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Master's degree dissertation

Theme:

Influence of Electromagnetic Fields on the Performance Efficiency of an Irrigation System

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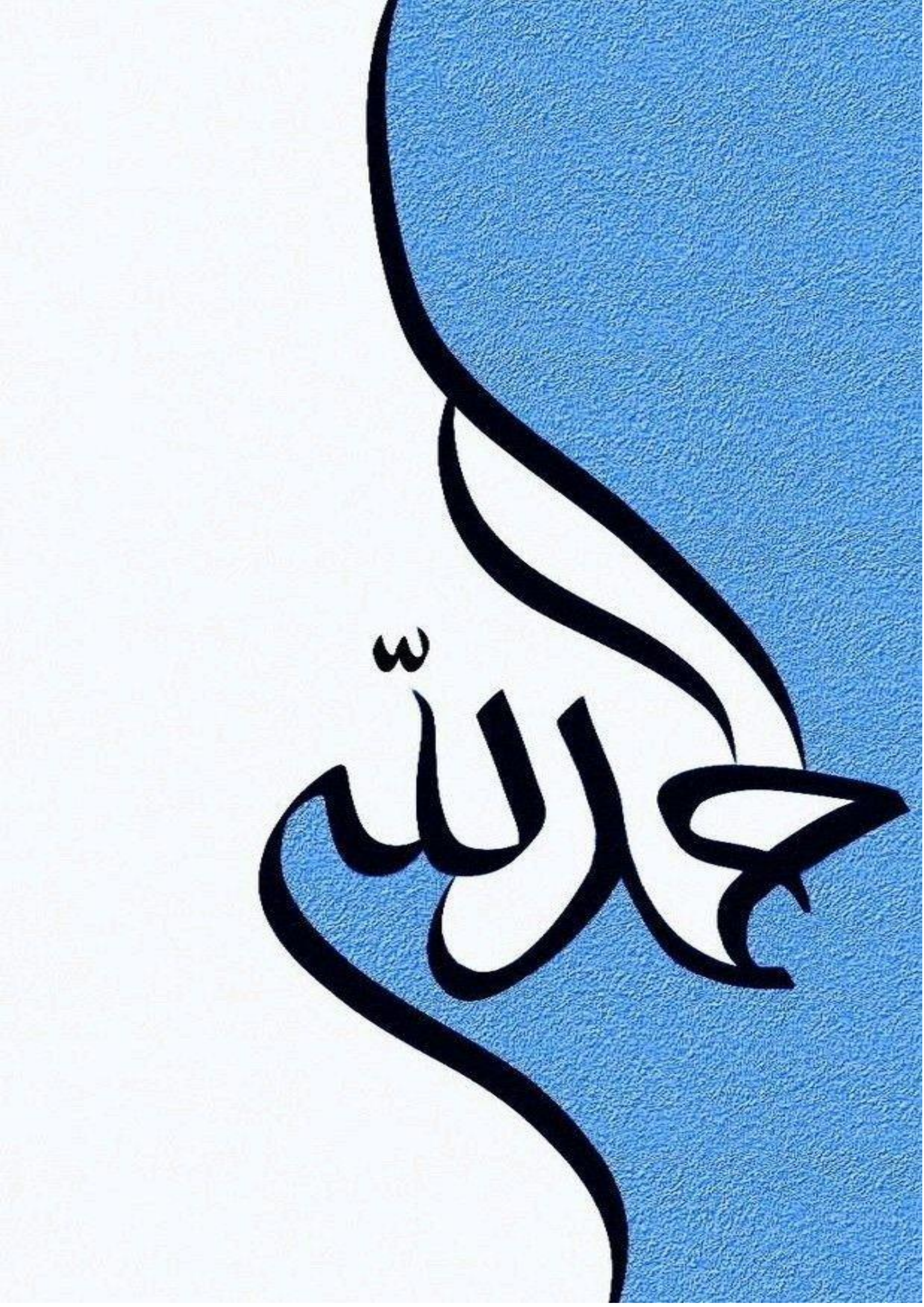
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of God, the Most Gracious, the Most Merciful. Praise be to God, and prayers and peace be upon the Messenger of God. And their final supplication is, "Praise be to God, Lord of the Worlds." Praise be to God, by whose grace good deeds are accomplished.

The soul glowed with extreme happiness for a moment I had long awaited and dreamed of, and my thoughts planted roses for it. A moment I toiled until I attained. I worked hard and persevered and arrived. I express my joy in a story whose chapters were completed and whose threads were finished spinning.

Thanks to God, I graduated from Badji Mokhtar Annaba University of Science and Technology.

Praise be to God, who made beginnings easy for me, completed endings for me, and brought me to the goals. No path has ended, no effort has been sealed, and no endeavor has been completed except by the grace of God. So praise be to God at the beginning and at the conclusion

DEDICATIONS

I dedicate this work to my dear parents, in appreciation of their love, continuous support, and priceless sacrifices throughout my academic journey.

To my brothers and sisters, for their constant encouragement and motivation.

I also dedicate it to my close friends, who have always been there for me and managed to put a smile on my face even in the toughest times.

And to everyone who believed in me and was a source of inspiration and strength to keep going

BADJI MOKHTAR – ANNABA UNIVERSITY

Faculty of Technology

Department of Electrical Engineering

Summary of the master 2 dissertation work

Submitted by Ms :

HAMOUDI Khadidja

Specialisation: Electrical Networks

Title of the Thesis:

Influence of Electromagnetic Fields on the Performance Efficiency of an Irrigation System

Summary:

This memo studies an irrigation system that relies on solar energy as an alternative and efficient source of electricity, taking into account the surrounding environmental conditions, especially the presence of a high-voltage power line near the site.
The study analyses the electromagnetic effects that may impact voltage stability in the system and examines how to address them to ensure optimal performance.

It also covers the components of the solar system, starting with solar panels, their types, and selection criteria, followed by the DC generator and the substation responsible for voltage regulation, and finally the use of MPPT technology, which enables the extraction of maximum power from the panels under various weather conditions.
The aim of the memo is to provide a comprehensive overview of how to design and operate a solar-powered irrigation system with high efficiency, while addressing technical and environmental challenges.
The study results were analysed using MATLAB to simulate the system's performance and evaluate its effectiveness.

Keywords:

Electromagnetic fields, Irrigation system, Solar energy, Photovoltaic panels MPPT, Electrical voltage , MATLAB

Université Badji Mokhtar- Annaba

Faculté de technologie

Département d'Electrotechnique

Résumé sur le travail de mémoire de Master 2

Soumis par Mme :

HAMOUDI Khadidja

Filière : Electrotechnique

Spécialité : Réseaux électriques

Intitulé du mémoire :

Influence des champs électromagnétiques sur l'efficacité de performance d'un système d'irrigation

Résumé

Cette mémoire porte sur l'étude d'un système d'irrigation fonctionnant à l'énergie solaire comme source alternative et efficace de production d'électricité, tout en tenant compte des conditions environnementales, notamment la présence d'une ligne à haute tension à proximité du site.

Les effets électromagnétiques susceptibles d'affecter la stabilité de la tension dans le système ont été analysés, ainsi que les moyens d'y remédier afin d'assurer une performance optimale.

La mémoire traite également des composants du système solaire, en commençant par les panneaux solaires, leurs types et les critères de choix, en passant par le générateur à courant continu et le transformateur secondaire chargé de l'ajustement de la tension, jusqu'à l'utilisation de la technologie MPPT permettant d'extraire la puissance maximale des panneaux quelles que soient les conditions climatiques.

L'objectif de cette étude est de fournir une vision globale de la conception et du fonctionnement d'un système d'irrigation alimenté par l'énergie solaire avec une efficacité élevée, tout en surmontant les défis techniques et environnementaux.
Les résultats de l'étude ont été analysés à l'aide du logiciel MATLAB pour simuler les performances du système et évaluer son efficacité.

Mots clés :

Champs électromagnétiques, Système d'irrigation, Énergie solaire, Panneaux photovoltaïques, MPPT , Tension électrique , MATLAB.

جامعة باجي مختار – عنابة

كلية التكنولوجيا

قسم الكهروتقني

ملخص عمل مذكرة الماستير2

مقدمة من طرف الانسة :
حمودي خديجة

الشعبة : الكتر وتقني
التخصص : شبكات كهربائية

عنوان الاطروحة :

تأثير الحقول الكهرومغناطيسية على كفاءة أداء نظام الري

ملخص :

تتناول هذه المذكرة دراسة نظام الري الذي يعتمد على الطاقة الشمسية كمصدر بديل وفعال لتوليد الكهرباء، مع مراعاة تأثير البيئة المحيطة، خاصة وجود خط من الجهد الكهربائي العالي بالقرب من الموقع.
تمت دراسة التأثيرات الكهرومغناطيسية التي يمكن أن تؤثر على استقرار الجهد الكهربائي في النظام، وتحليل كيفية التعامل معها لضمان كفاءة الأداء.
كما تم التطرق إلى مكونات النظام الشمسي، بدءًا من الألواح الشمسية وأنواعها ومعايير اختيارها، مرورًا بمولد التيار المستمر، والمحول الفرعي المسؤول عن تعديل الجهد، وصولًا إلى استخدام تقنية MPPT التي تسمح باستخلاص أقصى طاقة ممكنة من الألواح تحت مختلف الظروف المناخية.
تهدف المذكرة إلى تقديم تصور شامل لكيفية تصميم وتشغيل نظام الري المعتمد على الطاقة الشمسية بكفاءة عالية، مع مواجهة التحديات التقنية والبيئية المحيطة به.
وقد تم تحليل نتائج الدراسة باستخدام برنامج MATLAB من أجل محاكاة أداء النظام وتقييم فعاليته.

الكلمات المفتاحية :

الحقول الكهرومغناطيسية , نظام الري , الطاقة الشمسية , الألواح الشمسية ,تقنيةMPPT , الجهد الكهربائي , برنامج MATLA

CHAPTER II : The Photovoltaic Pumping System

CHAPTER III : System Modelling and Control

CHAPTER IV : Energy and Economic

GENERAL INTRODUCTION

Electric energy is the backbone of life due to its use in many fields. In addition to the fact that traditional energy sources are depleting and insufficient to meet the alternative. With the global increase in petroleum and electricity prices, countries have turned their attention to solar energy as a safe and clean renewable energy source.

Solar energy has many advantages that encourage its use and reliance. Among the most important of these advantages are:

- It is a renewable energy source, as sunlight is inexhaustible and always available around the world.
- It can be used for multiple applications such as electricity and heat production, water desalination and distillation, powering satellites, air conditioning systems (cooling/heating), and water extraction and pumping from wells.
- It has low maintenance costs; although the initial setup cost may be high, maintenance is affordable and inexpensive.
- The continuous development in solar energy technologies, especially in the fields of nanotechnology and quantum physics, aims to improve the efficiency and effectiveness of solar power systems in the future.

Water is usually available in streams and wells and requires energy to be lifted to usable levels. This involves energy to pump it through pipelines and transport it to usage areas. Pumping systems have evolved from manual labor, to animal power, to natural sources like wind power, and later to petroleum and electricity-powered engines. With the emergence of solar energy, it has become a suitable replacement for conventional sources.

Solar-powered water pumps represent the future and are the ideal solution for all water supply needs—whether for irrigation, drinking, or other uses. They have the advantage of requiring minimal supervision due to their long service life and very low maintenance costs. Moreover, they produce no noise or pollution, and their capital payback period compared to diesel pumps ranges between 3 to 5 years.

Algeria's geographical location encourages the development and exploitation of solar energy. The high intensity of solar radiation and the long duration of sunlight, which exceeds ten hours per day for several months, enable the country to cover part of its energy needs through solar power. These advantages can be especially beneficial in remote areas, particularly in photovoltaic water pumping applications.

CHAPTER I :

OVERVIEW OF ELECTRICAL NETWORKS AND THE ELECTROMAGNETIC FIELD

I.1 Introduction

An Electric al network is a set of infrastructures that enables the transmission of Electric al energy frome production centres to consumer. It consists of power liens operated at different voltage levels, interconnected through electrical substations. These substations allow the distribution of electricity and the conversion from one voltage level to another using transformers. The main modes of electric energy transmission are overhead, underground, and submarine transmission. Overhead transmission uses bare conductors, while underground transmission uses insulated cables. Underground transmission lines are commonly used for medium and high voltage levels due to higher energy demand. They are increasingly used in modern networks because of their greater safety during bad weather (such as storms or lightning), lower cost over short distances, and reduced maintenance requirements.

I.2 Historia

Background The first power distribution system, built in the early 1880s, was based on the idea of Thomas Edison. It supplied direct current (DC) electricity to some customers in Manhattan. However, transmitting DC electricity over long distances while maintaining nearly the same low voltage for all consumers proved impractical due to high energy losses. This issue was overcome by introducing electrical transformers into alternating current (AC) power systems. One of the first AC systems was built in 1886 by George Westinghouse and William Stanley. AC systems quickly replaced DC systems, and by the end of the 1890s, electricity supply had become predominantly AC. In the beginning, power systems were operated as monopolies. A single company provided generation, transmission, and sometimes distribution services. For a long time, these sectors were considered a natural monopoly. As for the combined transmission and distribution networks, they represent a real challenge. Moreover, competition in these sectors raises another issue: in a power system, electricity follows physical flow laws (Kirchhoff's laws). Thus, interconnecting networks owned by competing companies may affect their ability to deliver electricity. Furthermore, environmental constraints discourage the excessive presence of overhead lines "covering the sky" or underground cables "digging up the streets".

In terms of power generation, the larger a power plant's capacity, the lower the cost per unit of electricity produced. Therefore, to achieve the lowest electricity price, the largest producers tend to operate at maximum capacity, benefiting from economies of scale. This situation provided little economic incentive for the operation of many small competing plants. Additionally, the massive investments required to build large power stations discouraged potential private investors.

Economies of scale reached their peak efficiency in the 1960s. From that point on, they were gradually undermined by several developments, including:

significant technological advances, improvements in turbine efficiency, the decline in natural gas prices, and the lifting of restrictions on gas combustion in some countries.

As a result, gas turbines and small combined cycle units became cheaper than older plants. This shift contributed to the liberalization of the generation segment.
Moreover, significant price differences between neighbouring power systems created additional motivation to establish a free market where producers could compete.

The unbundling process in electricity services began in Chile in 1982, and has since become widespread globally. The deregulation of electricity markets was driven by political decisions and ideological shifts, as part of a broader economic liberalization that included sectors such as natural gas, telecommunications, and air transport.
The original goals of deregulation were twofold: to reduce prices and to improve reliability.

I-3 Description of Networks

The parts of the electrical power system are illustrated in **Fig I-1**.

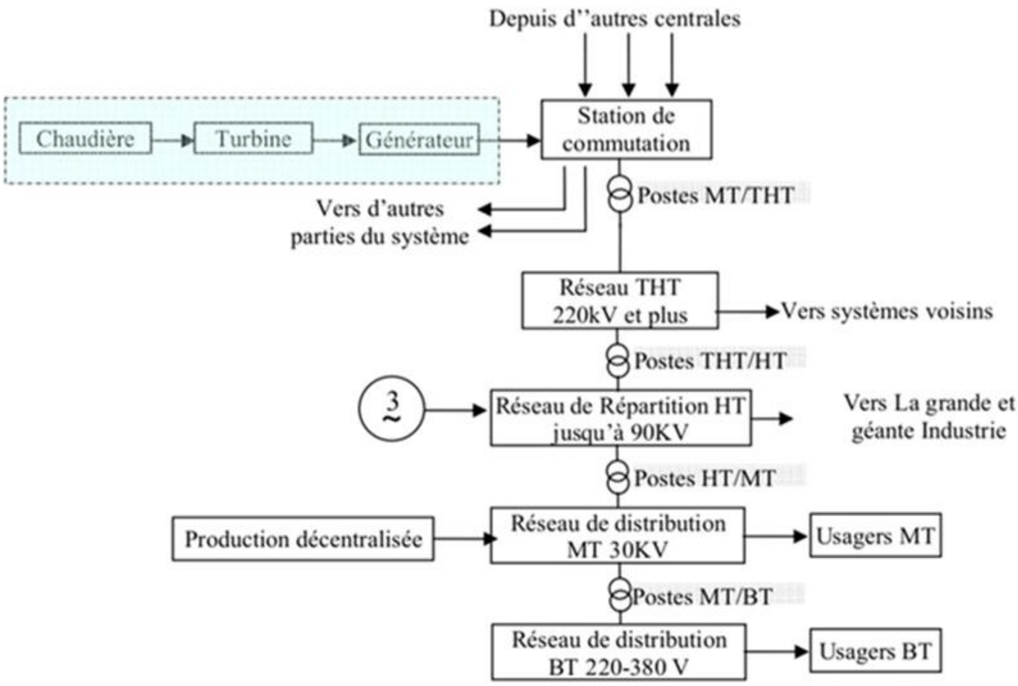


Fig. I.1: Configuration of the electro-energy system

- **The Extra High Voltage (EHV) Transmission Network**

It is generally the network that enables the transport of energy from remote production centers to consumption centers. This network can be partially radial in very large countries with hydroelectric production sites particularly located in sparsely populated areas (Canada, Algeria, Venezuela…). This network can be meshed, but meshing is generally the result of a mature network or of medium-sized countries such as European countries. It is on the EHV network that large power plants (> 300 MW) are in principle connected.

These networks are mostly overhead and underground in cities or at their approach. They are designed for a given transit, generally corresponding to the thermal limit of the line, or also its stability. Particular attention must be paid to the corona effect, which at EHV can cause very significant losses depending on the climate and altitude.

Line pylons are generally equipped with two circuits (2 times 3 phases), sometimes even four or six circuits. The lines are protected by one or more shield wires, almost systematically equipped today with optical fibers for the transmission needs of the operator or rented to telecom operators.

Phases are transposed in certain countries to avoid phase load imbalances (mutual influence of one circuit on another).A specific problem of EHV networks is the voltage control of long lines.

- **Distribution Network**

This network is essentially meshed for the previously mentioned reasons of stability and quality (waveform, availability…) of the energy. They have many similarities with the EHV networks (neutrals directly grounded…). It is on these networks that small and medium power plants (50 - 300 MW) are generally connected.

- **The Medium Voltage (MV) Distribution Network**

MV networks will be called those covering the range 1 to 36 kV according to the IEC.

MV networks differ significantly from HV networks by the distribution principle: three wires. In Algeria, the MV levels are 10 and 30 kV. These networks are characterized by a balanced three-phase distribution.

The MV neutral of the HV/MV transformer is grounded through an impedance whose characteristics depend on the desired performance (low short-circuit currents, low overvoltages, availability).

This system is characterized by two distribution principles, 3 and 4 wires: with non-distributed neutral and with distributed neutral. These two principles are incompatible with each other and follow very different principles of operation, protection, and maintenance. We also distinguish:

Rural networks, generally overhead, radial and loopable

Urban networks, essentially underground and loopable

MV networks have such particularities that they alone would deserve an extensive development; therefore, only a few essential features will be provided.

However, in what follows, we will only be interested in so-called three-wire networks, the only types of networks used in Algeria

I.4 Structure of the Algerian Electrical Network

Electric energy, produced in power plants (with power ranging between a hundred MW and 1300 MW), must be delivered to consumers—that is, to all individuals and especially to the various companies distributed throughout the territory.

This role is fulfilled in Algeria by the SONELGAZ network, whose lines, almost always three-phase, ensure the following three main functions: transmission, distribution, and delivery.

I.4.1 Transmission Network

It consists of extra high voltage (EHV) lines (400 kV and 220 kV lines), supplied by power plants through step-up substations (10 to 25 kV / 220 or 400 kV), enabling, at

any moment, significant energy exchanges between production centers and consuming regions, and even between neighboring countries.

I.4.2 The Distribution Network

It consists of high voltage lines (93 kV, 60 kV lines), supplied by the EHV network through so-called interconnection substations, whose role is to distribute electric energy throughout the entire territory (the mesh of this network is therefore much denser than that of the transmission network).

I.4.3 The Delivery Network

Comprising two stages:

Medium voltage lines (10 or 30 kV), supplied by HV/MV substations, whose role is to provide electric energy directly to major consumers and to the various MV/LV substations.

Low voltage lines (LV 380 V), which supply three-phase users with 220–380 V and single-phase users with 220 V.

<table>
<tr><th rowspan="3">Almelec Câble mm²</th><th colspan="3">MW*KM</th></tr>
<tr><th colspan="3">ΔU / U =7.5% cos φ= 0.9</th></tr>
<tr><th>15 KV</th><th>20 KV</th><th>33 KV</th></tr>
<tr><td>54.6</td><td>22</td><td>39</td><td>105</td></tr>
<tr><td>75.5</td><td>28</td><td>49</td><td>133</td></tr>
<tr><td>117</td><td>37</td><td>66</td><td>175</td></tr>
<tr><td>148.1</td><td>42</td><td>76</td><td>205</td></tr>
</table>

I.5 Components of an Electrical Power Network

I.5.1 Source

The source or generator is a fundamental component of the electrical network. It forms the core of the entire system. Its function is to convert the original form of energy (hydraulic, solar, wind, gas turbine, or thermal, etc.) into electrical energy.
In the case of internal combustion, the alternator is kept at an approximately constant speed by its driving engine using a feedback-controlled system, in order to maintain an almost constant frequency regardless of the load.

Fig. I.2 :Representation of an electrical energy source

I.5.2 Power Lines

Power lines perform the function of "energy transmission" over long distances. Their role is to transport electrical energy from the production site to the consumers.

Fig. I.3 : Electric Laundry

I.5.3 Power Transformers

A transformer is a device designed to transfer power by modifying the amplitude of signals (current, voltage) while maintaining the same frequency.

There are two types of power transformers found in electrical networks:

Autotransformers, which do not have insulation between the primary and secondary windings. They have a fixed transformation ratio while in operation, although this ratio can be changed when the autotransformer is taken out of service.

Load tap-changing transformers, which are capable of changing their transformation ratio while in operation. They are used to maintain a constant secondary voltage and play an important role in voltage regulation.

Conservateur Relais Buccholz

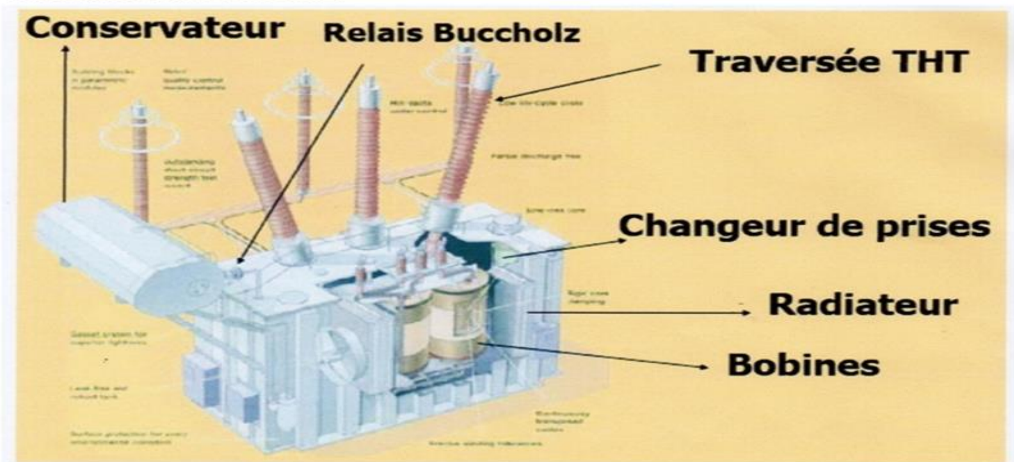


Fig. I.4 : Cross-section of a transformer

Since transformers are particularly expensive equipment, their protection is ensured by various redundant mechanisms.

I.5.4 Electrical Substations

Electrical substations are the nodes of the electrical network. They are the connection points of power lines [**4]**

Fig. I.5 : High voltage electrical substation

I.6 High and Extra-High Voltage Lines

Sources of electrical energy for industrial and domestic use can be divided into two main categories: transportable and locally usable.

The transportable type includes hydroelectric and conventional thermal energy.

For locally used energy, the following types are distinguished:

1.Conventional thermal power in urban load centers

2.Micro-hydroelectric power stations

3.Wind energy

4.Solar thermal energy

5.Solar cells or photovoltaic energy

6.Geothermal energy

I.6.1 Standard Nominal Voltage Values

The voltages adopted for the transmission of electric power in alternating current must comply with standard specifications established in all countries and at the international level. An example of these values is shown in the following table:

Nominal Tension in KV	132	220	275	345	400	500	750	1000	1150
Maximum operating Limit in KV	145	245	300	362	420	520	765	1050	1200

Table I.1 : Nominal voltage levels of HV and THT networks

The maximum operating voltages specified above must under no circumstances be exceeded in any part of the system, as the insulation levels of all equipment are based on these values.

I.7 High and Extra-High Voltage Transmission Lines

I.7.1 Definition of Electrical Lines

An electrical line is a set of conductors, insulators, and accessory components designed for the transmission of electrical energy. The conductors are generally made of aluminium, copper, steel, etc. The insulators consist of a solid part (*porcelain, glass, paper, etc*.) combined with a gas (*air,* SF_6) or a liquid (*oil*).

The transmission of electrical energy from the producer to the consumer is carried out using power lines, which constitute the arteries of an electrical power system.

These lines are composed of three phases, which form a three-phase system. The advantage of the three-phase system is that the sum of the voltages and the sum of the currents across the three phases is equal to zero. This results in a reduction of the

electric and magnetic fields as one moves away from the phases. The transmission of electricity through the lines is always accompanied by the presence of:

- *An electric field, which is related to:*

The voltage.

The proximity of other phases, the guard cable(s), the ground, or any nearby object.

The configuration of the line (220 kV, 400 kV, etc.).

- *A magnetic field, which is related to:*

The value of the current flowing through the conductors.

The configuration of the line.

The higher the voltage (and therefore the current under normal operating conditions), the stronger the electric and magnetic fields will be.

I.7.2 Types of Lines

Electric lines can be classified according to several criteria:

- Position in space: overhead lines, underground lines (cables)
- Voltage level
- Nature of the voltage: direct current, alternating current (single-phase or three-phase)

The energy transmission lines are divided into two main voltage levels:

- Extra High Voltage (EHV) from 220 to 800 kV. These lines form the national grid known as the main transmission and interconnection network (in Algeria, EHV mainly includes 220 and 400 kV levels).
- High Voltage (HV) from 45 to 160 kV. These lines are used for regional energy distribution from large EHV substations (in Algeria, HV mainly includes 63 and 90 kV levels).

- **Bundled Lines**

Bundled lines are used exclusively for HV and EHV networks to reduce power losses. **Fig I.6** shows the different types of bundled conductors used for high voltage lines. **[5]**

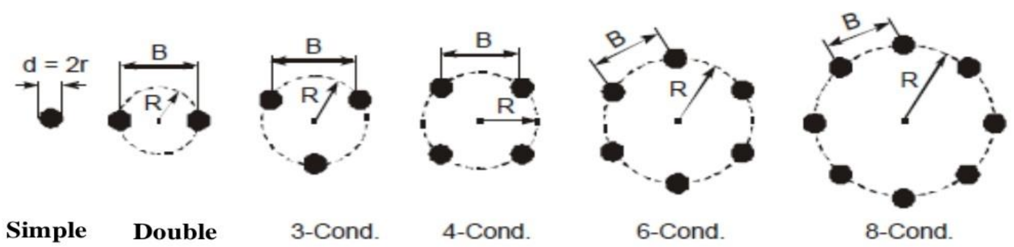


Fig. I.6 : Configuration of bundled conductors for HV and THT lines

With:

d : **2r** is the diameter of a single conductor, and r is its radius

B: the distance between two adjacent conductors

R: radius of the bundled line

I.7.3 The pylons used in HV and EHV

The necessity of increasing voltage for the transport of electrical energy over long distances, crossing large valleys and rivers, has led to the appearance of new steel pylon structures. Several different conductor arrangements are used.

Figure **I.7 (a)** shows a pylon with horizontally arranged conductors. The horizontal arrangement increases the widths of the pylon, which produces a more visible effect.

Figure **I.7 (b)** shows a pylon of a double-circuit line with vertically arranged conductors. This results in a taller and more compact appearance.

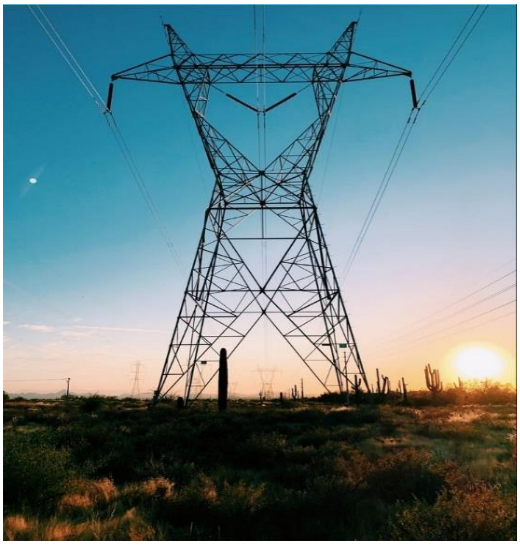


Fig.a

Fig.b

Fig. I.7 : Example of high and very high voltage pylons

I-8 Magnetic Fields of EHV Lines

Electric and magnetic fields are generated by the electrical network, belonging to the family of "extremely low frequency" (from 1 to 300 Hz) fields. They have an effect frequency of 50 Hz. The distribution networks are connected to industrial, commercial, and residential networks, and all operate at the same frequency of 50 Hz. Therefore, each electrical device connected to an electrical outlet also becomes a source of an electric and/or magnetic field at a frequency of 50 Hz.

I-9 Sources of Electromagnetic Fields

Electromagnetic fields in our environment are created by both natural and artificial sources. A source is any device that produces electromagnetic disturbance. The transmission and distribution of electrical energy, waves, electrostatic discharges, lightning, etc., are among the main causes of disturbances.

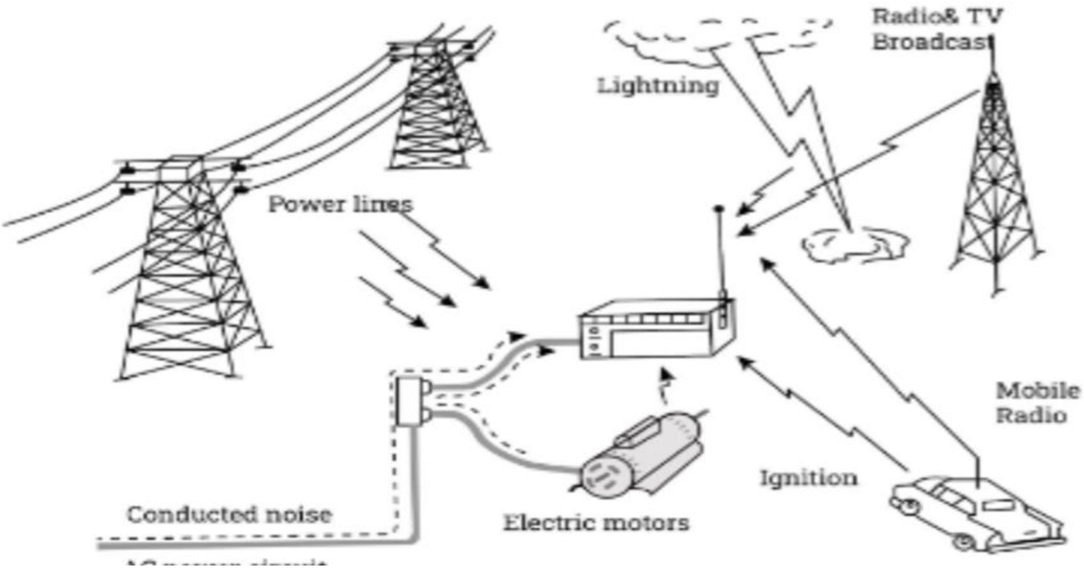


Fig. I.8 : Different sources of electromagnetic fields

In general, electromagnetic fields or electromagnetic radiation are a way to transport energy without the need for a material medium. These radiations are used in many applications over a very wide frequency range. **[6]**

I.10 Magnetic Fields of High Voltage Lines (THT)

They are also influenced by the geometric positions of the measurement point, the distance between the line phases, and their geometric height from the ground. The magnetic field is not related to the voltage level, but is directly related to the current carried through the line.

The magnetic field fluctuates significantly depending on the variation in the line's load and is influenced by various elements:

- The currents flowing through the conductors (in general, high voltage lines carry an average current of 700 A).
- It can be observed that the intensity of the magnetic field is highest directly beneath the conductors and decreases rapidly as the distance from the pylon axis increases. **[7]**

A result published by CIGRE is shown in Fig. I.9, which illustrates how the magnetic induction field in (μT) changes at 1.5m above the ground in a plane.

Perpendicular to the mid-span line in the linear corridor. **Fig. I.9** shows the current intensity taken into account

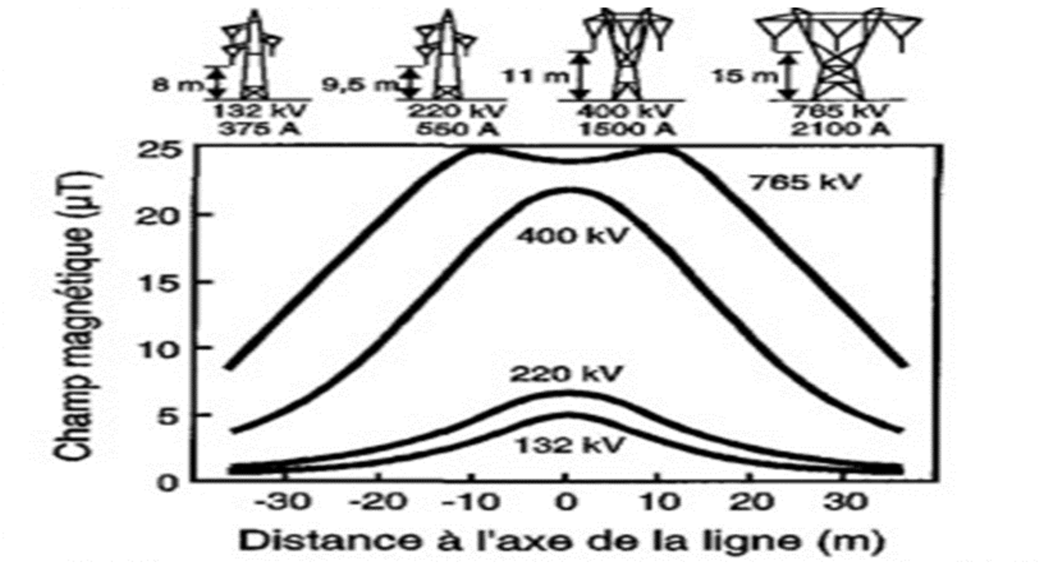


Fig. I.9 : Magnetic field as a function of the distance from the axis of electric lines of different voltages

Conclusion

The electrical grid is an essential system for modern society, based on physical principles such as electromagnetic induction. Transmission lines generate electromagnetic fields, the effects of which on the environment and health are still being studied and debated. The move toward smart grids and renewable energies underscores the importance of managing these interactions to optimize the grid while reducing environmental impact. In short, informed management of the relationship between the electrical grid and electromagnetic fields is crucial to ensuring a sustainable and secure future.

CHAPTER II :

THE PHOTOVOLTAIC PUMPING SYSTEM

II.1 Introduction

Electricity is the cornerstone of life due to its use in many fields. With traditional energy sources becoming depleted and insufficient to meet the growing demand, renewable energy sources are being considered as alternatives. In light of the high costs of petroleum products and electricity worldwide, countries have turned their attention to using solar energy as a safe and clean alternative source of renewable energy.

Solar water pumps are seen as the future and the ideal solution for all water supply needs—whether for agriculture, drinking, or other uses. They stand out for not requiring constant monitoring, having a long lifespan, and requiring minimal and low-cost maintenance. Additionally, they produce no noise or pollutants, and their capital payback period compared to diesel pumps ranges from 3 to 5 years.

II.2 Renewable Energies

Today's world has witnessed a fundamental transformation in the field of electricity production systems specifically, the deregulation of the electricity market. The reasons behind this deregulation vary from one country to another. One of its main consequences, however, is the emergence of new production methods known as renewable energies within existing electrical networks.

Renewable energies are inexhaustible energy sources, available at will, and come in various forms. Thanks to their low pollution impact, they enable the development of a productive energy system with numerous advantages. They are cleaner, more environmentally friendly than fossil and nuclear energies, ecological, widely available across the globe, and free once the production systems are paid off.

II.3 Types Of Renewable Energy

II.3.1 Biomass Energy

The term biomass refers to all organic material of plant or animal origin (wood, plant waste, algae) that can serve as an energy source through combustion. Biomass is one of the leading renewable energy sources produced in Europe, ranking ahead of hydroelectric, wind, and geothermal energy. This energy is used to generate electricity through the production of heat.

Fig II.1: Biomass Energy

Released by the combustion of these materials or by the biogas resulting from the fermentation of such materials in biomass power plants. Although it emits greenhouse gases, these are naturally absorbed by trees.
However, biomass can provide the cheapest and most locally sourced energy on the market. **[9]**

II.3.2 Geothermal Energy

Geothermal energy, from the Greek geo (earth) and thermos (heat), refers both to the science that studies the Earth's internal thermal phenomena and to the technology that aims to harness it. By extension, geothermal energy also refers to the energy derived from the Earth's internal heat that is converted into usable thermal energy.

To capture geothermal energy, a fluid is circulated deep underground. This fluid may come from a naturally occurring reservoir of hot water or be water injected under pressure to fracture a hot, impermeable rock. **[10]**
In both cases, the fluid heats up and rises to the surface carrying thermal energy (calories). This energy is either used directly or partially converted into electricity.

Fig II.2 : Geothermal Energy

II.3.3 Hydroelectric Energy

Hydroelectric energy is a form of energy that uses hydraulic power to generate electricity through a hydroelectric turbine. This turbine converts the mechanical energy of moving water (such as waterfalls, rivers, or currents) into electricity.

Fig II.3 : Hydroelectric Energy

As a result, it produces renewable electricity while emitting very low levels of greenhouse gases.

However, it is not entirely a sustainable energy source, as it often involves the construction of dams, which can obstruct the movement of species, sediments, and boats. **[9]**

II.3.4 Wind Energy

Wind energy is a source of power that depends on the wind. The sun heats the Earth unevenly, creating areas of differing temperatures and atmospheric pressure around the globe **[11]**. These pressure differences give rise to air movements, known as wind. This energy is used to generate electricity through wind turbines, also called aerogenerators, which harness the power of the wind

Wind energy is undoubtedly the ultimate form of clean energy. With no emissions or waste of any kind, it offers a high-performance coefficient and ensures strong energy independence. Whether on land or offshore, wind turbines demonstrate excellent production capabilities and represent a viable alternative for the most remote areas where access to electricity is difficult. **[12]**

Fig II.4 : Wind Energy

II.3.5 Solar Energy

Solar energy is the energy derived from solar radiation, primarily harnessed through technologies such as solar panels to produce electricity or heat. **[9]**

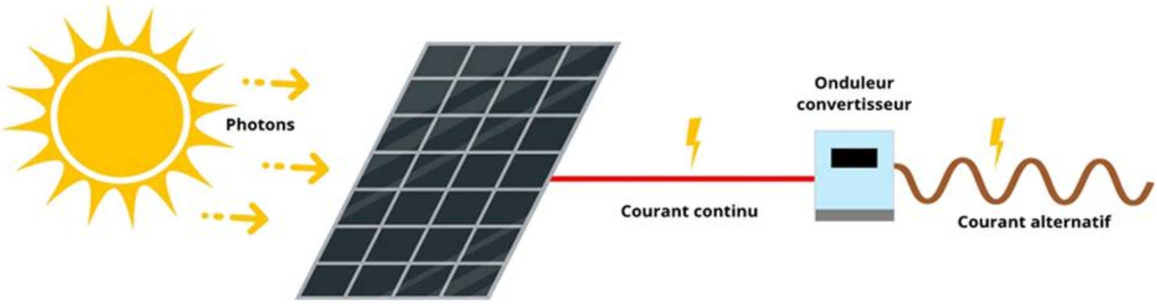


Fig II.5 : Solar Energy

Solar energy is generated and utilized through various processes:

***a**. Solar thermal energy*:

Uses dark-colored panels to generate heat. The sun's heat can also be used to produce steam, which is then converted into electricity.

***b.** Photovoltaic solar energy*:

Uses solar panels to directly convert sunlight into electricity.

Fig II.6 : Photovoltaïque module

***c.** Solar Thermodynamic Energy :*

Solar thermodynamic energy uses the sun's heat to generate electricity, typically through solar concentration systems that focus sunlight to heat a fluid and produce steam, which then drives an electric turbine.

II.3.6 Solar Potential

Due to its strategic location, Algeria possesses the largest solar energy resources in the Mediterranean region. The country enjoys an annual average of over 2,000 hours of sunshine.

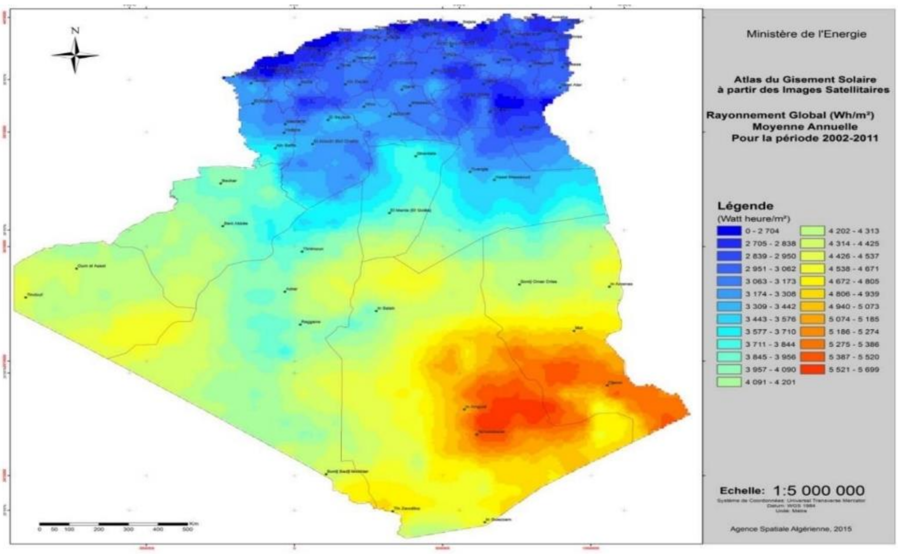


Fig II .7: Solar Potential in Algeria

Algeria has significant solar potential due to its high level of sunshine throughout the year. This renewable resource offers a major opportunity for the development of solar energy and the reduction of dependence on fossil fuels, thereby contributing to the transition toward a more sustainable and environmentally friendly economy. **[13]**

II.4 The Photovoltaic Generator

II.4.1 Operating Principle of the Photovoltaic Cell

A photovoltaic cell is a semiconductor device, generally made from silicon. It consists of two layers—one doped P and the other doped N—creating a PN junction with a potential barrier.

When photons are absorbed by the semiconductor, they transfer their energy to the atoms in the PN junction, causing the electrons in those atoms to break free and generate electrons (negative charges) and holes (positive charges). This creates a potential difference between the two layers. This difference in potential can be measured between the positive and negative terminals of the cell. The structure of a photovoltaic cell is illustrated in **Fig. II.8** below.

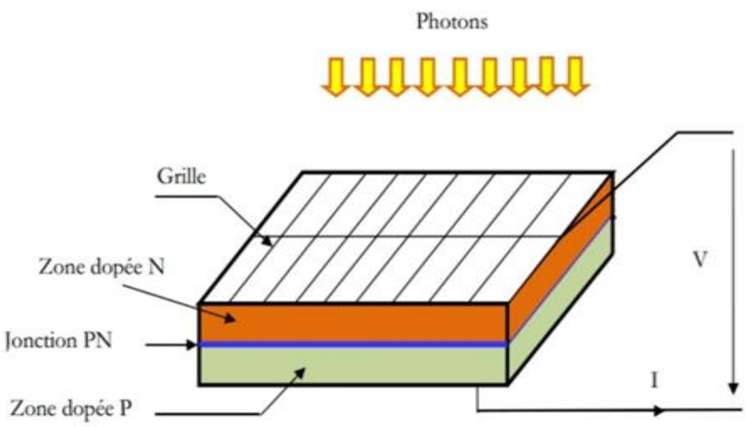


Fig II.8 : Structure of photovoltaic cell

The photovoltaic generator is made up of multiple modules assembled in series and parallel according to the required power output. Each module itself consists of photovoltaic cells, usually connected in series.

These cells are encapsulated within a single structure to form a module. This encapsulation serves two main purposes:

Protection of the cells from external elements (such as impacts, humidity, corrosion, dust, etc.).

Temperature control of the cells, allowing for efficient dissipation of the portion of incident energy that is not converted into electrical energy.

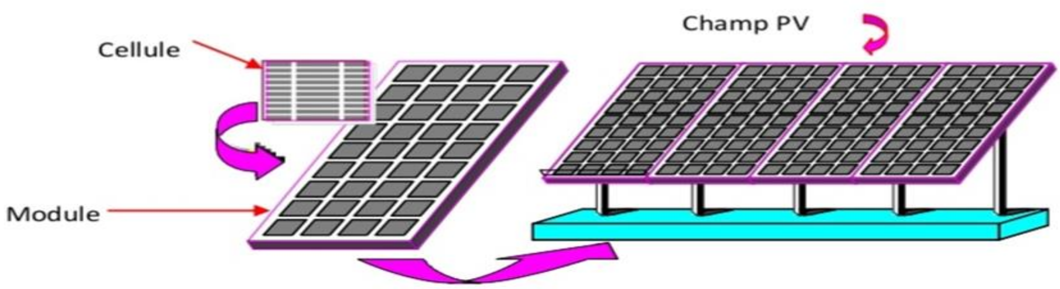


Fig II .9: Components of a photovoltaic generator

The voltage delivered by a PV cell is very low, so to obtain voltages compatible with the loads to be powered, several cells must be connected in series or in parallel.

Moreover, the photovoltaic generator is formed by interconnecting modules in series and/or in parallel to achieve even greater power output**. [14]**

II.4.2 Interconnection of Modules

The interconnection of solar modules refers to the process of electrically connecting solar panels together to form a photovoltaic system, thus enabling the collection and use of the electricity generated by these modules.

Series Connection of Photovoltaic Modules

When photovoltaic modules are connected in series, their voltages add up while the current remains constant, ideally between modules with the same current. Otherwise, the entire string adopts the lowest current.

Ohm's Law:

$$Ug = U1+U2+ \ldots\ldots +Un \qquad Ig = Imin \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \textbf{II.1}$$

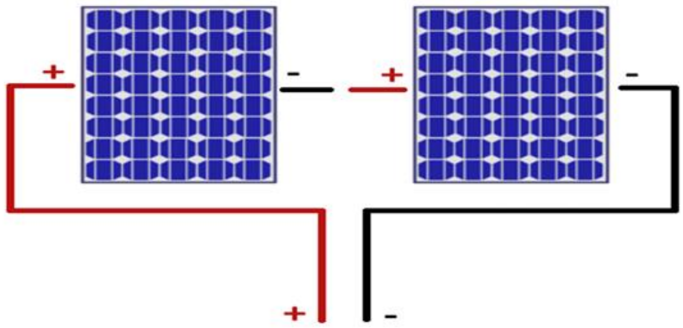


Fig. II.10: Series Connection of Solar Panels

Series Connection:

- The voltages of the panels add up.
- The current corresponds to the rated current of a single module.

- **Parallel Connection (GPV setup):**

In a parallel connection of solar panels, the positive terminals are connected together, and the negative terminals are connected together. This setup increases the system's current (amperage) without changing the voltage.

Ohm's Law :

$$Ig = I1+I2+\ldots\ldots In \qquad Ug = Umin \ldots \ldots\ldots\ldots \textbf{II.2}$$

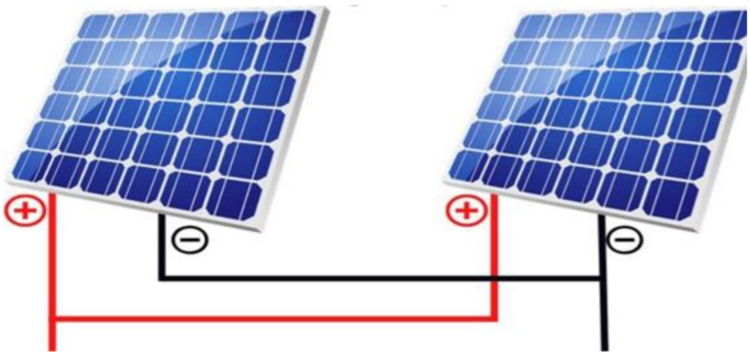


Fig. II.11: GPV Mixed Connection

- **Mixed Configuration of Photovoltaic Modules**

By combining series and parallel connections in a photovoltaic system, a balance between voltage and electric current is achieved, resulting in a mixed configuration. This type of arrangement allows for obtaining maximum current at a specific voltage.

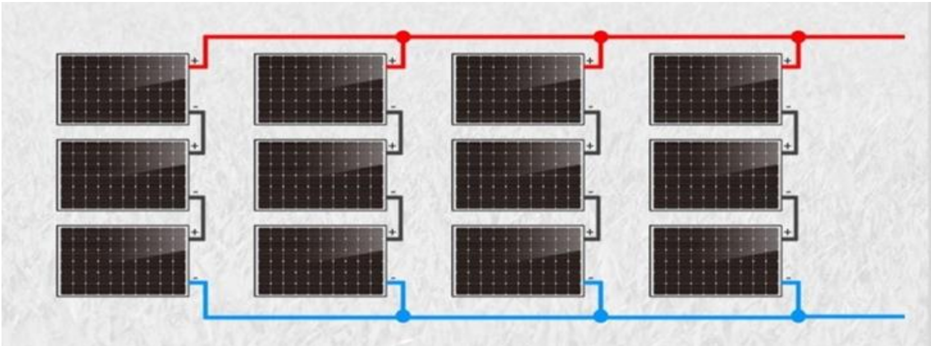


Fig. II.12: Hybrid Configuration

II.4.3 Principle of Conversion in PV Systems

A photovoltaic cell operates based on the photovoltaic effect, a physical phenomenon that generates an electromotive force when the surface of the cell is exposed to light. The voltage produced can range between 0.3 and 0.7 V, depending on the material, its configuration, and the surrounding temperature of the cell.

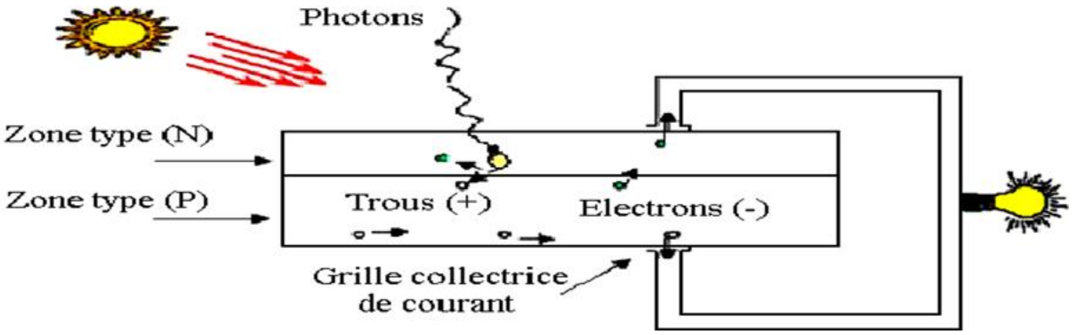


Fig. II.13: Explanation of the Conversion Principle in PV Systems

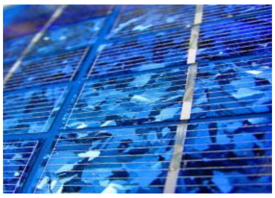
A PV cell is made from two layers of silicon—one P-doped (with boron) and the other N-doped (with phosphorus)—thus creating a PN junction with a potential barrier, as shown in **Fig. II.13.**

II.4.4 Solar Cell Technology

Silicon is one of the most abundant materials on Earth, commonly known as sand, but a high degree of purity is required to make it into an optical cell, which makes the process expensive. According to the known techniques used, there is monocrystalline silicon with an efficiency of 16 to 18%, polycrystalline silicon with an efficiency of 13 to 15%, and amorphous silicon with an efficiency of 5 to 10%. Other materials, such as gallium arsenide and cadmium telluride, have been tested in laboratories and demonstrated efficiencies of up to 38%.

II.5 Different Types of PV Cells

The table below summarizes some characteristics of these three types of solar cells **[15]:**

Technology	*Yield*	*Lifetime*	*Advantage*	*Inconvenience*
poly crystalline Silicom 	12-15%	35 years old	Good performance for a cell	Higt cost , material loss , first in the manufacturing process

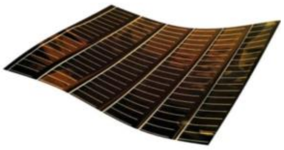
Silicium amorphe 	6-10%	<10	Facile à fabrique	Mauvaise rendement
CdTe 	8-11 %	Not evaluated	Absorbe 80 of incident photons	Cadmium is highly polluting
Organic cell 	10%	Currently low	Efficiency still very low	Low manufacturing cost , flexible design

Tableau II.1: Performances des déverses technologies de cellules

II.6 Advantages of a PV Installation

- First, high reliability. The installation has no moving parts, which makes it particularly suitable for remote areas. This is why it is used on spacecraft.
- The operating cost is very low due to minimal maintenance requirements, and it does not require fuel, its transport, or highly specialized personnel.
- Photovoltaic technology has ecological benefits as the end product is non-polluting, silent, and causes no disturbance to the environment, except for the space occupied by large-scale installations. **[16]**

II.7 Components of a Photovoltaic Pumping System

Generally, a photovoltaic pumping system consists of a photovoltaic generator, a **DC/AC** converter, a pumping subsystem (motor and pump), piping and accessories, and finally a water tank. In photovoltaic pumping systems that operate directly with solar input, storing water in tanks is the most commonly adopted solution, compared to electrochemical storage in batteries.

Water pumping using photovoltaic energy is used for drinking water supply and small-scale irrigation.

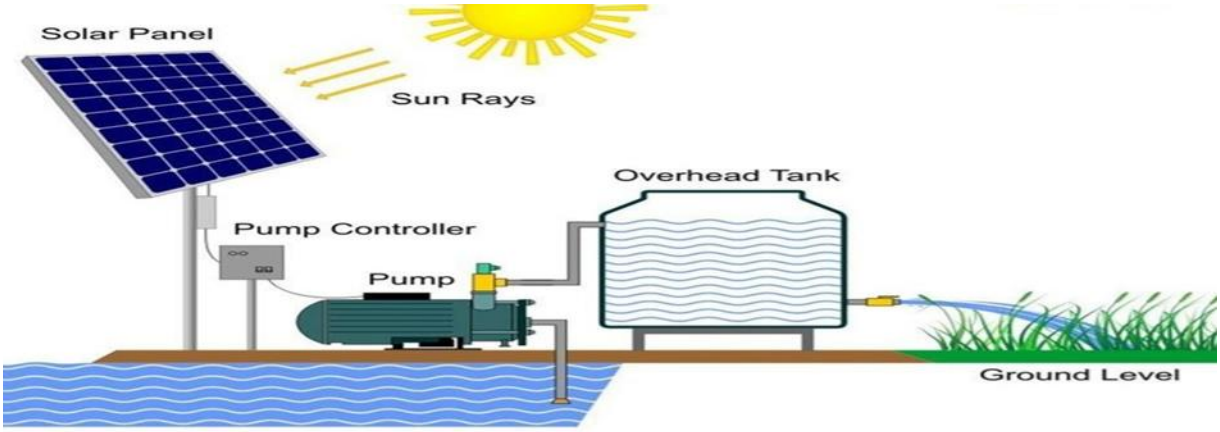


Fig. II.14: Diagram of a Photovoltaic Pumping System

II.8 Selection and Sizing of the Pump

II.8.1 Pump-Motor Selection

The sizing of a pumping system must be carried out with great care.

Various parameters listed in **Table II.2** must be taken into account.

- *Pumps can be classified according to different criteria.*

***Design**

- centrifugal
- Positive displacement

***Position in the system**

- Surface mounted
- Submersible

***Type of motor used**

- Direct current (DC)
- Alternating current (AC)

1	Is it a borehole, a well, a watercourse, ….etc.
2	If it is a well or a borehole, what is its diameter?
3	Depth of the borehole or well in meters
4	Static water level of the borehole in meters
5	Drawdown in meters
6	Hourly flow rate of the well or borehole at drawdown in m^3/h
7	Seasonal variation of the static water level in meters
8	Vertical discharge height in meters
9	Horizontal lengh
10	Inner diameter of the horizontal pipe in meters (if applicable)
11	Minimum desired flow rate in m^3 per day during the sunniest period
12	Minimum desired flow rate in m^3 per day during the least sunny period
13	Period of use

Table II.2: Parameters of a Pumping System

In summary, we can say that centrifugal pumps are generally used for deep wells and high flow rates.

Positive displacement pumps, on the other hand, are used for low flow rates.

As for the motor, DC (direct current) is generally more efficient and easier to use with a PV system, but unfortunately less affordable than AC (alternating current). However, the latter requires the use of an inverter to operate with PV systems.

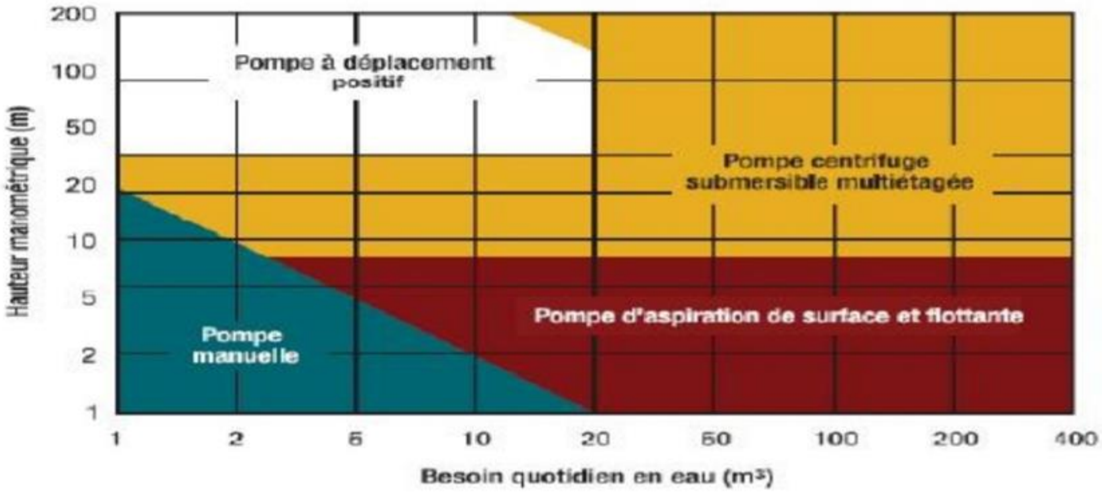


Fig. II.15: Pump Type Selection

As for the motor, DC (direct current) is generally more efficient and easier to use with a PV system, but unfortunately, it is less financially accessible than AC (alternating current). However, the latter requires the use of an inverter to operate with PV systems.

II.9 Advantages of Solar Pumping Systems

- They help avoid the constraints of electrical grids and costly fuel expenditures.
- They produce clean energy and contribute to reducing climate pollution.
- They are highly reliable, durable, and require minimal maintenance (unlike gasoline pumps).
- They can be adapted to the current energy needs of the consumer and can be easily expanded.
- Properly installed solar energy systems are safe and low-risk due to the system's low voltage, and adequate protection minimizes the risk of fire.

II.10 Centrifugal Pump

A pump is a machine used to transport a fluid, which can be water or any other substance (oil, fuel, etc.), by sucking it in and then discharging it at a certain pressure.

A pump is a system that transfers energy to a liquid in order to cause its flow through a pipeline.

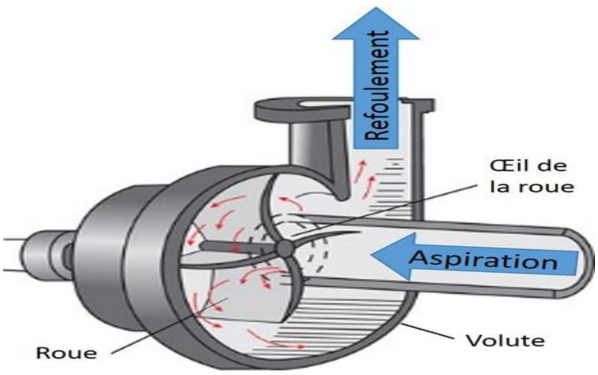


Fig.II.16 : Centrifugal Pump

II.10.1 Classification of Pumps

According to the applications and different water sources (wells, boreholes, river pumping, etc.), several types of pumps can be used in photovoltaic pumping systems.

Among these pumps, we find turbo pumps and volumetric pumps:

a. Turbo Pump

A turbo pump is a device in which the energy transferred to the liquid is primarily kinetic energy, imparted by a rotor. However, it is not invariably related to the movement of the rotor, nor is it uniformly distributed throughout the liquid.

The different types of turbo pumps are:

- ***Centrifugal Pumps***

In this type of pump, the movement of the liquid is strictly normal to the axis, as it enters the center of the wheel and is thrown outward by the combined action of centrifugal force and the rotor blades. The volute of the casing converts the speed gained by the liquid into pressure.

- ***Propeller Pumps***

In this type of pump, the fluid is given a movement parallel to the pump's axis, imparted by a propeller-shaped impeller. The partial conversion of energy into pressure is done through a diffuser with blades or by increasing the flow section.

- ***Helico-Centrifugal Pumps***

This type of pump has an impeller that is an intermediate between the two extreme types: centrifugal and propeller. The movement imparted to the liquid is therefore both centrifugal and axial.

b. Volumetric Pumps

A volumetric pump is one in which the flow of the liquid is directly proportional to the movement of a movable part within the pump casing.

Volumetric pumps are of two kinds: reciprocating volumetric pumps and rotary pumps:

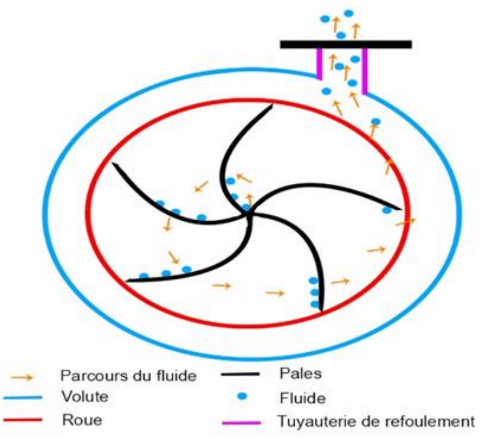


Fig. II.17: Difference Between Centrifugal Pump and Volumetric Pump Rotary Volumetric Pumps

These pumps consist of a moving part that rotates around an axis within the pump casing, creating the movement of the pumped liquid by displacing a volume from the suction side to the discharge side.

- ***Gear Pumps***

The liquid flows between the teeth and the casing of the pump. The gears can be of the straight or helical type, either single or double.

- *Vane Pumps*

In this type of pump, an eccentric rotor is equipped on its perimeter with vanes or blades. These blades are thrown against the casing by centrifugal force, ensuring a seal between the casing and rotor. The liquid, trapped between two successive vanes, is driven and forced toward the discharge.

- *Screw Pumps*

In screw pumps, the rotor is shaped like a cylinder, with a screw on its outer surface. The liquid is trapped between the screw of the casing and that of the rotor. It progresses parallel to the axis of the cylinder.

- **Reciprocating Volumetric Pumps**

The moving part is animated by a reciprocating movement.

- *Piston Pumps*

The principle of piston pumps is to use volume variations caused by the back-and-forth motion of a piston in a cylinder. These alternating movements create suction and discharge phases.

When the piston moves in one direction, the liquid is compressed: the intake valve closes, and the discharge valve opens. The process is reversed when the liquid is sucked into the pump.

- *Diaphragm Pumps*

In diaphragm pumps, the reciprocating movement is transmitted to a diaphragm, which compresses a liquid contained between the diaphragm and the casing, also equipped with intake and discharge valves. The advantage of this type of pump is that it allows for complete isolation of the liquid being pumped.

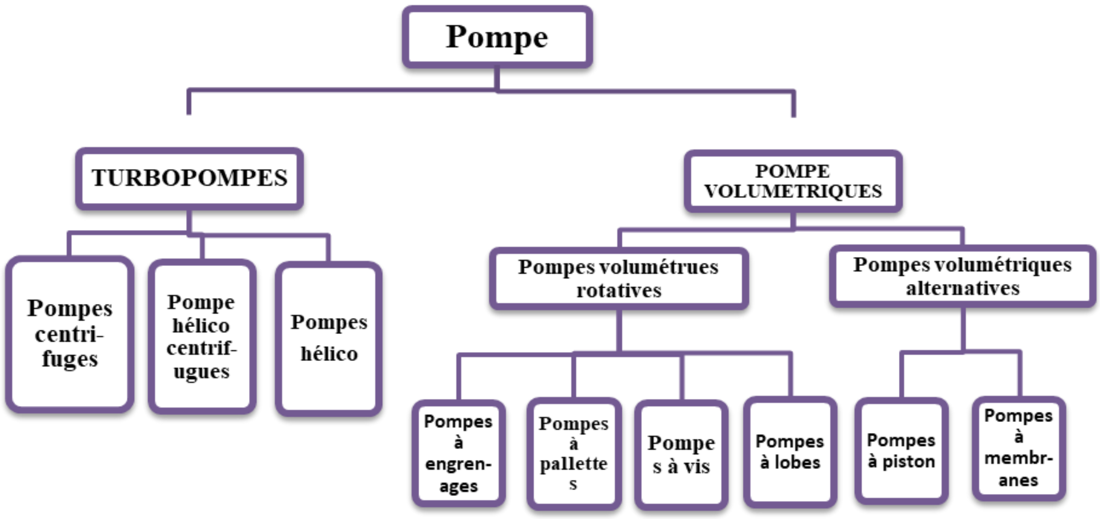


Fig. II.18: Pump Classification

II.10.2 Advantages of Centrifugal Pumps

- Generally simple construction, with only one moving part: the rotor.
- Low cost.
- Compact size.
- Wide clearances, allowing easy handling of liquids containing suspended solids.
- Generally low maintenance cost.
- Little impact of wear or corrosion on performance.
- Wide range of material qualities available depending on the required service.
- High operational flexibility.
- Automatic adjustment of flow rate according to pressure.
- Limited power consumption, hence safe to use.

II.10.3 Operating Principle of a Centrifugal Pump

Under the effect of the impeller’s rotation, the liquid trapped between the impeller blades is projected from the axial region toward the diffuser due to centrifugal force. This creates a vacuum at the pump inlet, causing suction of the liquid, while simultaneously creating compression at the impeller outlet. This is sufficient to establish a continuous flow of liquid.

At the impeller outlet, the liquid is collected in a volute connected to the discharge port, where the kinetic energy is transformed into potential energy. As a result, at the discharge outlet, a pressurized flow is available, expressed as the manometric discharge head. **[16]**

Conclusion

Agriculture is the main source of income for **40%** of the world's population. However, access to water remains a constant challenge for many people. To overcome this issue, solar water pumps play an increasingly important role in agricultural projects, facilitating water supply and encouraging research for the development and modernization of the sector.

CHAPTER III :

SYSTEM MODELING AND CONTROL

III.1 Introduction

Modelling an electrical system involves representing the system in a mathematical or graphical form in order to better understand its operation and analyse its performance.

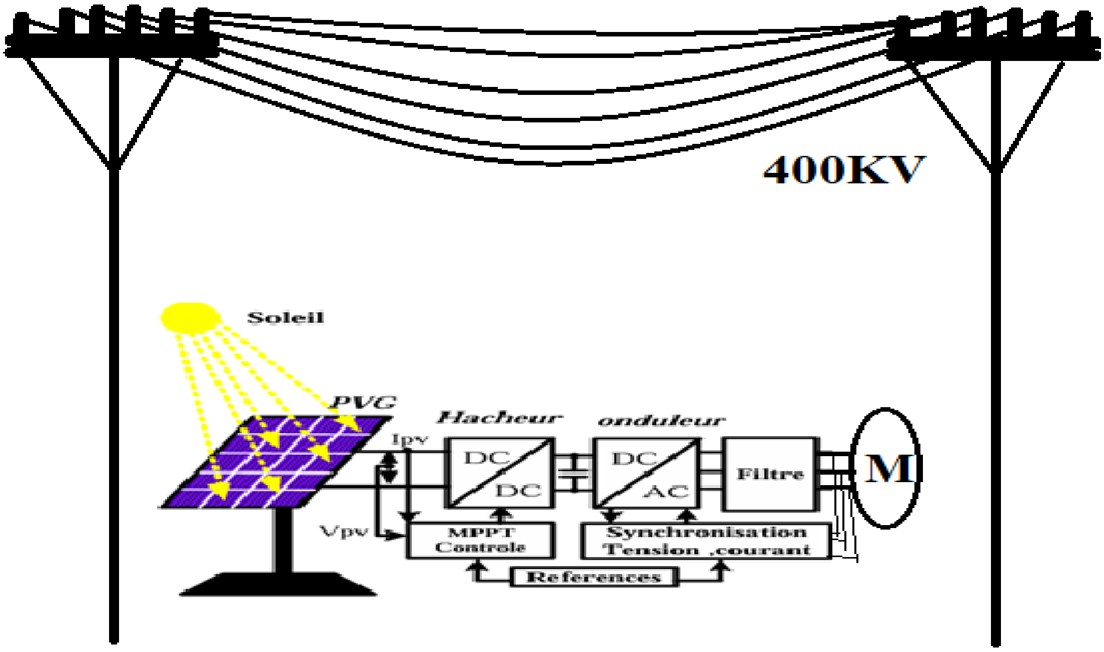


Fig. III.1: Block diagram of an off-grid PV system

We carried out the modelling and sizing of the different components of the studied system.

III.2 Modelling of Electrical Grids

The single-phase voltages of the 400 kV electrical grid can be represented using their RMS (root mean square) values.

$V = \frac{V_{max}}{\sqrt{2}}$ and with a frequency of 50 Hz by the following equations:

$$V_a = V_{max} \sin(wt) \quad \text{.......(III.1)}$$

$$V_b = V_{max} \sin\left(wt - \frac{2\pi}{3}\right) \quad \text{.......(III.2)}$$

$$V_c = V_{max} \sin\left(wt - \frac{4\pi}{3}\right) \quad \text{.......(III.3)}$$

III.3 Modelling of the Photovoltaic Panel

III.3.1 Case of an Ideal Cell

The simplest model of a PV cell is shown as an equivalent circuit in **Fig. III.2,** consisting of an ideal current source in parallel with an ideal diode. The current source represents the current generated by photons (commonly referred to as Iph), and its output remains stable under constant temperature and irradiance.

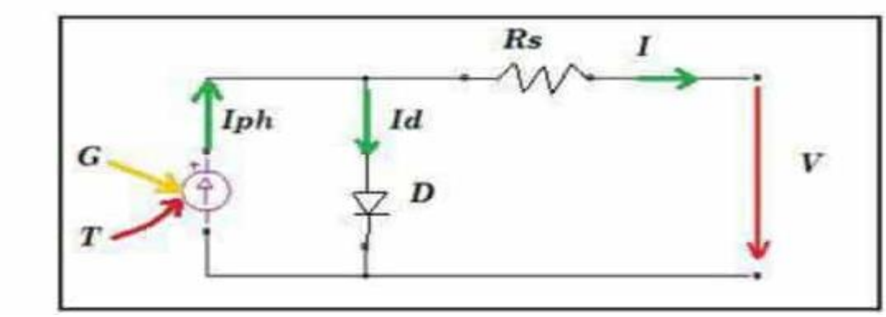


Fig. III.2: Equivalent circuit diagram of an ideal cell

There are two main parameters frequently used to characterize a PV cell: the short-circuit current and the open-circuit voltage. Module manufacturers usually provide the values of these parameters in their datasheets [**19].**

The output current **I=Ipv** of the **PV** cell is calculated by applying Kirchhoff's law to the equivalent circuit shown in the previous figure:

$$I = Ipv = Iph - Id \quad \text{(III.4)}$$

Iph: The current is considered equivalent to the short-circuit current Isc when

Vpv = 0 representing the short-circuit condition.

Id: The current flowing through the diode. The diode current is given by the Shockley equation as follows:

$$Id = I0\left(\exp\left(\frac{qv}{nkT}\right) - 1\right) \quad \text{(III.5)}$$

Where:

V: The output voltage [volts]

I_0: The reverse saturation current [amperes]

n: The quality factor

q: The electron charge constant,

K: The Boltzmann constant,

By substituting equation **(III.5**) into (**III.4**), we obtain the current-voltage relationship of the PV cell:

$$Ipv = Iph - I0\ (\exp\ (\frac{q(Vpv+IpvRs)}{n\ KT}) - 1) \ldots\ldots\ldots\ldots\ldots \textbf{(III.6)}$$

- ***Case of a Real Cell***

The equivalent circuit of a real photovoltaic cell takes into account parasitic resistive effects due to manufacturing, as shown in **Fig.III.3.**

This equivalent circuit consists of a diode **(d)** characterizing the junction, a current source representing the photocurrent, a series resistance (**Rs**), and a parallel resistance **(Rsh**) [**20**].

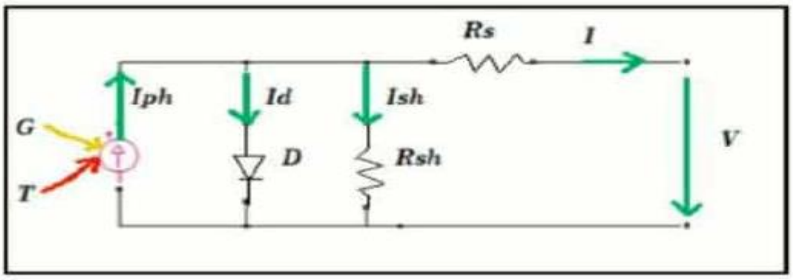


Fig. III.3: Equivalent circuit diagram of a photovoltaic cell

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

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

$$\textbf{Ipv = Iph – Id – Ish} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{(III.7)}$$

I_{pv}: The current generated by the photovoltaic cell is expressed in the following mathematical form:

I_{ph}: The photocurrent generated by the cell (proportional to the incident radiation)

I_d: The current flowing through the diode:

$$\textbf{Id = I0 (exp(} \frac{qv}{nkT} \textbf{) -1) = } I_0 \textbf{ (exp (}\frac{Vd}{Vt}\textbf{)} - 1 \ldots\ldots \textbf{(III.8)}$$

$$I_0 = Ior\ ((\frac{T}{Tn})^3\ e^{[\frac{Eg}{BK}(\frac{1}{Tn}-\frac{1}{T})]} - 1) \ldots\ldots\ldots\ldots\ldots\ldots \textbf{(III.9)}$$

I_{or}: The short-circuit current of the cell at reference temperature and irradiance.

T: The temperature of the PV cell junction [°K].

B: The ideality factor of the junction.

E_g: Bandgap energy [eV]

R_s: Series resistance, symbolizing the bulk resistance of the semiconductor material, as well as the ohmic and contact resistances at the cell connections.

V_{pv}: The output voltage

I_{sh}: The current flowing through the resistance .

$$\mathbf{Ish} = \frac{Vpv+Ipv.Rs}{Rsh} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(III.10)}$$

R_p: The shunt resistance represents leakage currents around the p-n junction and at the corners of the cell.

By substituting equations (**III.5)** and (**III.10**) into equation **(III.7**), the current becomes:

$$\mathbf{Ipv = Iph - I0}\ [e^{(q\frac{Vpv+IpvRs}{Vt})} - 1] - \frac{Vpv+Ipv.Rs}{Rsh} \quad \ldots\ldots\ldots\ldots\ldots\ldots\text{(III.11)}$$

III.4 Modelling of the Chopper

A chopper is an electronic device that converts one DC voltage level into another, typically using a controlled switch (such as an IGBT or MOSFET).

III.4.1 Operating Principle

A chopper operates by chopping the input voltage using a controlled switch (MOSFET, IGBT, etc.), followed by filtering to obtain a steady DC output voltage.

III.4.2 Types of Choppers

- Buck Converter:
- Boost Converter:
- Buck-Boost Converter: can be either greater or less than
- Bidirectional Chopper: Allows energy transfer in both directions

- ***Buck Chopper:***

This is a direct DC-DC converter, commonly known as a Buck Chopper or Series Chopper in the literature.

The switch shown in **Fig.III.4** can be replaced with a transistor, since the current always remains positive and the switching (opening and closing) must be controlled.

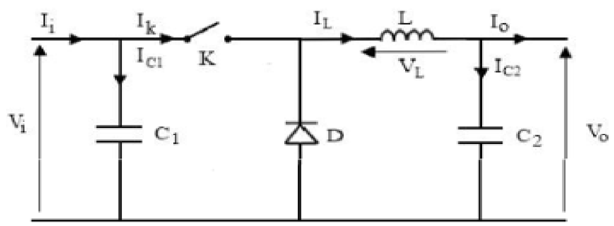


Fig. III.4: Buck Converter

- ***Equivalent Mathematical Model***

Fig.III.4 shows the equivalent circuit diagram of a buck converter when the switch is closed, while **Fig.III.5** represents the same converter when the switch is open during the time interval (1-α) Te

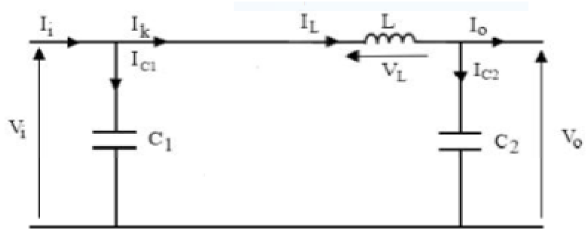


Fig. III.5: Buck Converter – Switch Closed

By applying Kirchhoff's law to the above circuit, we obtain the following equations:

$$Ic_1(t) = C_1\frac{dVi(t)}{dt} = Ii(t) - IL(t) \text{ ....}\textbf{(III.12)}$$

$$Ic_2\,(t) = C_2\,\frac{dV0(t)}{dt} = Ii(t) - I0(t)\text{......................}\textbf{(III.13)}$$

$$V_L(t) = L\,\frac{dIi(t)}{dt} = Vi(t) - V0(t)\text{......................}\textbf{(III.14)}$$

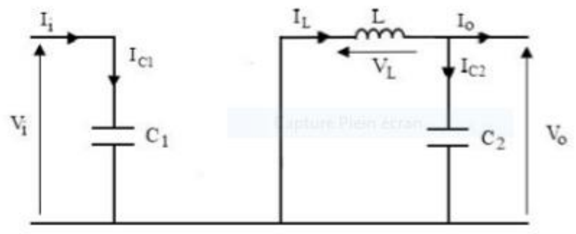


Fig. III.6: Buck Converter – Switch Open

$$Ic1(t) = C1\,\frac{dVi(t)}{dt} = Ii(t)\text{..........................}\textbf{(III.15)}$$

$$Ic2(t) = C2\,\frac{dV0(t)}{dt} = IL(t) - I0(t) \text{ ... ...}\textbf{(III.16)}$$

$$V_L(t) = L\frac{dIL(t)}{dt} = V0(t) \quad \text{(III.17)}$$

This DC-DC converter uses a DC input source, composed of an inductor in series with a voltage source, to supply a DC output load, which consists of a capacitor connected in parallel with a resistive load.

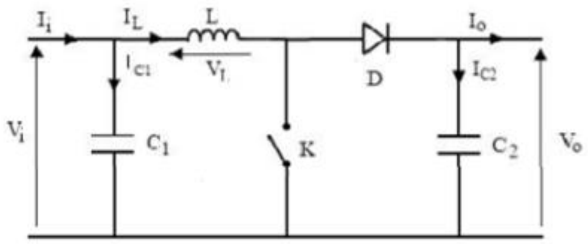


Fig. III.7: Boost Converter

- ***Equivalent Mathematical Model***

Fig.III.9 shows the equivalent circuit of the boost converter when switch **K** is closed, **i.e**., during the interval [0,αTe]

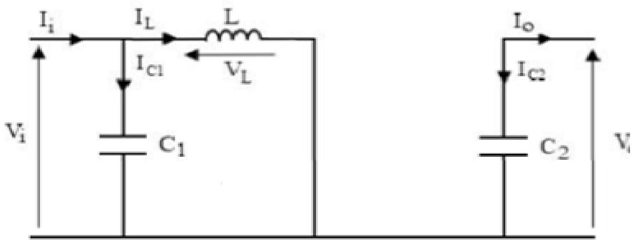


Fig. III.8: Boost Converter – Switch Closed

Applying Kirchhoff's laws to the equivalent circuits of the two operating phases gives the following equations:

$$Ic_1(t) = C1\frac{dVi(t)}{dt} = Ii(t) - IL(t) \quad \text{(III.18)}$$

$$Ic_2(t) = C2\frac{dVi(t)}{dt} = -I_0(t) \quad \text{(III.19)}$$

$$V_L(t) = L\frac{dVi(t)}{dt} = Vi(t) \quad \text{(III.20)}$$

When the switch **K** is open, the equivalent circuit representing the operation of the Boost converter is as follows:

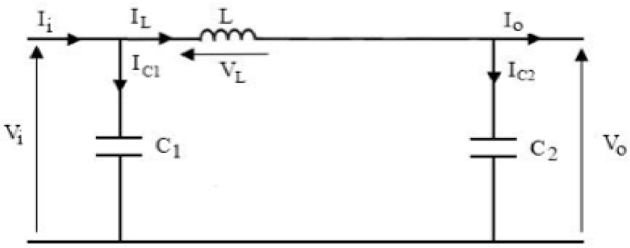


Fig. III.9: Boost Converter – Switch Open

$$Ic1(t) = C1 \frac{dVi(t)}{dt} = Ii(t) - IL(t) \quad \text{(III.21)}$$

$$Ic2\ (t) = C2 \frac{dV0(t)}{dt} = IL(t) - I0(t) \quad \text{(III.22)}$$

$$IL(t) = C1\frac{dIL(t)}{dt} = Vi(t) - V0(t) \quad \text{(III.23)}$$

The use of DC-DC converters provides high flexibility and efficiency in managing DC electrical power [**13**].

In our case, it helps maintain the optimal operating point despite variations in weather conditions.

III.5 Modelling of the Inverter

An inverter is a static converter that transforms direct current (**DC**) energy into alternating current (**AC**) energy. The output voltage waveform of the inverter should closely resemble a sine wave (sinusoidal shape), meaning the harmonic distortion must be very low, which largely depends on the control technique used. **Fig. III.11** shows the symbol of an inverter.

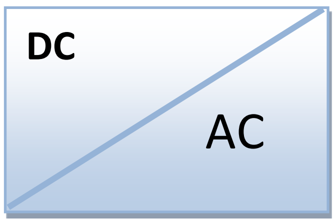


Fig. III.10: Symbol of the DC-AC Converter

The voltage inverter is typically composed of **IGBT** transistors or thyristors. It allows imposing voltage waveforms with variable amplitudes and frequencies on the grid, starting from a **DC** voltage. The diagram of a two-level three-phase inverter is shown in **Fig. III.12**. The DC bus is connected to a capacitor with capacitance **C** under a **DC** voltage **Vdc**. The inverter's objective is to maintain a constant voltage across the **DC** bus terminals and to adjust the power factor at the connection point with the grid.

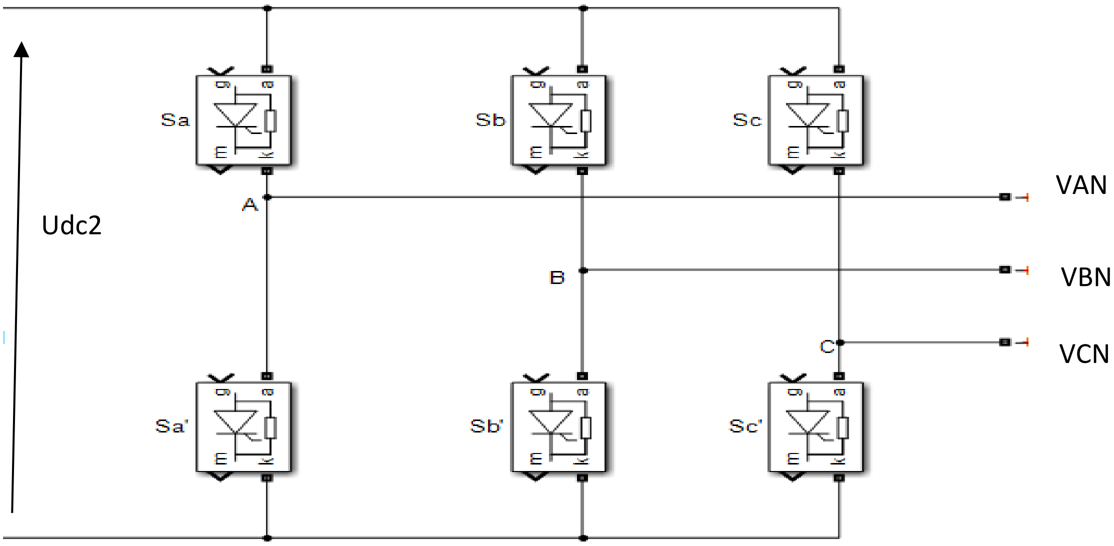


Fig. III.11: Structural Diagram of a Two-Level Three-Phase Inverter

The switches **(Sa, Sb ,Sc,** $\overline{Sa}, \overline{Sb}, \overline{Sc}$) are controlled in a complementary manner to ensure the continuity of the alternating currents in the load on one hand and to avoid short-circuiting the source on the other hand. The relationship between the DC voltage and the AC voltages varies depending on the state of these switches. The voltage vector at the output of the inverter is given by: [**17]**

$$\begin{bmatrix} Van \\ Vbn \\ Vcn \end{bmatrix} = [\frac{Vdc}{3}] \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} Sa \\ Sb \\ Sc \end{bmatrix} \quad \text{(III.24)}$$

Where:

$\mathbf{V_{dc}}$ is the **DC** bus voltage at the inverter input, (Sa,Sb,Sc,) are the switching states of the inverter legs for the three phases **(a,b,c)** , respectively. **[18].**

The number of possible switching states for a two-level inverter is eight, represented by eight voltage vectors: six active vectors and two zero vectors **(see Table III.1**)

If **ia,ib,ic** are the currents on the AC side, the current on the DC side can be given by:

$$I_{DC} = S_a i_a + S_b i_b + S_c i_c \quad \text{(III.25)}$$

Sa	Sb	Sc	Output vector
0	0	0	$V_0 = 0$
1	0	0	$V_1 = \frac{2}{3}\, Vdc$
1	1	0	$V_2 = \frac{1}{3}\, Vdc + J\frac{\sqrt{3}}{3}\, Vdc$
0	1	0	$V_3 = -\frac{1}{3}\, Vdc + J\frac{\sqrt{3}}{3}\, Vdc$
0	1	1	$V_4 = -\frac{2}{3}\, Vdc$
0	0	1	$V_5 = -\frac{1}{3}\, Vdc - J\frac{\sqrt{3}}{3}\, Vdc$
1	0	1	$V_6 = \frac{1}{3}\, Vdc - J\frac{\sqrt{3}}{3}\, Vdc$
1	1	1	V7 = 0

Table III.1: Possible Switching Sequences in a Two-Level Inverter

III.6 Filter

A filter in a solar power system is a device used to eliminate signal harmonics, thereby ensuring optimal operation and extending the system's lifespan **[13]**.

III.6.1 Filter Topology

There are several types of filters. These possible topologies are illustrated in **Fig. III.13**.

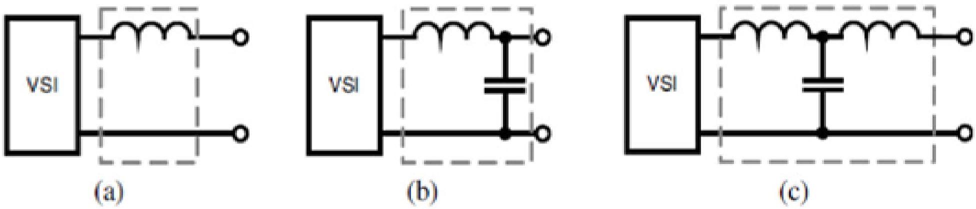


Fig. III.12: Basic Filter Topologies

III.7 Fuzzy Logic

The general principle and theoretical foundation of fuzzy logic involve aspects of possibility theory, using membership sets known as fuzzy sets to represent various system variables; and fuzzy reasoning, which enables the generation of appropriate control actions or decisions **[19].**

III.7.1 Fuzzy Logic Control

As with any fuzzy logic controller, the design follows three main steps, as illustrated in **Fig. III.14** Fuzzification: Converts real-world measurements—such as error and its derivative—into linguistic variables by assigning them to fuzzy subsets.

Rule Base and Inference: Uses a set of rules (IF...AND...THEN) to determine the fuzzy decision based on input states.

Defuzzification: Converts the fuzzy output decision into a crisp real-world value.

The complexity of fuzzy logic control generally lies in the tuning of input-output scaling gains and the definition of fuzzy control rules. This is the main focus of this section [**20].**

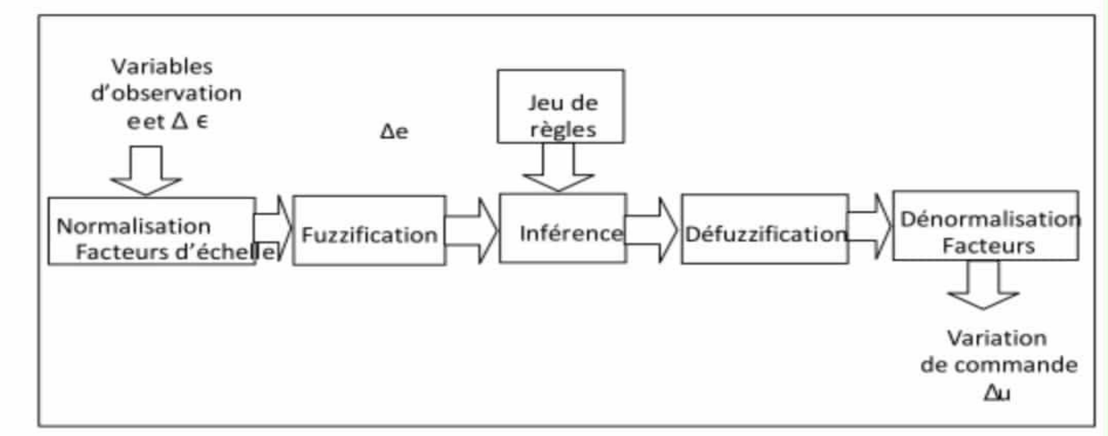


Fig. III.13: Structure of a Fuzzy Controller

III.8 Maximum Power Point Tracking (MPPT)

As shown in **Fig. III.15**, an MPPT (Maximum Power Point Tracker) controller is used to control the DC-DC converter by adjusting its duty cycle **[21].**

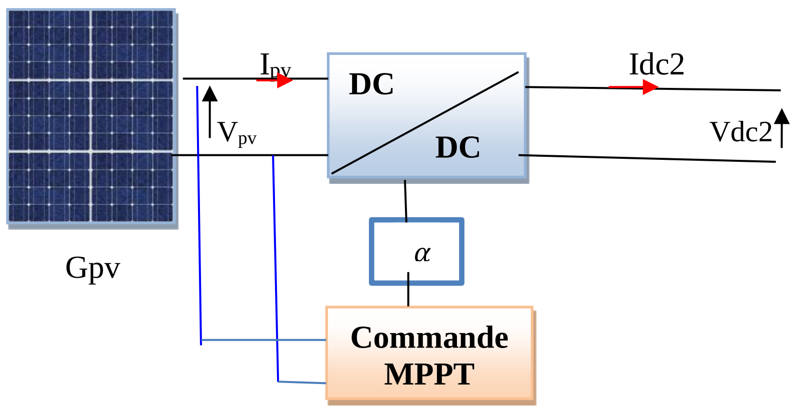


Fig. III.14: Basic Chain of a Photovoltaic System with a Converter

III.8.1 Need for MPPT Control

Harnessing solar energy holds great potential. Photovoltaic panels are designed to optimize performance. Even with a relatively low known efficiency, maximizing the extracted power is essential. However, PV panels are affected by weather conditions (sunlight, temperature, shading), which impact the amount of power that can be harvested **[22].**

In fact, even under constant conditions, the power extractable from a PV panel varies with the voltage (or current) applied across its terminals. Therefore, the operating system must adapt continuously to extract the maximum possible energy—this is the core idea behind **MPPT**.

III.8.2 Operating Principle of MPPT Control

During the operation of a PV generator, various disturbances can affect the Maximum Power Point (**MPP**). **Fig III.15** illustrates a case of such disturbances and shows how the **PV** system responds to them.

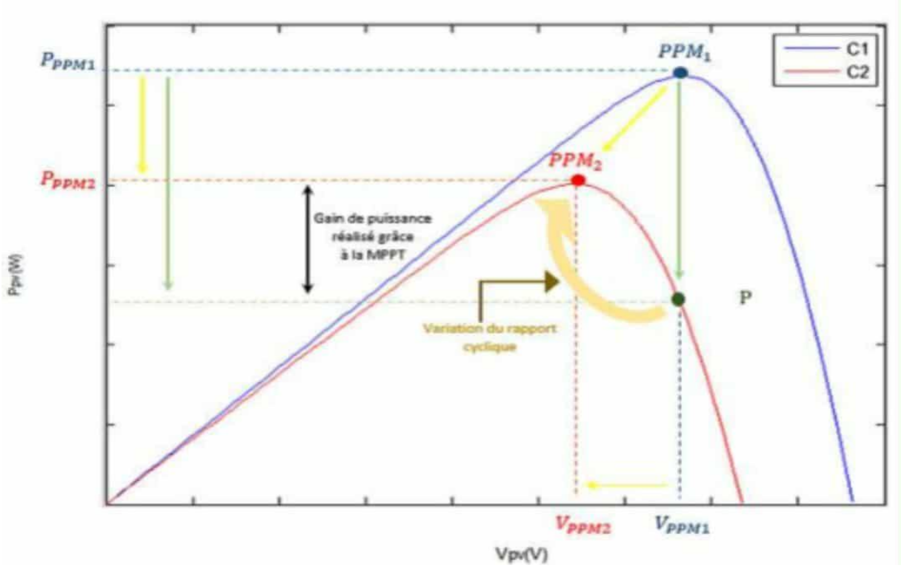


Fig. III.15: Tracking and Recovery of the Maximum Power Point (MPP)

We assume that a **PV** generator (**GPV**) operates under condition **C1**, which presents a single maximum power point **PPM1**. If **MPPT** tracking is properly ensured, the **PV** system can extract maximum power by aligning the operating point with PPM1. At some point, the operating condition shifts from **C1** to another condition **C2**. In response to this new condition, the duty cycle is adjusted so that the initial voltage $\mathbf{V_{PPM1}}$ changes to $\mathbf{V_{PPM2}}$, aligning the new operating point with the new maximum power point **PPM2** (as shown by the yellow arrows).

In contrast, if no tracking is performed—meaning the operating point voltage is not adjusted—the GPV maintains the previous voltage $\mathbf{V_{PPM1}}$. Since the operating condition has changed, the operating point shifts to a location on the new power curve that results in a lower power output (green arrows), thus not utilizing the full available power.

III.8.3 Methods for Maximum Power Point Tracking (MPPT)

To achieve optimal performance, **MPPT** control aims to transfer the maximum possible electrical power from the photovoltaic source to the connected load. MPPT algorithms can be grouped into three main categories, as summarized in **Fig. III.16**.

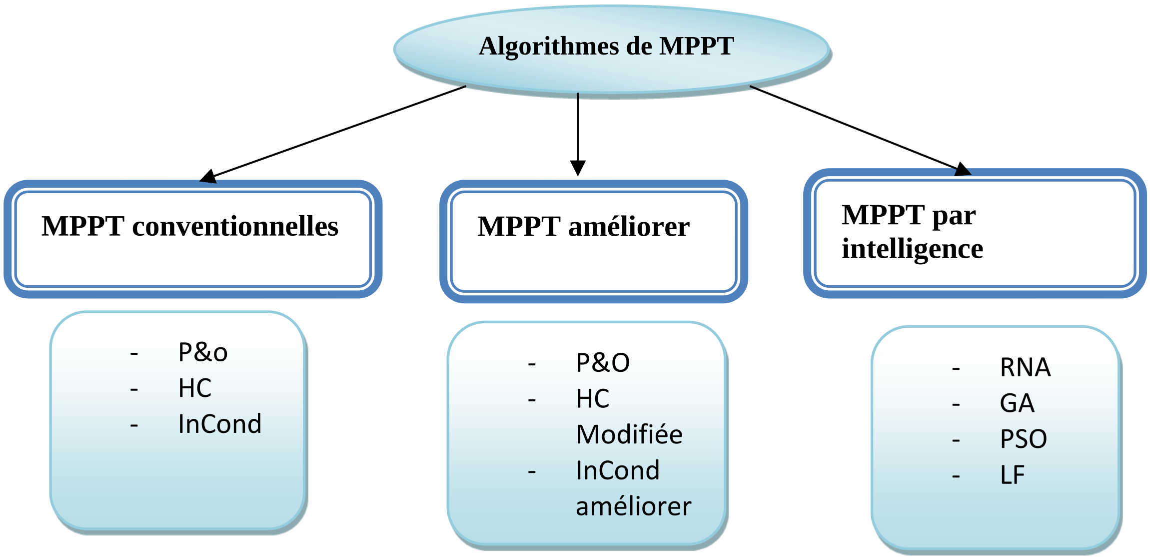


Fig. III.17: Classification of MPPT Methods

III.9 Modelling of an Induction Motor

The modelling of an asynchronous motor (or induction motor) is based on a set of fundamental formulas derived from its equivalent electrical circuit. Below are the key equations to be considered:

III.9.1 Slip (s)

Slip is defined as the relative difference between the synchronous speed and the rotor speed, and it is calculated as follows:

$$s = \frac{ns-n}{ns} \quad \text{.......................(III.26)}$$

- s: Slip (unitless, value between 0 and 1)
- n_s: Synchronous speed (in rpm)
- n: Rotor speed (in rpm)

III.9.2 Synchronous speed

$$ns = \frac{60\,f}{p} \quad \text{........................(III.27)}$$

- **f**: Network frequency (Hz)
- **p**: Number of pole pairs

III.9.3 Electromagnetic Torque

$$C = \frac{3\,P2}{ws} = \frac{3\,Re'.s.|I2'|^2}{ws} \quad \text{……………..(III.28)}$$

- P_2: Power transmitted to the rotor
- R_2': Rotor resistance referred to the stator
- I_2': Rotor current referred to the stator
- Ws = $\frac{2\pi\,ns}{60}$: Synchronous angular velocity

III.9.4 Voltage and Current

Based on the Park equivalent circuit or the Steinmetz equivalent circuit, the following equations can be written:

$$Zeq = R1 + j\,X1 + \left(\frac{j\,Xm.(\frac{R2'}{S}+jX2)}{\frac{R2'}{S}+j(X2+Xm)}\right) \quad \text{…………(III.29)}$$

And we deduce the stator current:

$$I1 = \frac{U1}{Zeq} \quad \text{…………………………..…………..(III.30)}$$

III.9.5 Absorbed Power and Efficiencies

- ***Active power absorbed:*** [23]

$$P1 = \sqrt{3}\,.U1.I1.\cos\theta \quad \text{…………………………(III.31)}$$

- ***Power transmitted to the rotor:***

$$P2 = P1 - P_{cu1} \quad \text{oA} \quad P_{cu1} = 3R_1I_1^2 \quad \text{……..…………(III.32)}$$

- ***Useful (mechanical) power:***

$$Pu = (1-s)\,.\,P_2 \quad \text{………………………………..(III.33)}$$

Conclusion

When integrated into the electrical grid, solar panels play a crucial role as a renewable, reliable, and sustainable energy source. This connection allows the direct injection of the energy produced into the grid, thus reducing dependence on conventional sources and improving overall energy efficiency. It also helps reduce electrical losses, stabilize the grid, and facilitates intelligent demand management through control and storage technologies.

Thus, grid-connected photovoltaic systems represent a strategic solution in the transition to a more sustainable and resilient energy system.

CHAPTER IV :

ENERGY AND ECONOMIC

IV.1 Economic Results

- ***Fig. IV.1***

Figure VI.1 shows an inverse relationship between the electric field (V/A) and the short-circuit current (Isc) of the PV panel.

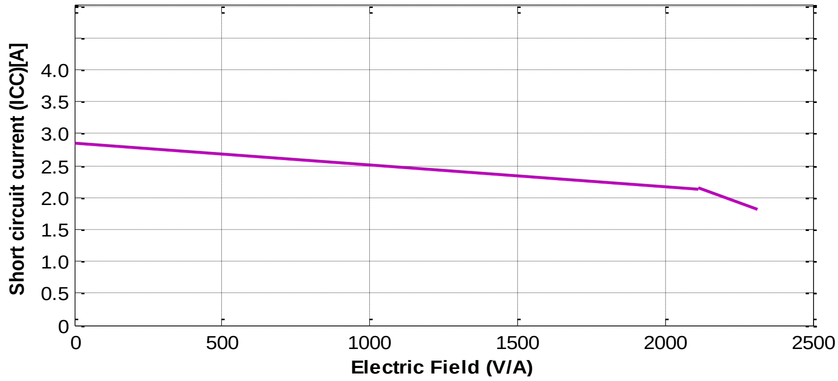


Fig.IV.1 : Short circuit current = **f** (Electric Field)

A nearly linear decrease in Isc is observed, dropping from approximately 2.7 A to 1.9 A as the electric field increases from 0 to 2350 V/A. This trend indicates a negative effect of the electric field on the panel's performance, particularly in the presence of high-voltage power lines (400 kV).

- ***FigIV.2***

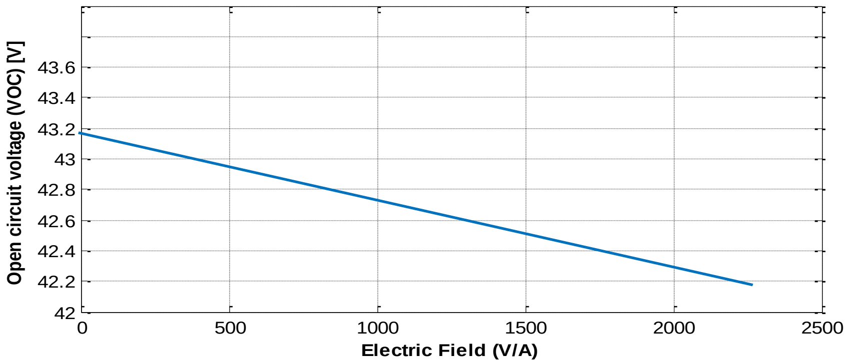


Fig.IV.2: Open circuit voltage = **f** (Electric field)

Fig.IV.2 shows the effect of the electric field **(V/A)** on the open-circuit voltage (Voc) of the photovoltaic panel. A linear decrease in voltage is observed, dropping from approximately **43.1 V** to **42.1 V** as the electric field increases from **0** to **2400 V/A**. This indicates that a high electric field reduces the panel's output voltage, which can negatively impact the overall efficiency of the photovoltaic system, especially near high-voltage power lines.

- ***Fig.IV.3***

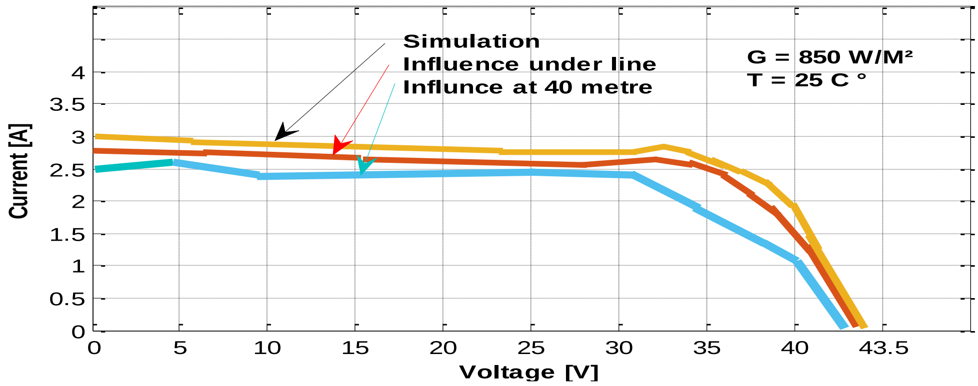


Fig.VI.3: Curent = f (Voltage)

Figure **IV.3** illustrates the current-voltage (**I-V**) characteristic of the panel under simulated and experimental conditions, with an irradiance of **850 W/m²** and a temperature of **25°C**. Three curves are presented:

- Simulation (**Orange**): represents the theoretical curve without disturbance.
- Influence under the line (**Red**): shows a significant decrease in both voltage and current.
- Influence at 40 meters (**Blue**): shows a slight improvement compared to the red curve but remains below the simulation.

It is observed that proximity to a high-voltage power line affects the panel's performance by reducing both the maximum voltage (**Voc**) and the output current, which lowers the generated power. The effect slightly diminishes as the distance from the line increases (**at 40 m**).

- ***Fig.IV.4***

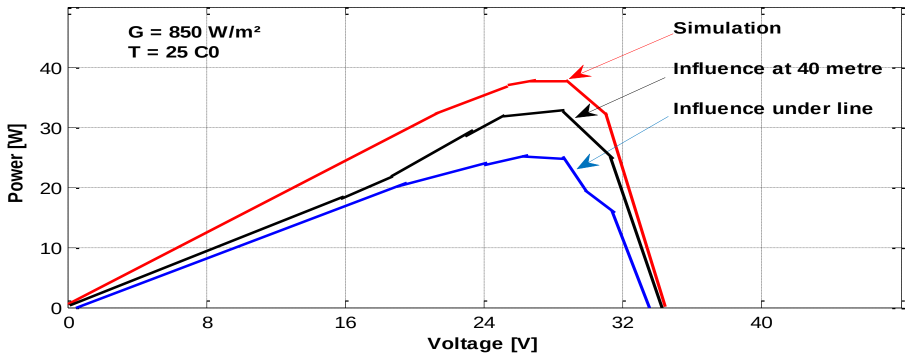


Fig.IV.4: Power = **f** (Voltage)

The figure shows that the output voltage of the **DC-DC** converter equipped with **MPPT** decreases under the effect of the electromagnetic field from a **400 k**V power line. The voltage is highest in the simulation, then decreases at **40 meters**, and reaches its minimum directly under the line. This demonstrates that the electromagnetic field degrades the performance of the **MPPT**.

- ***Fig.IV.5***

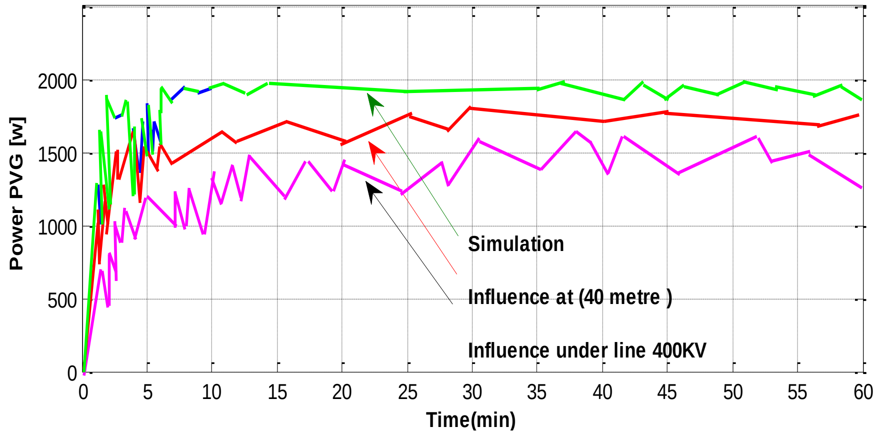


Fig.IV.5: Power = **f** (Time)

The curve shows that the power is highest under simulation conditions (**green line**), decreases under the influence of the field at **40 meters** (**red line**), and drops further under a 400 kV high-voltage line (**purple line**). This clearly indicates a negative impact of intense electromagnetic fields on the efficiency of photovoltaic panels.

- ***FigIV.6***

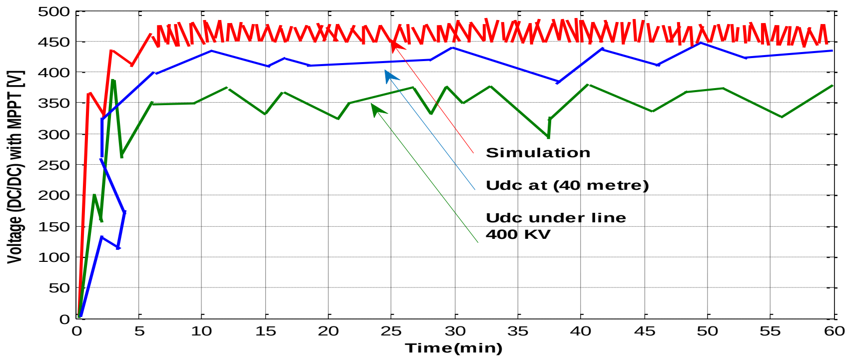


Fig IV.6 : Voltage with MPPT = **f** (Time)

The voltage is the most stable and highest in the simulation case (**red curve**). It decreases slightly at **40 meters** from a high-voltage line (**blue curve**) and drops further directly under a 400 kV line (**grey curve**). This indicates that the electromagnetic field negatively affects the performance of the DC-DC converter, especially in the direct presence of a very high-voltage line.

- ***FigIV.7***

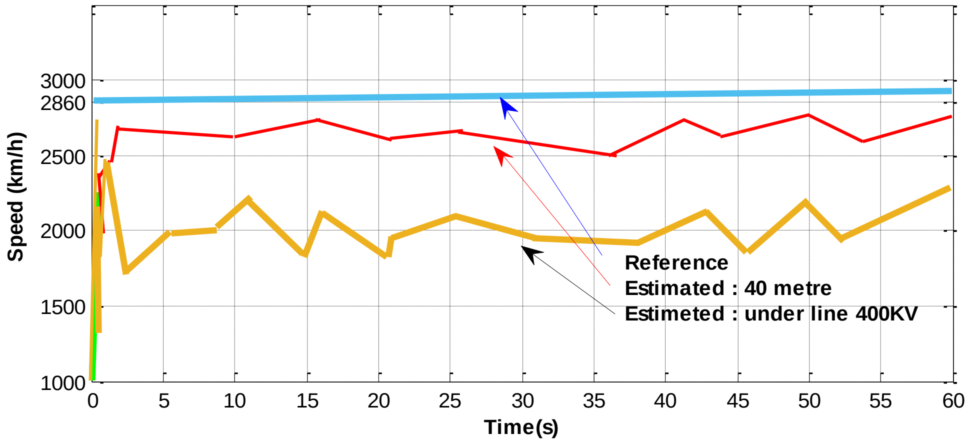


Fig.IV.7: Speed = **f** (Time)

The figure illustrates the effect of the electromagnetic field on the speed of an electric motor.

The reference speed is **2860 km/h**. The best performance was observed at **40 meters**, while a significant drop was recorded directly under the **400 kV** line, indicating a disturbance in speed control caused by the electromagnetic field.

Conclusion

In this chapter, the impact of electric voltage on solar panels was analysed through observations of images from the MATLAB program. It was demonstrated that excessive voltages can reduce the efficiency of the panels and cause issues such as wear and overheating. Therefore, it is essential to handle the panels with care and take preventive measures to ensure their proper operation and longevity.

GENERAL CONCLUSION

This thesis aims to highlight the importance of using solar energy to power irrigation systems, as a sustainable and efficient solution to current environmental and economic challenges.

The study examined the influence of electromagnetic fields generated by nearby high-voltage power lines, analysing their impact on the performance of electrical components, especially solar panels and power converters.

A technical and analytical approach was adopted, with a focus on the MPPT technology and its role in maximizing solar energy output. Simulations were carried out using MATLAB software to assess the system's performance in an environment affected by electromagnetic disturbances.

The results demonstrated that proper system design and careful selection of components, while considering external factors, can ensure high efficiency of the solar irrigation system, making it a promising solution for modern agriculture, particularly in remote areas.

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