015%/°C
Temperature coefficient of power	-0.5±0.05%°C

Table III.2: electrical characteristics of the MSX60 photovoltaic module

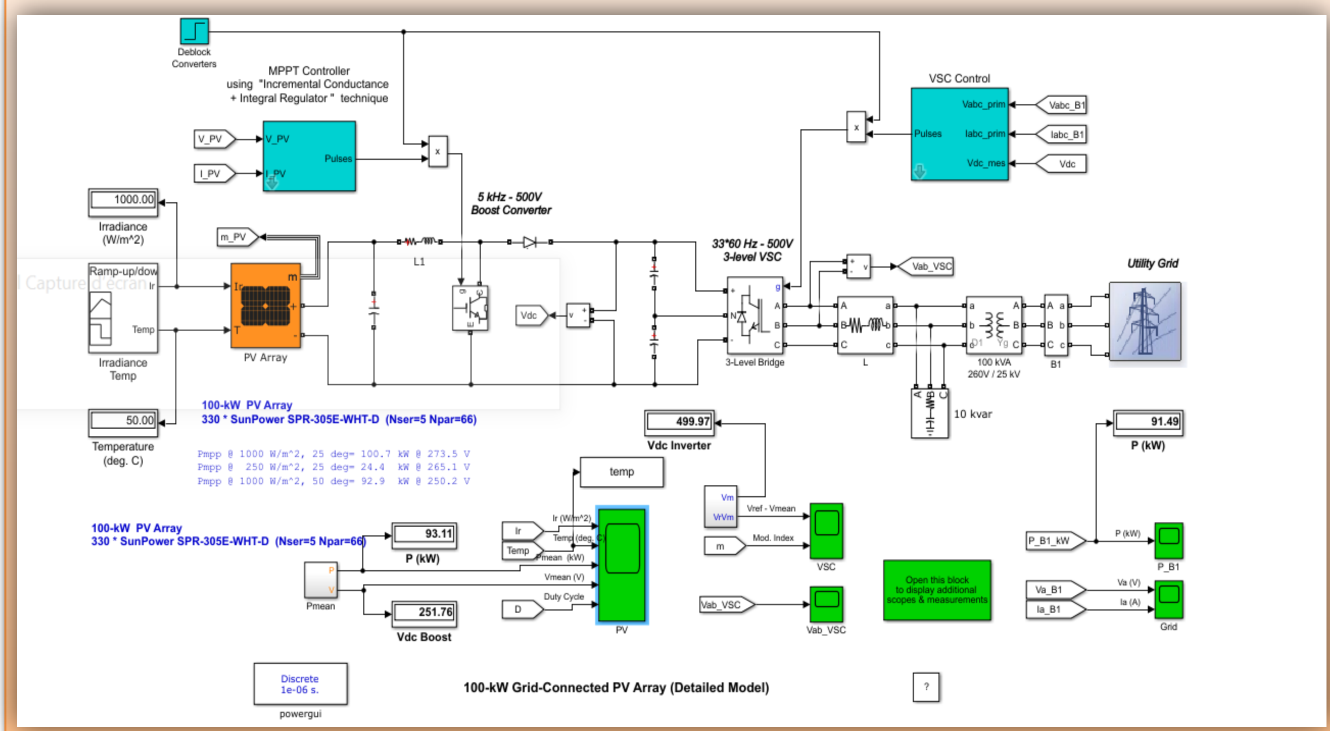

Figure III .01: Block diagram of a photovoltaic system adapted to the MPPT control

III.5 Electrical characteristics of photovoltaic modules:

There are several indicators to measure the performance of PV modules. The peak power (Wp) is one of the most significant indicators, it represents the maximum electrical power that the panel can provide under the standard measurement conditions, i.e. when it is connected to an optimal load, when the temperature at the junction of the cells is 25 °C and when it receives from the sun at a power of 1000W/m² (this corresponds approximately to a perpendicular exposure to the sun's rays at noon by clear weather).

The current-voltage characteristic **(I=f(V))** illustrates the variation of the output current as a function of the output voltage. It is also an important indicator for measuring the performance of PV modules. From this characteristic we can draw the power-voltage characteristic **(P=f(V)).**

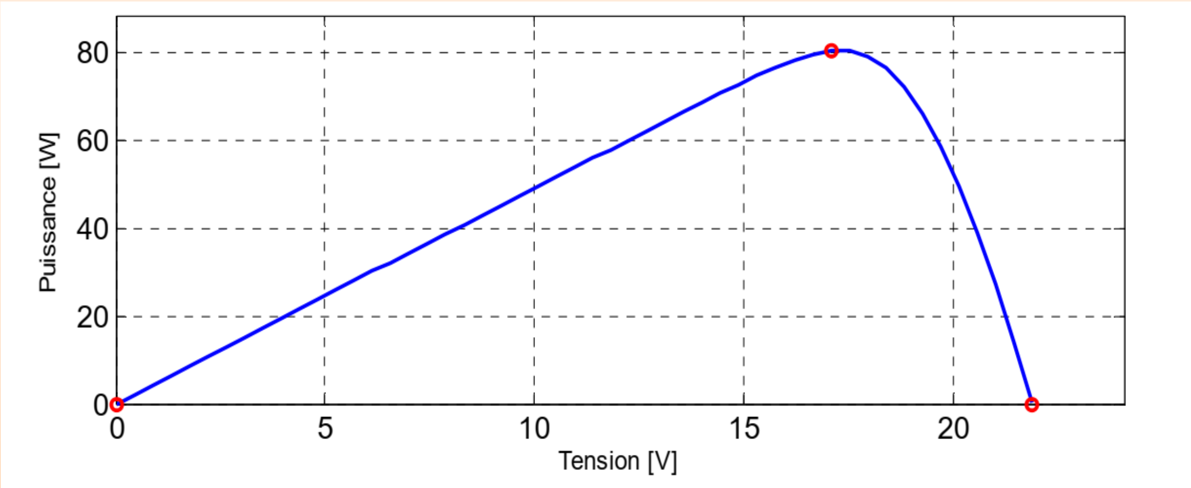

Figure III.02: Pace of the power as a function of the voltage at (T=25C° G=1000W/m²).

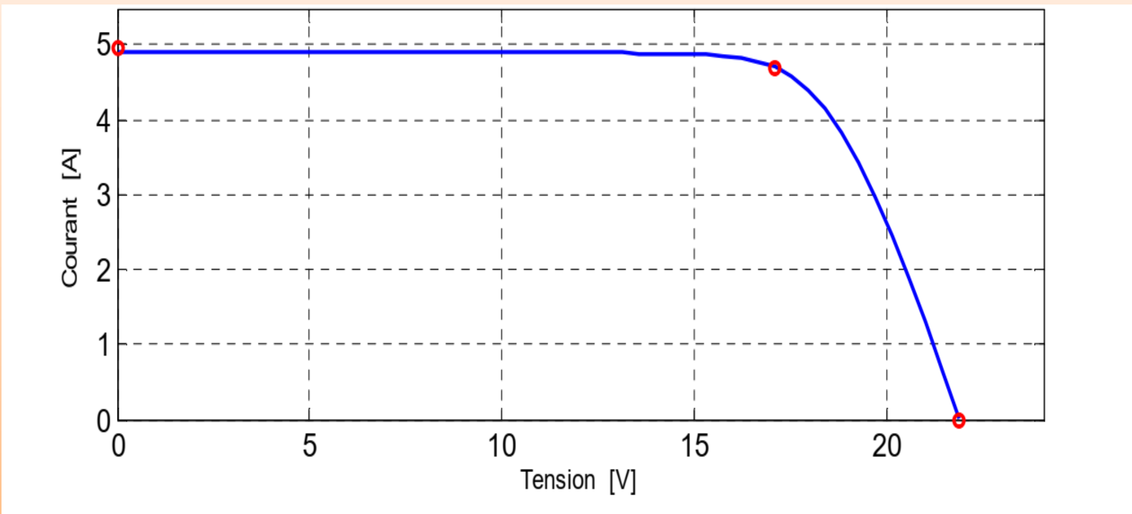

Figure III.03: Current rate as a function of voltage at (T=25C° G=1000W/m²).

III.6 Influence of illuminance and temperature on the electrical characteristics of GPV:

The electrical I–V and P–V behavior of a photovoltaic generator is highly sensitive to both irradiance and temperature, meaning that the PV current (Ipv) and voltage (Vpv) vary markedly when the irradiance G or the cell temperature T changes.

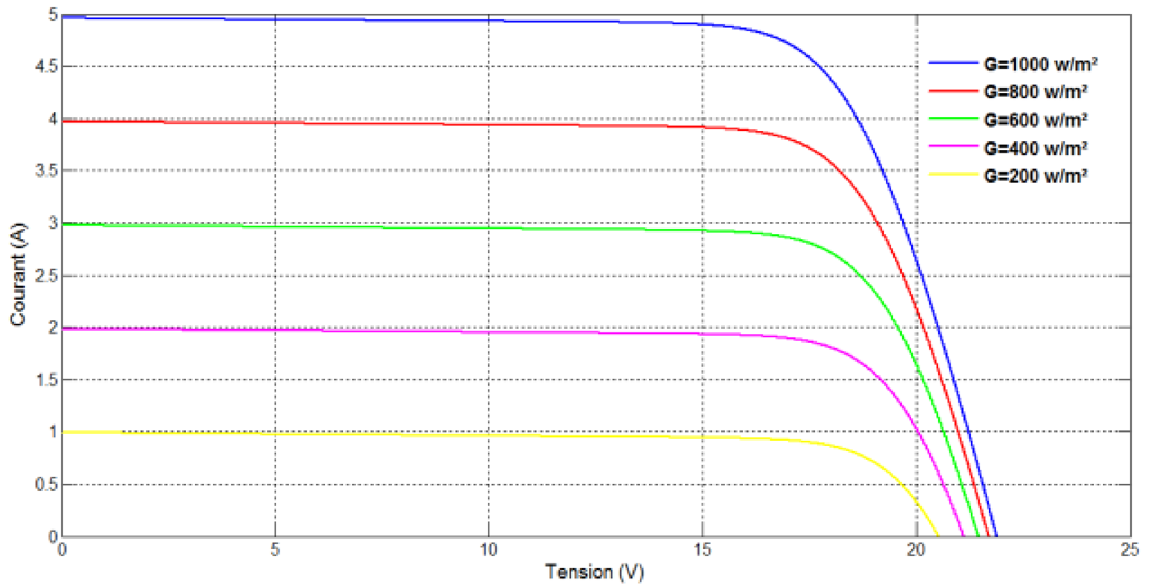

Figure III.04: Allure de la caractéristique I-V

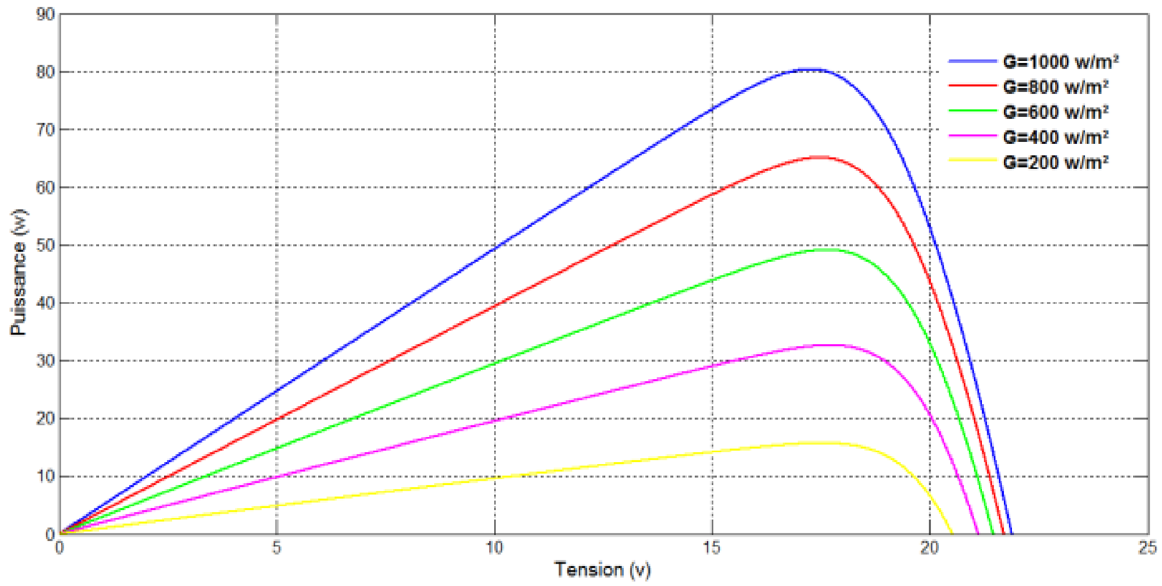

Figure III.05: Allure de la caractéristique P-V

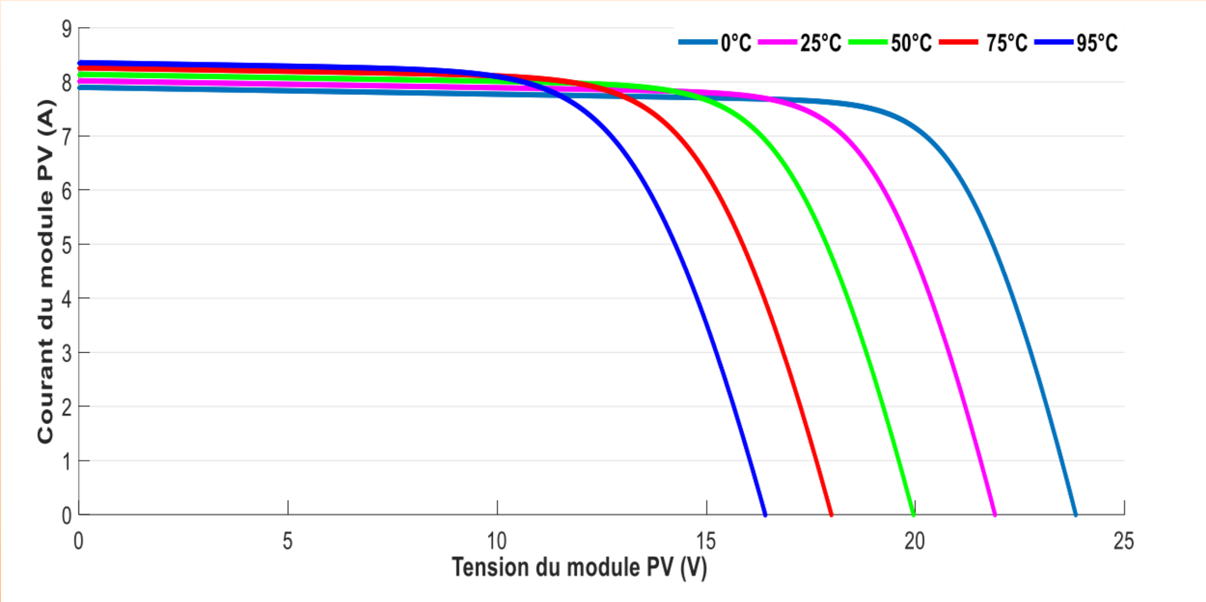

Figure III.06: Allure de la caractéristique I-V

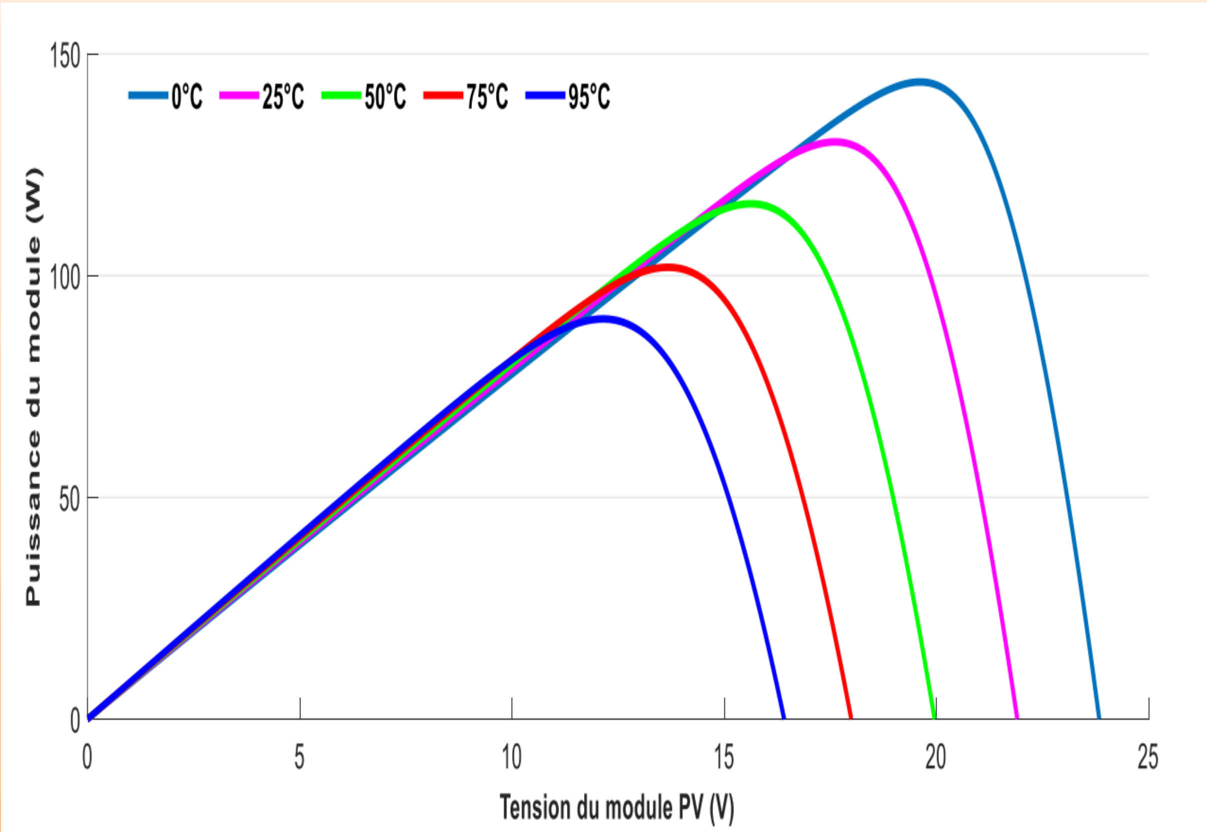

Figure III.07: Allure de la caractéristique P-V

- ✓ According to Figures (III.18) and (IV.19), it can be seen that the maximum voltage Vpp corresponding to the maximum power varies only slightly with the illumination, unlike the current Im which increases sharply with the illuminance.
- ✓ From Figures (IV.20) and (IV.21), it can be seen that the increase in temperature leads to a decrease in the open-circuit voltage, as well as a decrease in the maximum power.
- ✓ These figures clearly show the dependence of the output current I and the output voltage V on temperature and illumination and reflect a power dependence of these two parameters.
- ✓ The output power is considerably reduced for decreasing insolation.
- ✓ The output power is reduced by an increase in panel temperature.

III.7 Simulation of the MPPT (P&O) control:

Conventional ideal conditions are very rarely met in practice, and the variation of these conditions is random and unpredictable. The change in sunlight and temperature has a direct impact on the current-voltage and power-voltage characteristics. For this reason, the integration of an MPPT command is mandatory.

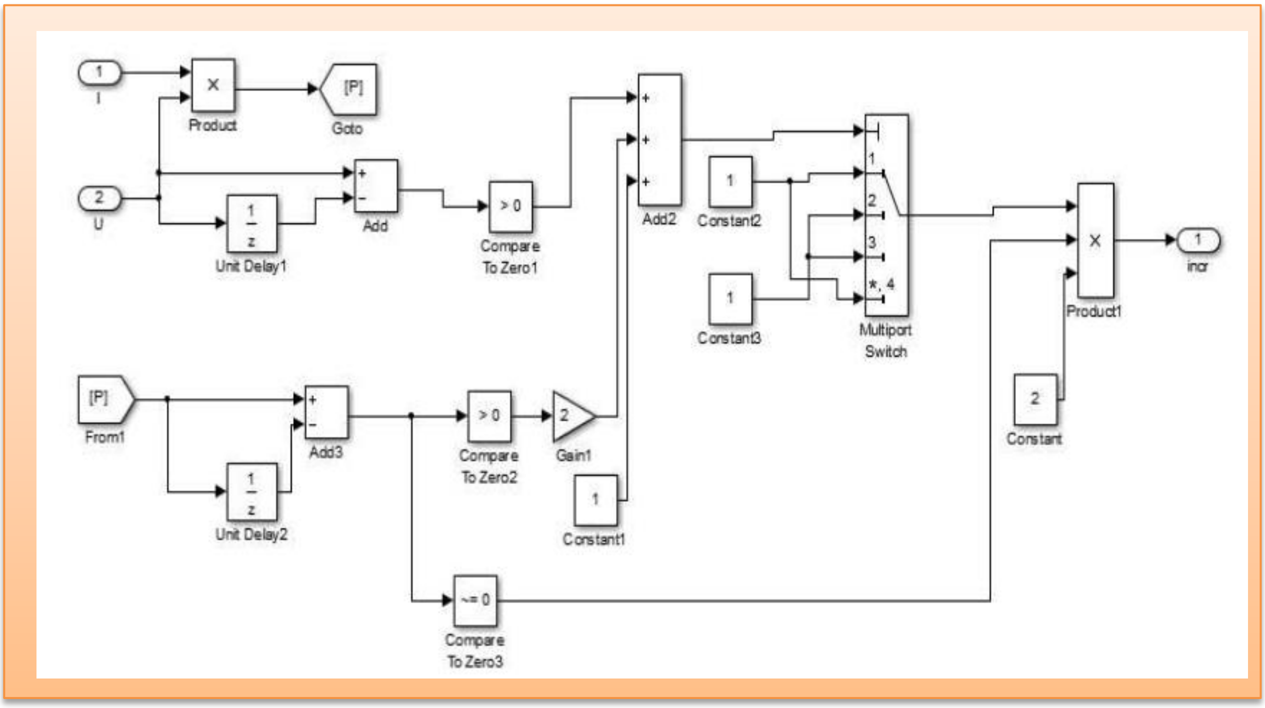

Figure III.08: Algorithm block schema (P&O)

The simulation results of the photovoltaic system adapted by the MPPT "disturbance and observation" command are shown in Figure (III.18) to (III.24). These figures represent the voltage, current and power generated by the photovoltaic array. Thus, the voltage, current and power at the output of the photovoltaic system.

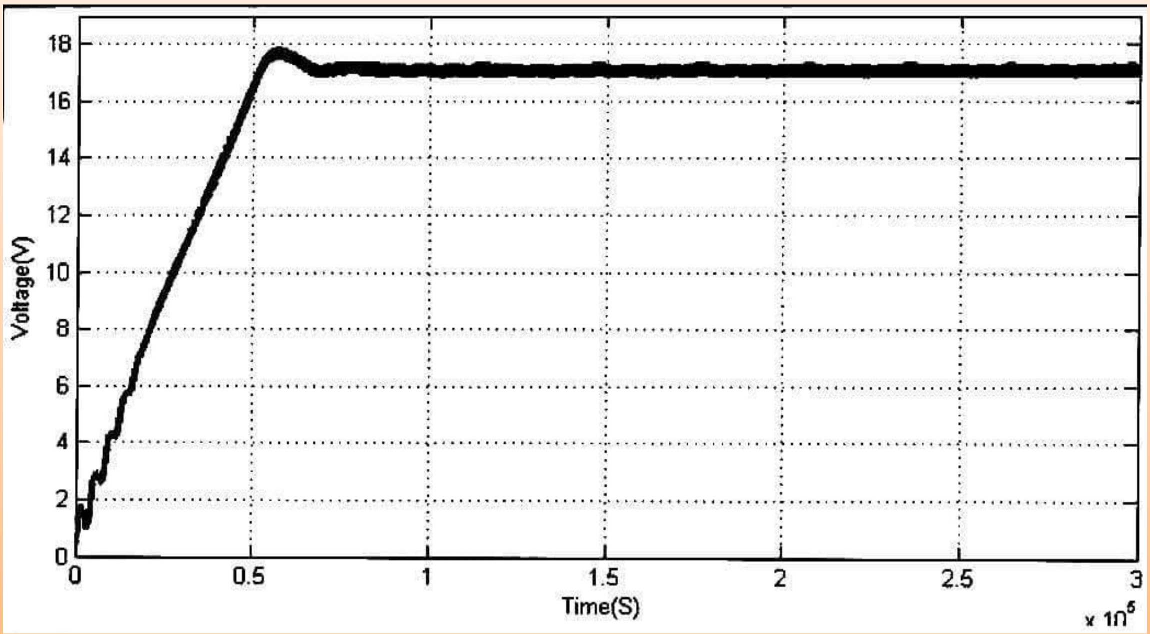

Figure III.09: Power as a function of time for (T=25°C, G=1000W/m²).

From Figure (III.25) it can be seen that the power takes a time of 0.7[S] in the transient regime, characterized by weak oscillations to stabilize at the maximum value [60W]. Permanent regime.

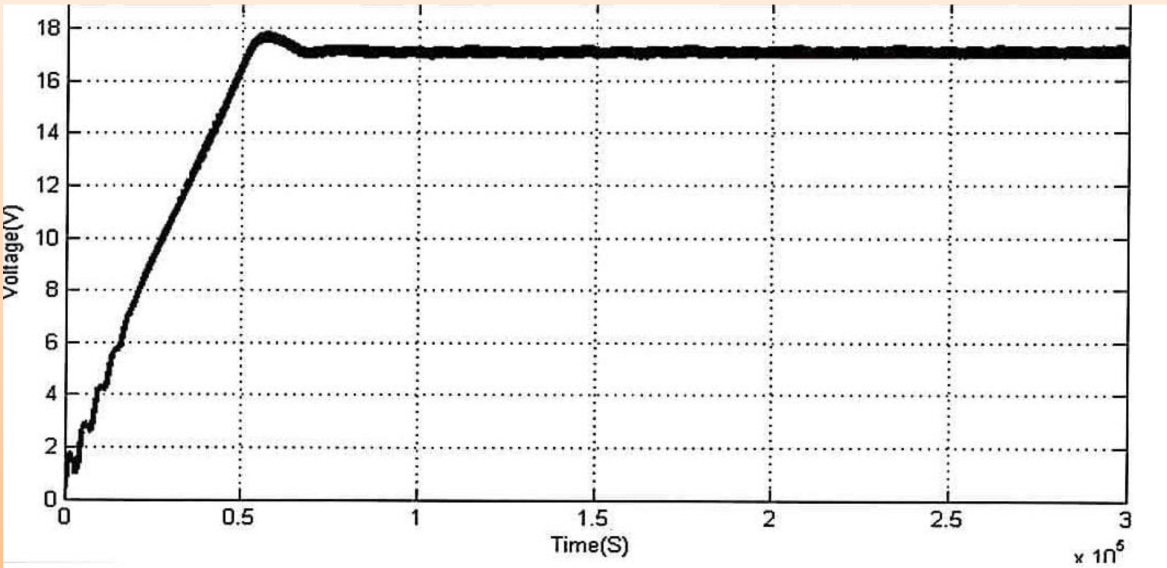

Figure III.10: Voltage as a function of time for (T=25°C, G=1000W/m²).

According to Figure (III.26**),** it can be seen that: the voltage passes through a transient regime lasts 0.7 [S], characterized by an increase up to the value 17.8 [V], then it stabilizes at the maximum value 17.1 [V], in the permanent regime.

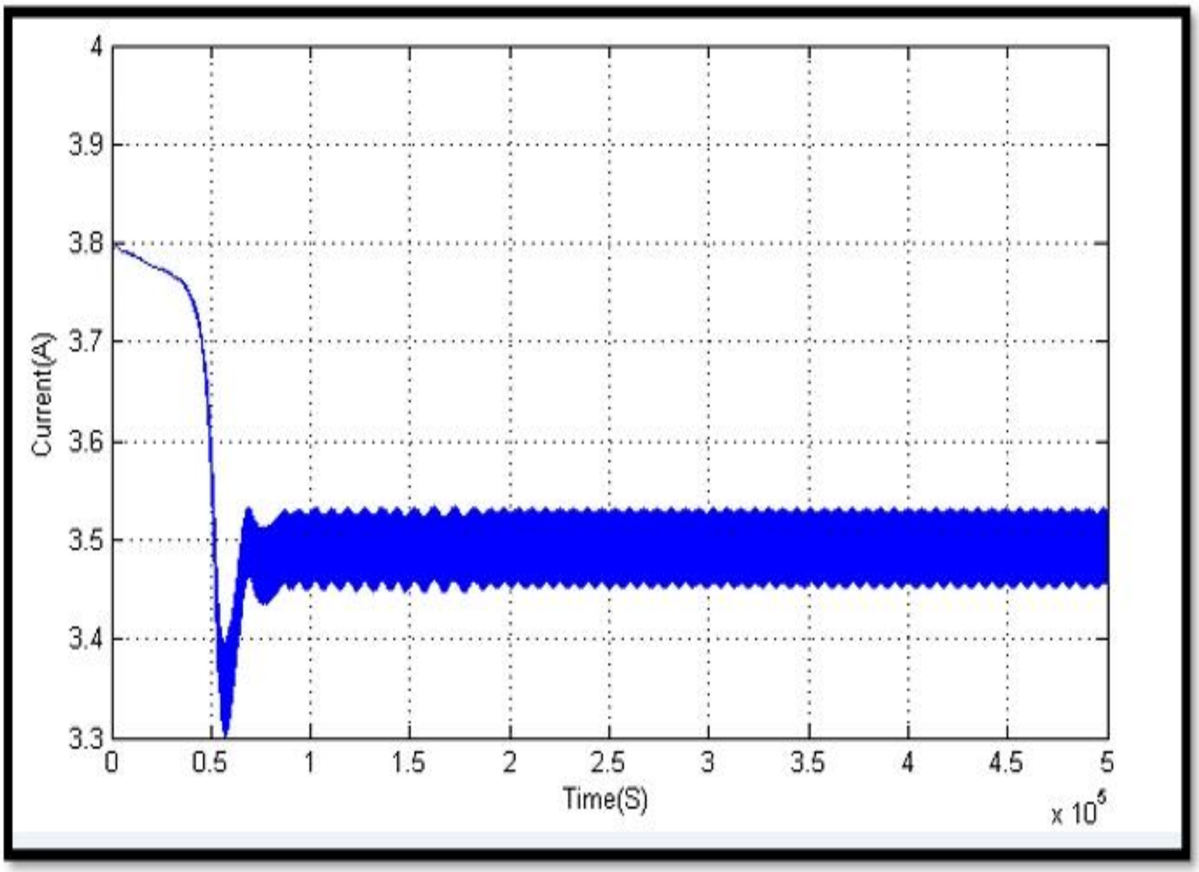

Figure III.11: Current as a function of time for (T=25°C, G=1000W/m²).

From Figure (III.27), it can be seen that during the period from [**0 to 0.7**] the current increases abruptly, then it decreases with significant oscillations, then it stabilizes at the maximum value 3.5 [A]

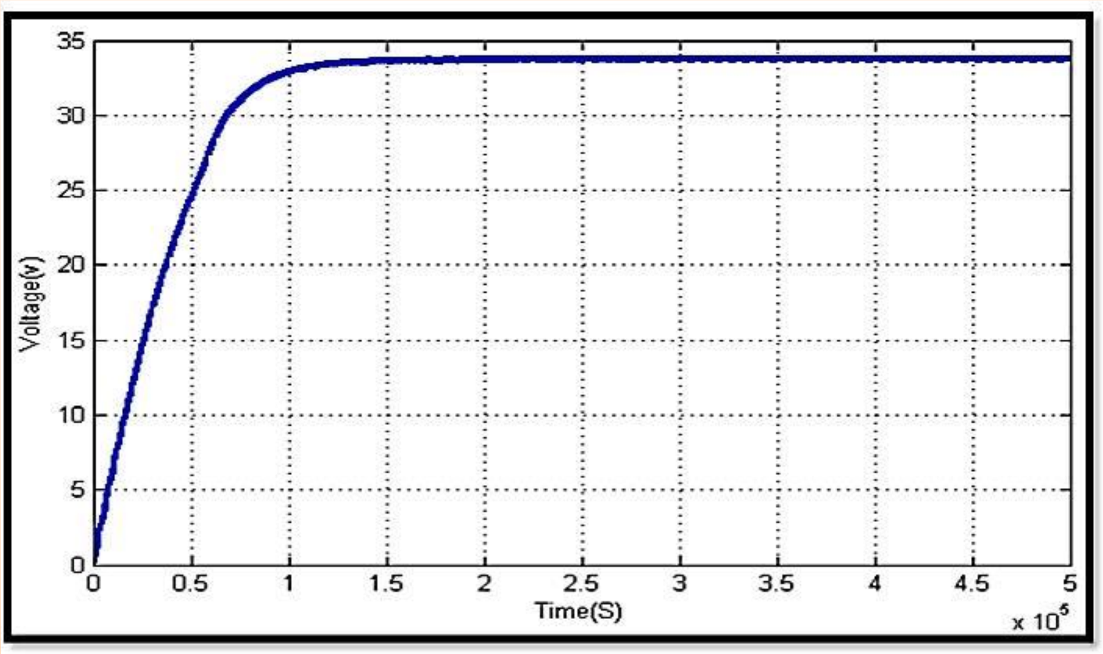

Figure III.12: Voltage at the output of the PV system (T=25°C, G=1000W/m²).

From Figure (III.28), it can be seen that the voltage at the output of the chopper is higher than the tension of the panel.

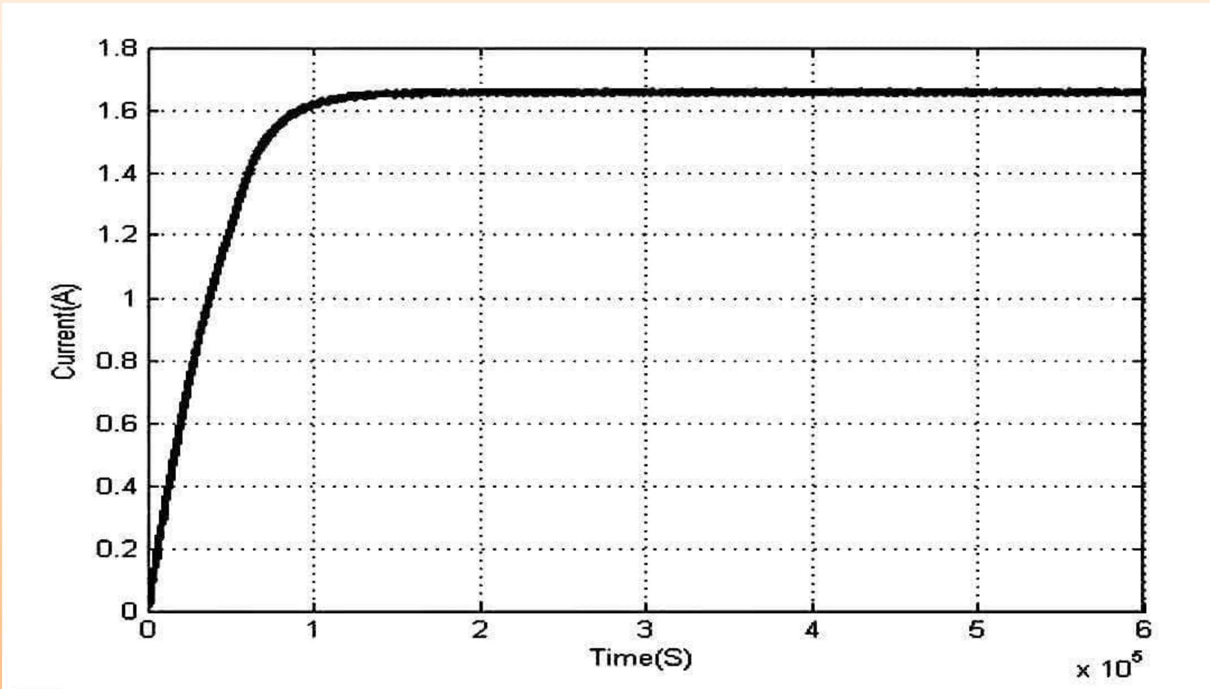

Figure III.13: Current speed at the output of the PV system (T=25°C, G=1000W/m²).

According to Figure (III.29), it can be seen that the current at the outlet of the chopper is less than the current of the panel.

III.8 Simulation of the neural network-based MPPT control:

The new technique chosen for the continuation of the maximum point is the neural method, which consists of three steps, we will apply them to approximate the output which is the duty cycle that corresponds to the maximum power, depending on the changes in illuminations and the temperature, where our system must be able to evolve, quickly and efficiently.

So to estimate MPPT we will use a perceptron neural network multilayers, whose role is to estimate the duty cycle which corresponds to the maximum power.

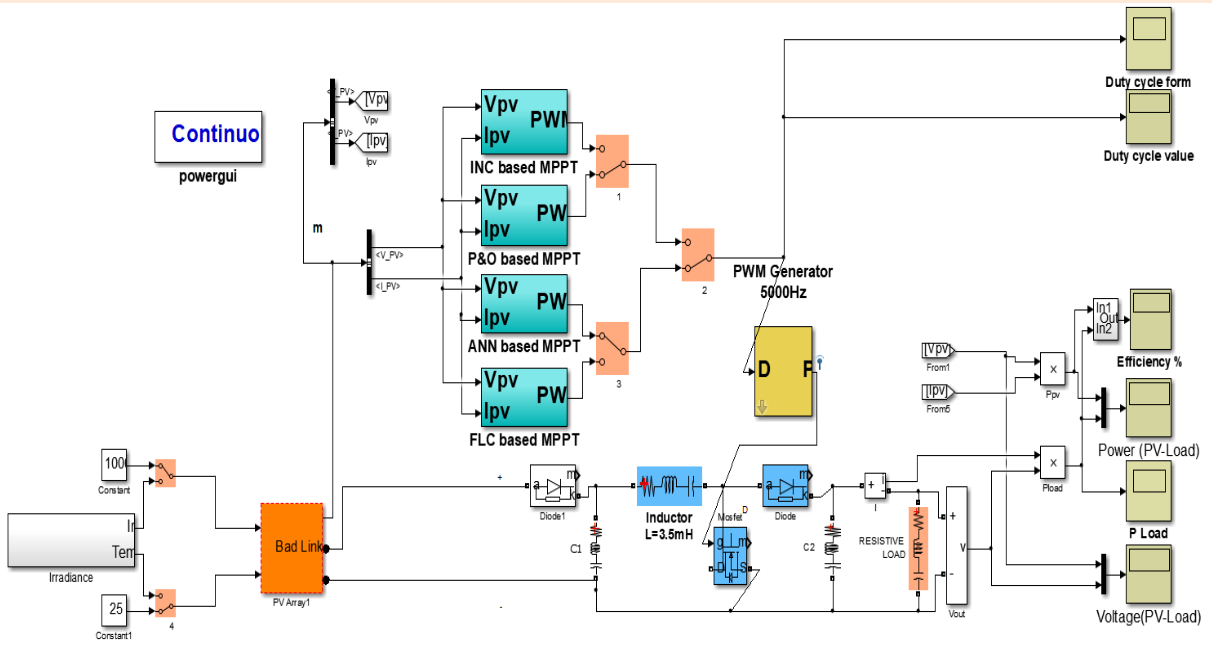

Figure III.14: Simulation of a Standalone PV System Using Multiple MPPT Algorithms Including Artificial Neural Networks (ANN)

III.8.1 Procedure for building a neural network:

1. The collection of a database.
2. The separation of the database into three subsets (training base, training database, validation and test base).
3. The choice of the neural network architecture (number of hidden layers, number of neurons

in these layers, etc.).

4. Data pre-processing.
5. Training of the neural network on the basis of learning and validation.
6. Measurement of neural network performance on the basis of testing.

The objective of this step is to gather a sufficient amount of data to build a representative database that will be used for training and testing the neural network, we exploited the simulation results obtained by the P&O method.

III.8.2 Choice of neural network architecture:

The first thing in the neural network implementation is the counting of the input and output variables of the problem. In this case we have a single input variable which is the maximum power as a function of illuminance (G) and temperature (T), and an output variable which is the duty cycle (D).

So the network that suits our need is the multilayer perceptron with:

- A hidden layer with a single neuron.
- A hidden layer has 10 neurons.
- An output layer has a single neuron.

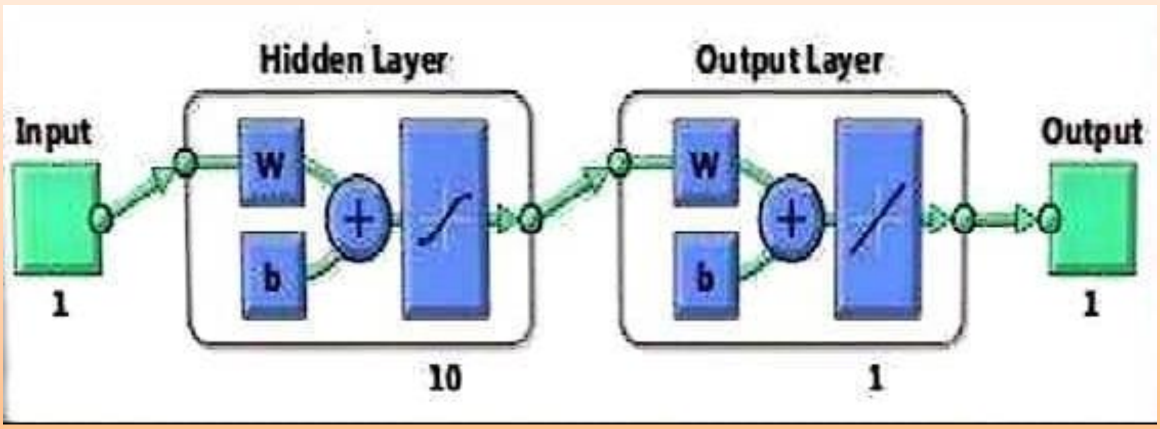

Figure III.15: architecture du RNN pour la commande MPPT

III.8.3 Comment développer le réseau neuronal artificiel :

Using the Matlab Neural Network Toolbox.

It is a hierarchical structure, The function of creating a network is specific to the network model used.

- ✓ **The new lvq (new learning vector quantization network) function**:
  to solve classification problems.
- ✓ **The wff (feed-forward back propagation network) function:**

to solve optimization problems.

There are other functions for creating a neural network (newlm, newcf, etc...), but since our problem is an optimization problem and our The structure of the network is hierarchical, the creation of the network is controlled by the NewFF function.

Network = newff (P, T, S, TF, BTF, BLF, PF, IPF, OPF, DDF);

P: input matrix (our case is the maximum power Pmpp). T: output matrix (our case is the duty cycle D).

S: number of neurons in the hidden layer (our case is a single hidden layer with 10 neurons).

TF: Enable function in layers, default is the function (tansig) for hidden layers, and the purelin function for the output layer.

BTF: network packet learning algorithm (default = trainlim). BLF: the network's incremental learning algorithm (default = learngdm). PE: Performance function (default = MSE main square error).

DDF: Deal division function, (default = dividend).

- ✓ **Network Test Result:**

Machine learning was performed using the Matlab software until a very small square error was obtained. (Figure III.32).

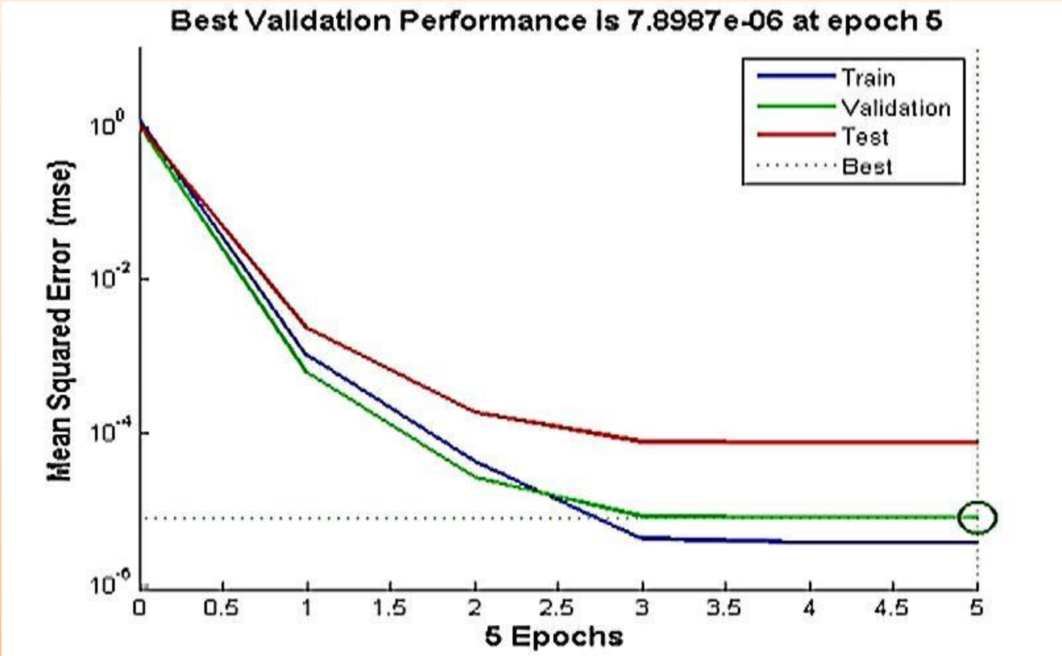

Figure III.16 : network learning outcome

Création du block Simulink

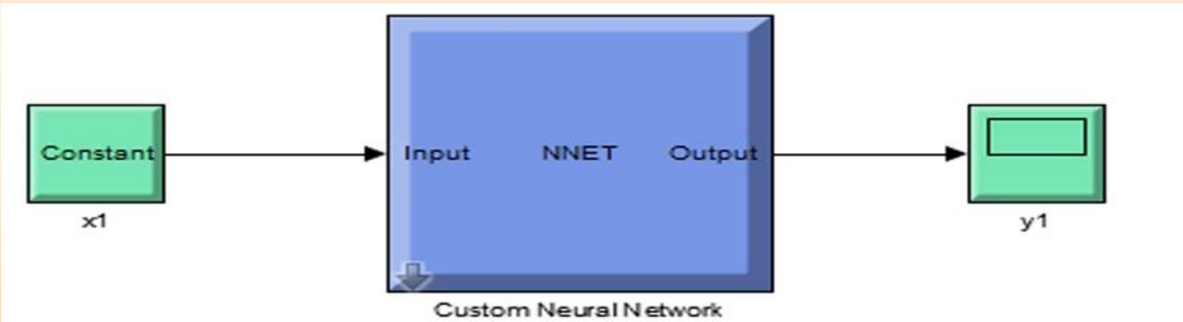

Figure III.17: schémaBloc du réseau de neurone artificielle dans SIMULIN

III.9 Simulation results:

III.9.1 Case: 01

We set the temperature at 25°C, and we set the illuminance to 900W/m², to see how the two systems will react.

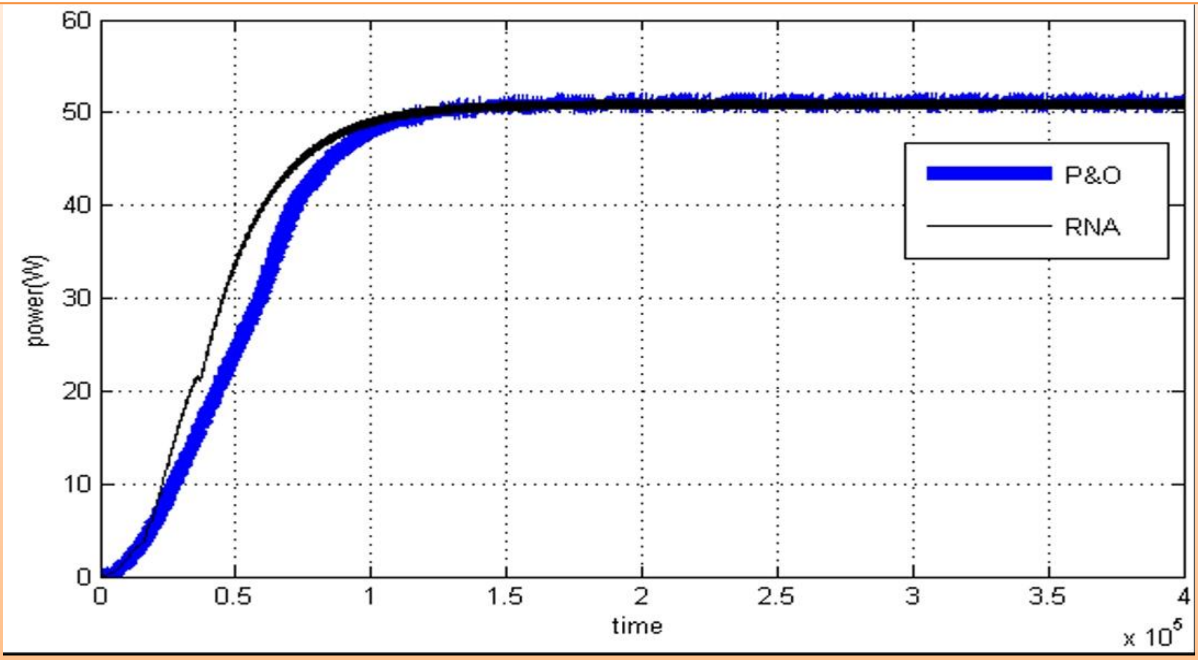

Figure III.18: Allure de la puissance en fonction du temps (T=25°C, G=900W/m²).

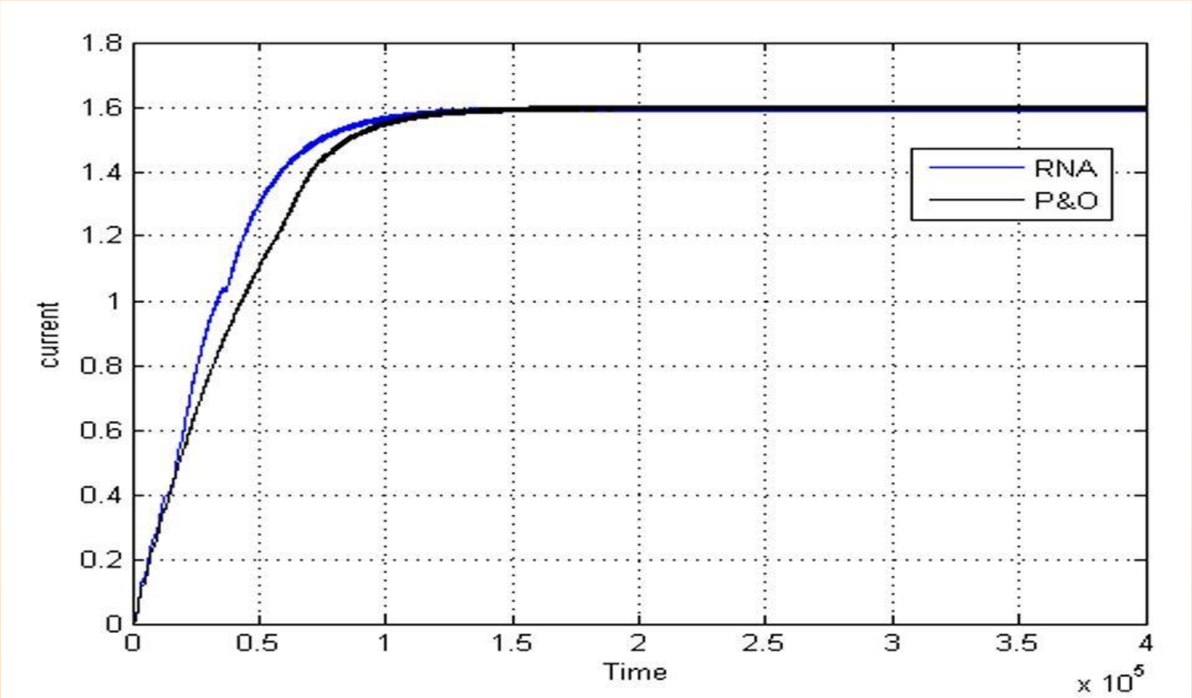

Figure III.19: Allure du courant en fonction du temps (T=25°C, G=900W/m²).

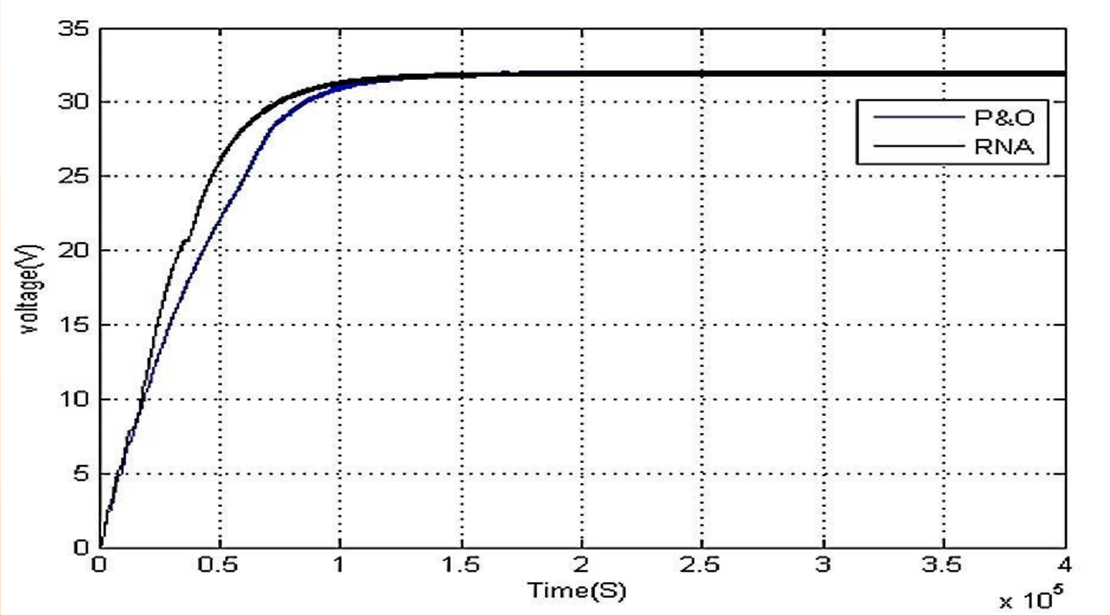

Figure III.20: Allure de la puissance en fonction du temps (T=25°C, G=900W/m²).

From the figures (III.34, III.35, III.36), it can be said that the MPPT system with neural network converges rapidly towards the maximum operating point compared to the MPPT system with P&O.

III.9.2 Case: 02

We set the temperature at 25°C, and we made a sudden change in the illumination between

[900 W/m², 0.900 W/m²], to see how the two systems will react.

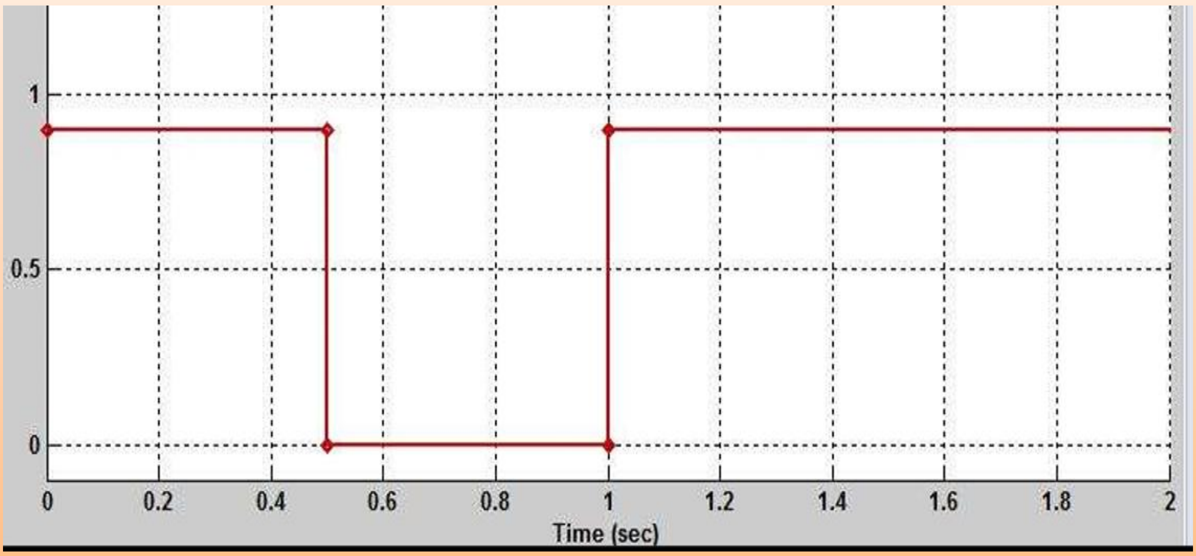

Figure III.21: Signale de l'éclairement à l'entrée du système PV

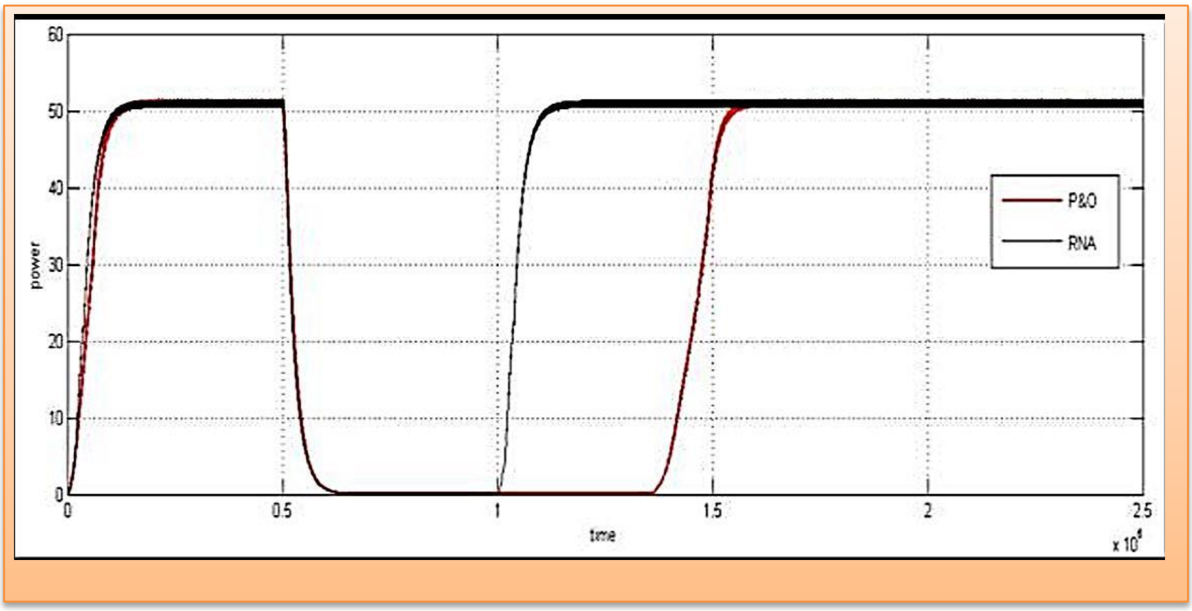

Figure III.22: Allure de la puissance en fonction du temps

According to Figure (III.38): the system with the MPPT (RNN) control, reacts more quickly (instantaneously) to the sudden change in illuminance, to stabilize at the value of the maximum power, compared to the system with the MPPT control (P&O), which takes an interesting time to stabilize at the maximum value of the power.

These results confirm the proper functioning of the P&O controller but also show that the better functioning of the neural controller. The latter has proven that he has Best performance, fast response time and very low steady-state error, and that it is robust to different variations in atmospheric conditions.

III.10 Conclusion:

In conclusion, the integration of artificial intelligence via neural networks into the MPPT algorithm demonstrates a high capability for maximum power point tracking under harsh desert conditions. Simulations in MATLAB/Simulink, which trained the neural model on irradiance and temperature inputs, achieved an average tracking efficiency of approximately 98 %–99 %, clearly outperforming conventional P&O and RNN algorithms. The results also exhibited excellent voltage and current stability around the optimal point—even during rapid irradiance fluctuations and elevated temperatures typical of desert environments—confirming the suitability of this approach for enhancing the output of autonomous photovoltaic systems.

Furthermore, incorporating detailed models of desert climatic variables (such as high temperatures and airborne dust) provided deeper insight into their impact on system performance, enabling the proactive design of effective cooling and cleaning strategies. Thus, this chapter offers concrete evidence of the practicality of AI-driven smart control for standalone PV systems and lays a solid foundation for future real-world implementation and real-time testing of the algorithm.

OVERALL CONCLUSION

Overall conclusion:

The results of this work indicate that the development of an autonomous electrical power system for desert areas requires an effective integration of precise engineering design, the selection of components suited to harsh environmental conditions, and the use of artificial intelligence tools to enhance control performance. Initially, a thorough analysis of suitable renewable energy sources revealed that solar energy is the most reliable option in desert environments due to the high availability of solar irradiance. Based on this, a standalone photovoltaic system was designed, accounting for the impact of climatic factors such as high temperatures, solar radiation, and dust, while relying on high-efficiency components like solar panels, batteries, and converters.

During the simulation phase, an MPPT algorithm based on artificial neural networks was integrated, enabling fast and accurate tracking of the maximum power point and ensuring voltage and current stability even under sudden weather changes. Simulations conducted in the MATLAB/Simulink environment confirmed that the use of artificial intelligence not only improves the overall efficiency of the system but also provides exceptional flexibility in dealing with fluctuating environmental dynamics.

This designed system represents a practical step toward intelligent and autonomous energy solutions, applicable in remote areas and scalable for future integration with hybrid energy sources or advanced control systems powered by machine learning and predictive control technologies.

References

Reference

[1] Énergies renouvelables et de récupération (ENR&R) [archive] Drivée Ile-de- France, consulté en mars

[2] H. Kanchev, "Gestion des flux énergétiques dans un système hybride de sources d'énergie renouvelable" Optimisation de la planification opérationnelle et ajustement d'un micro réseau électrique urbain Hal Id école centrale de lille, 2015

[3] Ferrah Billel, "Etude d'un système Hybride (photovoltaïque –éolien)", Mémoire de master, Université de Annaba, 2015

[4] Khaled Ferkous, "Étude d'une chaine de conversion d'énergie éolienne" Mémoire de Magister, université de Constantine, 2009

[5] Khan, M. J., Iqbal, M. T., & Hinchey, M. (2018). A review of hybrid renewable energy systems for remote areas. Renewable and Sustainable Energy Reviews, 94, 299–313.

[6] Sinha, S., & Chandel, S. S. (2015). Review of recent trends in optimization techniques for solar photovoltaic–wind based hybrid energy systems. Renewable and Sustainable Energy Reviews, 50, 755–769.

[7] Rehman, S., Bader, M. A., & Al-Moallem, S. A. (2012). Cost of solar energy generated using PV panels. Renewable and Sustainable Energy Reviews, 16(2), 681–693.

[8] Mellit, A., & Kalogirou, S. A. (2014). Economic viability of hybrid photovoltaic–diesel–battery power systems for rural electrification using genetic algorithm. Energy for Sustainable Development, 18, 34–43.

[9] Université de Ghardaïa, 2022 **.** Dimensionnement d'un système multi-sources à énergies renouvelables pour un site isolé.

[10] Université de Ouargla, 2023 **.**– Conception d'un système hybride solaire-éolien pour un pompage agricole.

[11] Université Hassan II – Casablanca (2021) – Étude et dimensionnement d'un système photovoltaïque autonome**.**

[12] Modélisation et simulation d'une source d'énergie renouvelable, Mémoire de Master, IGEE – Institut de Génie Électrique et Électronique

[13] Université de Biskra (2021), Conception d'un système solaire autonome utilisant des batteries et des supercondensateurs, Mémoire de Master, Département de Génie Électrique, Université Mohamed Khider - Biskra.

[14] Université de Batna 2 (2020), Simulation et commande d'un système photovoltaïque hybride sous MATLAB/Simulink, Mémoire de Master, Département de Génie Électrique, Université de Batna 2.

[15] Université de Tiaret (2021), Simulation et commande d'un système photovoltaïque hybride sous MATLAB/Simulink, Mémoire de Master, Département de Génie Électrique, Université de Tiaret

[16] Université de Batna 2 (2020), Simulation et commande d'un système photovoltaïque hybride sous MATLAB/Simulink, Mémoire de Master, Département de Génie Électrique, Université de Batna 2.

[17] Kalantar, H., et al. (2020). Smart energy management of photovoltaic systems using AI techniques in desert environments. Renewable Energy, 145, 1590-1602**.**

[18] Ghenai, C., & Bellos, E. (2021). AI-Based Optimal Control of Hybrid Renewable Energy Systems in Harsh Environments. Energies, 14(12), 3578**.**

[19] Ghenai, C., & Bellos, E. (2021). AI-Based Optimal Control of Hybrid Renewable Energy Systems in Harsh Environments. Energies, 14(12), 3578.

[20] Kalantar, H., et al. (2020). Smart energy management of photovoltaic systems using AI techniques in desert environments. Renewable Energy, 145, 1590–1602.

[21] International Electrotechnical Commission (IEC). "IEC 61215: Terrestrial photovoltaic (PV) modules – Design qualification and type approval", IEC, 2021.

[22] NREL (National Renewable Energy Laboratory). "Best Practices for Operation and Maintenance of Photovoltaic and Energy Storage Systems", U.S. Department of Energy, 2016.

[23] S. Yadav et al., Performance analysis of PV modules under desert conditions, Renewable Energy Journal, Elsevier, 2019.

[24] A. Mahdy and E. Bahnasawi, Assessment of photovoltaic technologies for hot desert climates, Energy Procedia, Volume 162, 2019