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Maximum Power Point in Organic Photovoltaic cells by using RTO Optimization Algorithm.

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"Beauty is no quality in things themselves: It exists merely in the mind which contemplates them; and each mind perceives a different beauty."
David Hume

First of all, We thank the God who gave us the courage and the strength to continue and finish this modest work.

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Rachid Labsi

Abstract

Nowadays, a lot of research work has been done to improve the use of sun energy, the most prominent of which is researched the photovoltaic cells to produce electricity. The generation of electricity using photovoltaic solar cells has been one of the most researched and studied subjects. Photovoltaic is the technology that uses solar cells. A solar cell is an electronic device which directly converts sunlight into electricity. Light shining on the solar cell produces both a current and a voltage to generate electric power. This process requires firstly, a material in which the absorption of light raises an electron to a higher energy state, and secondly, the movement of this higher energy electron from the solar cell into an external circuit. The electron then dissipates its energy in the external circuit and returns to the solar cell. A variety of materials and processes can potentially satisfy the requirements for photovoltaic energy conversion, but in practice nearly all photovoltaic energy conversion uses semiconductor materials in the form of a *p-n* junction.

Because in the recent technology of PV cells has a very high cost, a new nanotechnology being inexpensive to fabricate, lightweight, and mechanically flexible, this revolutionary technology for electrical energy production called: ***Organic Photovoltaic cells** (OPV)* which is selected to do a study it in this work.

The Photovoltaic voltage-current (V-I) characteristic is nonlinear and changes with irradiation and temperature. In general, there is a point on the V-I or voltage-power (V-P) curves, called the **Maximum power point** (***MPP***), at which PV operates with maximum efficiency and produces its maximum output power. The state of the art techniques to track the maximum available output power of PV systems are called the maximum-power point tracking (MPPT).

The issue of maximum power point tracking (MPPT) has been addressed in different ways in the literature: examples of fuzzy logic, neural networks, DSP and Perturb and Observe (***P&O***) based implementations. Nevertheless, the Root Tree Optimization (***RTO***) technique is the best one used from its efficiency and robustness.

In this thesis, we have used the Root Tree Optimization (***RTO***) algorithm to search the Optimal value of maximum power point ($\boldsymbol{MPP_{opt}}$), for Organic Photovoltaic cells (***OPV***) and compare the obtained results to another method called *Perturb and Observe* (***P&O***), and this is done for a given temperature and irradiance, to improve the utilization of the produced energy when connected to a load.

Keywords: Optimal value of maximum power point (MPP_{opt}), Root Tree Optimization (*RTO*), Perturb and Observe (*P&O*), Organic Photovoltaic cells *(OPV),*

Photovoltaic voltage-current (V-I) characteristic.

الملخص

في الوقت الحاضر، تم القيام بالكثير من العمل البحثي لتحسين استخدام طاقة الشمس، ومن أبرزها البحوث المتعلقة بالخلايا الضوئية لإنتاج الكهرباء.
لقد كان توليد الكهرباء باستخدام الخلايا الشمسية الضوئية واحداً من أكثر المواضيع بحثا ودراسة.
الكهروضوئية هي التكنولوجيا التي تستخدم الخلايا الشمسية ، وهي عبارة عن جهاز إلكتروني يحول أشعة الشمس مباشرة إلى كهرباء. ينتج الضوء الساطع على الخلية الشمسية كلاً من التيار الكهربائي والجهد لتوليد الطاقة الكهربائية.و تتطلب هذه العملية أولاً ، مادة يرفع فيها امتصاص الضوء إلكترونًا إلى حالة طاقة أعلى ، وثانيًا ، حركة إلكترون الطاقة العالي هذا من الخلية الشمسية إلى دارة خارجية. ثم يقوم الإلكترون بتبديد طاقته في الدائرة الخارجية ويعود إلى الخلية الشمسية. يمكن أن تفي مجموعة متنوعة من المواد والعمليات بمتطلبات تحويل الطاقة الكهروضوئية ، ولكن في الممارسة العملية ، يستخدم كل تحويل الطاقة الكهروضوئية تقريبًا مواد أشباه الموصلات في شكل *p-n* junction.

ولأن التكنولوجيا الحديثة للخلايا الكهروضوئية لديها تكلفة عالية جدا ، وتكنولوجيا النانو الجديدة كونها غير مكلفة للتصنيع ، وخفيفة الوزن ، ومرنة ميكانيكيا ، هذه التكنولوجيا الثورية لإنتاج الطاقة الكهربائية تسمى: الخلايا الضوئية العضوية (***OPV***) والتي تم اختيارها هنا للقيام بدراستها في هذا العمل.

ان خاصية الجهد الكهروضوئي الحالية (V-I) غير خطية وتتغير مع الإشعاع ودرجة الحرارة. بشكل عام ، هناك نقطة على منحنيات V-I أو الجهد الكهربي (V-P) ، تسمى نقطة الطاقة القصوى (***MPP***) ، حيث تعمل PV بأقصى قدر من الكفاءة وتنتج أقصى طاقة خرج. يطلق على أحدث التقنيات لتعقب أقصى طاقة إنتاج متوفرة للأنظمة الكهروضوئية تتبع نقطة القدرة القصوى (MPPT).

لقد تمت معالجة مسألة تتبع نقطة القدرة القصوى (MPPT) بطرق مختلفة في الأطروحات: أمثلة على ذلك: المنطق الغامض والشبكات العصبية والتطبيقات القائمة على DSP و خوارزمية اضطراب ومراقبة (***P&O***). ومع ذلك ، فإن تقنية جذور الشجر المثالية (***RTO***) هي أفضل التقنيات المستخدمة من حيث كفاءتها وقوتها.

في هذه الرسالة ، استخدمنا خوارزمية جذور الشجر المثالية (***RTO***) للبحث في القيمة المثلى لنقطة الطاقة القصوى ($\boldsymbol{MPP_{opt}}$) ، للخلايا الضوئية العضوية (OPV) ومقارنة النتائج التي تم الحصول عليها بطريقة أخرى تسمى: خوارزمية اضطراب ومراقبة (***P&O***) ، ويتم ذلك بالحصول على درجة حرارة معينة والإشعاع ، لتحسين استخدام الطاقة المنتجة عند توصيله مع الحمل.

الكلمات المفتاحية: القيمة المثلى لنقطة الطاقة القصوى (MPP_{opt}) ، خوارزمية جذور الشجر المثالية (RTO) ، خوارزمية اضطراب ومراقبة (P&O)، الخلايا الضوئية العضوية (OPV) ، خاصية الجهد الكهروضوئي (V-I).

Résumé

Aujourd'hui, de nombreux travaux de recherche ont été réalisés pour améliorer l'utilisation de l'énergie solaire, Le plus important d'entre eux concerne les cellules photovoltaïques pour la production d'électricité. La production d'électricité à l'aide de cellules solaires photovoltaïques a été l'un des sujets les plus recherchés et étudiés.

Le photovoltaïque est la technologie qui utilise les cellules solaires. Une cellule solaire est un dispositif électronique qui convertit directement la lumière du soleil en électricité. La lumière sur la cellule solaire produit à la fois un courant et une tension pour générer de l'énergie électrique. Ce processus nécessite, d'une part, un matériau dans lequel l'absorption de la lumière élève un électron à un état d'énergie plus élevé, et, d'autre part, le mouvement de cet électron de plus haute énergie de la cellule solaire à un circuit externe. L'électron dissipe alors son énergie dans le circuit externe et retourne à la cellule solaire. Une variété de matériaux et de procédés peuvent potentiellement satisfaire aux exigences de la conversion d'énergie photovoltaïque, mais en pratique, presque toute la conversion d'énergie photovoltaïque utilise des matériaux semi-conducteurs sous la forme d'une jonction p-n.

Comme la technologie récente des cellules PV a un coût très élevé, une nouvelle nanotechnologie peu coûteuse à fabriquer, légère et mécaniquement flexible, cette technologie révolutionnaire de production d'énergie électrique appelée : **Cellules Photovoltaïques Organiques** (***OPV***) qui a été sélectionnée pour l'étudier dans ce travail.

La caractéristique tension-courant photovoltaïque (V-I) est non linéaire et change avec l'irradiation et la température. En général, il existe un point sur les courbes V-I ou tension-puissance (V-P), appelé point de puissance maximale (***MPP***), auquel PV fonctionne avec un rendement maximal et produit sa puissance de sortie maximale. Les techniques de pointe pour suivre la puissance de sortie maximale disponible des systèmes PV sont appelées la poursuite de point de puissance maximale (MPPT).

La question de la poursuite maximale du point de puissance (MPPT) a été abordée de différentes manières dans la littérature: exemples de logique floue, réseaux de neurones, DSP et implémentations basées sur l'algorithme de Perturbation et Observation (***P & O***). Néanmoins, l'algorithme d'Optimisation des Racines des Arbres (***RTO***) est la meilleure en termes d'efficacité et de robustesse.

Dans cette thèse, nous avons utilisé l'algorithme ***RTO*** *(Root Tree Optimization)* pour rechercher la valeur Optimale du point de puissance maximale (MPP_{opt}) dans les cellules photovoltaïques Organiques (***OPV***) et comparer les résultats obtenus à une autre méthode appelée : perturbation et observation (***P & O***). , et ceci est fait pour une température et un éclairement énergétique donnés, afin d'améliorer l'utilisation de l'énergie produite lorsqu'il est connecté à une charge.

Mots clés : valeur optimale du point de puissance maximale (*MPPopt*), l'algorithme d'Optimisation des Racines des Arbres (*RTO*), perturbation et observation (*P & O*), caractéristique courant-tension photovoltaïque (V-I).

Dedication

With all my heart, I dedicate this modest work.

To her who filled me with love and tenderness, At the candle that lit my way, my dear mother.

To the one who gave me the best of himself, my dear father.
To my dear wife and my children.

To all my family.

To all my electromechanical colleagues from the University of El Oued

promotion 2019.

To everyone I love.

Rachid Labsi

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A	Area.
K	Boltzmann constant (8.617×10^{-5} eV/K).
I	Current.
J	Current density.
E	Elementary charge (1.6×10^{-19} coulomb).
n	Ideality factor.
V_{oc}	Open circuit voltage.
J_{ph}	Photocurrent density.
I_{ph}	Photocurrent.
h	Planck's constant (6.626×10^{-34}Js).
P	Power.
P_{in}	Power per unit area.
ɳ	Power conversion efficiency.
I_0	Reverse saturation current.
J_0	Reverse saturation current density.
R_s	Series resistance.
R_{sh}	Shunt resistance.
I_{sc}	Short circuit current.
J_{sc}	Short circuit current density.
c	Speed of light (299, 792,458 m/s).
T	Temperature.
V	Voltage.

λ	Wavelength.
AM	Air Mass.
AM0	Air Mass zero solar spectral irradiance.
AM 1.5	Air Mass 1.5 solar spectral irradiance.
AM 1.5G	Global Air Mass 1.5 solar spectral irradiance.
MPP	Maximum Power Point.
MPP_{opt}	Optimal Maximum Power Point.
ICT	Information and Communications Technology
RTO	Root Tree Optimization.
P&O	Perturb and Observe.
H&C	Hill Climbing.
RCC	Ripple Correlation Control.
DE	Differential Evolution.
GA	Genetic Algorithm.
ANN	Artificial Neural Network.
FLC	Fuzzy Logic Controller
PSO	Particle swarm Optimization
OPV	Organic Photovoltaic.
IPV	Inorganic Photovoltaic.
PV	Photovoltaic.
Q	Electron Charge. (Coulomb).
σ	The frequency of photons.
GHI	Global Horizontal Irradiance.
STC	Standard Test Conditions: Irradiations 1KW/m^2 and Temp.25°C).
CREG	Electricity and Gas Regulatory Commission.

GPV	Photovoltaic Generator.
LUMO	Lowest Unoccupied Molecular Orbital.
HOMO	Highest Occupied Molecular Orbital.
PECVD	Plasma Enhanced Chemical Vapor Deposition.
CIGS	Copper Indium Gallium diselenide
CdTe	Cadmium Telluride.
DSSCs	Dye-Sensitized Solar Cells.
KCL	Kirchhoff Current Law
KVL	Kirchhoff Voltage Law
I-V	Current-Voltage Characterization
eff	Efficiency.
E	Energy.
FF	Fill Factor.
ITO	Indium Tin Oxyde.
P3HT	Poly (3-hexyl thiophene).
PCBM	(6,6)-Phenyl C_{61} – butyric Acid Methyl ester.
PEDOT	Poly (3, 4-ethylene dioxythiophene).
C1, C2 and C3	Adjustable Parameters.
P_{best}	Best Solution.
g_{-best}	Global best.
C_1, C_2	Acceleration constants.
w	Inertia weight.
$V_{i\,(k)}$	Velocity of i^{th} particle at iteration ‘k’.
w_{max}	Maximum value of weighting factor.
w_{min}	Minimum value of weighting factor.
$Iter_{max}$	Maximum number of iterations.
Iter	Current number of iteration.
M	Mesh trial point.

Δ_k	Mesh size parameter.
f_i	Fitness function.
x_c	Center of mass.
l	Upper limit of the parameter.
r	Normal random number.
x_{new}	New point xnew.
α_1, α_2 and α_3	Adjustable parameters.
P_m	Mutation rate.
P_c	Crossover rate Pc.
X_0	Initial points.
D_w	Degree wetter.
R_n	Rate of the nearest root to water.
It	Iteration step.
$x_{new}(It+1)$	New candidate for the iteration (It+1).
$x_{best}(It)$	Best solution to the previous generation.
i	Number of candidate.
N	Population scale.
l	Upper limit of the parameter end.
randn	Normal random number between [-1, 1].
R_c	Rate of the continuous root in its orientation Rc.
$X(It)$	Previous candidate for the iteration It.
rand	Random number between [0, 1].
R_r	Rate of the random root Rr.
X_r	Individual randomly selected from the previous generation.
c_1, c_2 and c_3	Adjustable parameters.

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General Introduction

During the past few years, the production of electrical energy is largely increased through conventional energy sources. Due to ever increasing demands for electrical energy and increased dependence on fossil fuels, the cost of unit power become high and also has adverse effects on environment. In order to overcome these problems, non-conventional energy sources are being used which help in decreasing carbon emissions, exhaustion and soaring prices of fossil fuels. The Photovoltaic power generation has shown a significant potential in fulfilling the worlds energy demand. The advantages of PGS include absence of fuel cost, low maintenance requirement, and environmental friendliness.

Due to these environmental and economic benefits, PV systems are being widely deployed as distributed energy resources in distribution generation systems and micro grids. However, the implementation and integration of PV systems still remains a great challenge due to very high investment cost. In parallel, other technologies based on ***Organic materials*** tend to develop and to solve in particular the problem of production costs.

Organic photovoltaic is a relatively new field since it has emerged in 1990s, and has since experienced a strong development especially from the early 2000s with successful scientific and technological breakthroughs. Today, some companies such as Heliatek, Mitsubishi Chemical, Belectric, invest in the development of this technology. Organic photovoltaic owns two advantages over the silicon industry that are: **i**) Likely low costs of production, and (**ii**) a potentially wider scope of application through flexibility and lightness of organic cells. Organic photovoltaic is a highly multidisciplinary field requiring advanced skills in molecular and macromolecular engineering, physic-chemistry and physical materials. Energy conversion efficiencies can be improved by working upstream on the understanding of chemical and physic-chemical mechanisms implemented in active materials and technological aspects of photovoltaic devices. Furthermore, there is no guarantee that the energy produced from PV cells keeps constant, because it depends entirely on the solar irradiance and ambient temperature. Second, the energy produced by the sun is restricted by the low conversion efficiency of PV module. So it is essential to make use of most of available solar energy.

As solar insolation and panel temperature vary with time, it is necessary to develop a MPPT algorithm to extract the Optimal value of maximum power from PV system at real time, therefore many methods have been proposed for MPPT like the Root Tree Optimization algorithm ***RTO***, Perturb and Observation (***P&O***), the Hill Climbing (H&C), the incremental conductance algorithm, Ripple Correlation Control (RCC), etc., performs well at high solar irradiance but the tracking efficiency drops at low sun irradiance.

In recent years, further research on PV MPPT has been conducted and the effect of partial shading condition has been taken in to account and have found that conventional methods show very poor

tracking performance. Many of them are not even able to track the true MPP under partially shaded PV array. Due to the inefficiency of these methods, several stochastic-based algorithms and artificial intelligence techniques have been developed, which are inspired by nature and biological structure. These include Particle swarm Optimization (PSO), Differential Evolution (DE), Genetic Algorithm (GA), Artificial Neural Network (ANN), Firefly, Fuzzy Logic Controller (FLC),…., can find solution to extract the maximum power under partially shaded and rapidly varying atmospheric condition.
The purpose of this work is to highlight the importance of new renewable energy which is known as '***Organic Photovoltaic (OPV)***', and provide an overview on the different generations for *OPV* then implement an equivalent circuit for the model to extract the important parameters of PV cell like I_{sc}, V_{oc}, Imax, V_{max}, FF, then calculate the most important parameter which is ***MPP***$_{opt}$ the Optimal Maximum Power Point by using the ***RTO*** algorithm.
At the end we showed the importance and the advantages of this technology in the market like it can be printed in different colors and styles making it a fancy add on and hence can be used on a number of products. Umbrellas, back-packs and tents being the products they will be really effective and very beneficial to the military as well. Soldiers are always in a need of power supply being in the out and always on the move. It will be make things easier to him if he can produce electricity from his tent and back-pack to recharge his satellite phone, GPS and other instruments needed.
This thesis consists of four chapters as follows:

Chapter I, an Introduction to Renewable Energy system is presented and the motivations for the research on this topic are presented.

Chapter II, We introduced the Organic Photovoltaic (OPV) devices and how it is offer great technological potential to make renewable source of electrical energy. The potential of organic photovoltaic resides in their low cost, not because of the low price of the materials applied, but due to the printing techniques applied for their fabrication.

Chapter III, we implemented an equivalent circuit for *OPV* cell in order to get a good idea on the electrical behavior and observe how the device parameters changes with any kind of applied treatment (Temperature, illumination, etc.) to the device, it is modeled with discreet electrical components such as voltage or current sources, diodes and resistors. It provides a scientific and realistic physical explanation for the Photovoltaic cells behavior.

Chapter IV, we proposed a new method for Optimization which is called *Root Tree Optimization* algorithm (***RTO***), this algorithm improved its robustness and efficiency which is validated on nonlinear functions and compared to recent methods (***P&O***) addressing the same problem; simulation results confirm its efficiency and reliability during the search of Optimal value for Maximum Power Point (***MPP_{opt}***) of solar cells.

We ended our work with a general conclusion and the future perspectives in this domain.

Chapter I

Introduction to Renewable Energy

Resume:

The aims of this chapter is to introduce the basic concepts of solar energy and power generation through the photovoltaic effect. The main elements of the photovoltaic system, the design parameters and the importance of PV systems in the future.

« You must understand the process before you can control it & the simplest control system that will do the job is the best. »

William L. Luyben (1990)

I.1 Introduction:

Solar energy is certainly the most elegant source of renewable energy. It does not require any particular maintenance and remains reliable for a long time, which is why it has become a reference in space applications and remote sites [01].
When light hits the surface of a photovoltaic cell part of their energy is restored as electrical energy. This phenomenon is called "Photovoltaic effect".
The combination of several PV cells in series / parallel gives rise to a Photovoltaic Generator (GPV) which produces high powers. The electrical energy thus produced is used in different ways to meet the needs of consumers [02].
This chapter aims to introduce the basic concepts of solar energy and power generation through the photovoltaic effect. The main elements of the photovoltaic system, the design parameters and the control methodologies of PV systems are discussed.

I.2 Solar Energy:

Solar energy, radiant light and heat from the sun, has been harnessed by humans since ancient times using a range of ever-evolving technologies. Solar energy technologies include solar heating, solar photovoltaic, solar thermal electricity and solar architecture, which can make considerable contributions to solving some of the most urgent problems the world now faces.
Solar technologies are broadly characterized as either passive solar or active solar depending on the way they capture, convert and distribute solar energy.
Active solar techniques include the use of photovoltaic panels and solar thermal collectors to harness the energy.
Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light dispersing properties, and designing spaces that naturally circulate air.

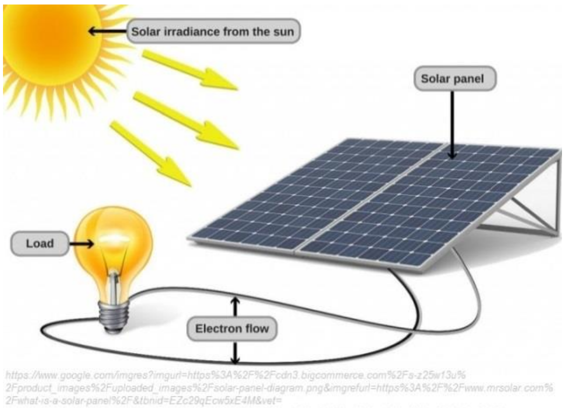


Figure.I.1 : *Solar Energy*

In 2011, the International Energy Agency said that "the development of affordable, inexhaustible and clean solar energy technologies will have huge longer-term benefits. It will increase countries' energy security through reliance on an indigenous, in exhaustible and mostly import-independent resource, enhance sustainability, reduce pollution, lower the costs of mitigating climate change, and keep fossil fuel prices lower than otherwise. These advantages are global. Hence the additional costs of the incentives for early deployment should be considered learning investments; they must be wisely spent and need to be widely shared".

I.2.1 Energy from the Sun:

The Earth receives 174 petawatts (PW) of incoming solar radiation(insolation) at the upper atmosphere. Approximately 30% is reflected back to space while the rest is absorbed by clouds, oceans and landmasses. The spectrum of solar light at the Earth's surface is mostly spread across the visible and near-infrared ranges with a small part in the near-ultraviolet. [03] Earth's land surface, oceans and atmosphere absorb solar radiation, and this raises their temperature. Warm air containing evaporated water from the oceans rises, causing atmospheric circulation or convection. When the air reaches a high altitude, where the temperature is low, water vapor condenses into clouds, which rain onto the Earth's surface, completing the water cycle. The latent heat of water condensation amplifies convection, producing atmospheric phenomena such as wind, cyclones and anti-cyclones.[04] Sunlight absorbed by the oceans and land masses keeps the surface at an average temperature of 14 °C.[05] By photosynthesis green plants convert solar energy into chemical energy, which produces food, wood and the biomass from which fossil fuels are derived.[06]The total solar energy absorbed by Earth's atmosphere, oceans and land masses is approximately 3,850,000 Oxyjoules (EJ) per year.[07] In 2002, this was more energy in one hour than the world used in one year.[08][09] Photosynthesis captures approximately 3,000 EJ per year in biomass.[10] The amount of solar energy reaching the surface of the planet is so vast that in one year it is about twice as much as will ever be obtained from all of the Earth's on-renewable resources of coal, oil, natural gas, and mined uranium combined.[11]Solar energy can be harnessed in different levels around the world. Depending on a geographical location the closer to the equator the more "potential" solar energy is available.
it is now admitted that the sun is a thermonuclear hydrogen-helium bomb transforming every second 564 million tons of hydrogen into 560 million tons of helium; the reaction takes place in its nucleus at a temperature of about 25 million degrees Celsius. Thus, every second, the sun is lightened by 4 million tons dispersed in the form of radiation [07]. Its light, at a speed of 300000km / s, takes about 8 minutes to reach the earth, its spectral distribution of the atmosphere is presented a maximum for a wavelength of about 0.5m, the black body temperature to the surface of the sun is about 5780 ° k:

Sun diameter = 1,391 million km
Diameter of the earth = 12 742 km
Average distance sun_ earth = 149,6 million km

I.2.2 Air Mass (AM) and Standardized Solar Spectrum:

The Air Mass is the path length which light takes through the atmosphere normalized to the shortest possible path length (that is, when the sun is directly overhead). The Air Mass quantifies the reduction in the power of light as it passes through the atmosphere and is absorbed by air and dust. The Air Mass is defined as :

$$AM = \frac{1}{\cos(\theta)}$$

where **θ** is the angle from the vertical (zenith angle). When the sun is directly overhead, the Air Mass is 1.

The efficiency of a solar cell is sensitive to variations in both the power and the spectrum of the incident light. To facilitate an accurate comparison between solar cells measured at different times and locations, a standard spectrum and power density has been defined for both radiations outside the Earth's atmosphere and at the Earth's surface.
The standard spectrum at the Earth's surface is called AM1.5G, (the G stands for global and includes both direct and diffuse radiation) or AM1.5D (which includes direct radiation only). The intensity of AM1.5D radiation can be approximated by reducing the AM0 spectrum by 28% (18% due to absorption and 10% to scattering). The global spectrum is 10% higher than the direct spectrum. These calculations give approximately 970 W/m^2 for AM1.5G. However, the standard AM1.5G spectrum has been normalized to give 1kW/m^2 due to the convenience of the round number and the fact that there are inherently variations in incident solar radiation.
The standard spectrum outside the Earth's atmosphere is called AM0, because at no stage does the light pass through the atmosphere. This spectrum is typically used to predict the expected performance of cells in space. [12]

I.2.3 Spectrum of Radiation:

Electromagnetic radiation is composed of "grains" of light called photons. The energy of each photon is directly related to the wavelength λ: The spectrum of the extraterrestrial radiation corresponds approximately to the emission of a black body brought to 5800 ° K. A standard curve, compiled according to the data collected by the satellites, is referred to as AM0. Its energy distribution is divided into

- Ultraviolet UV 0.20 < l < 0.38 mm 6.4%
- Visible 0.38 < l < 0.78 mm 48.0%
- Infrared IR 0.78 < l < 10 mm 45.6%

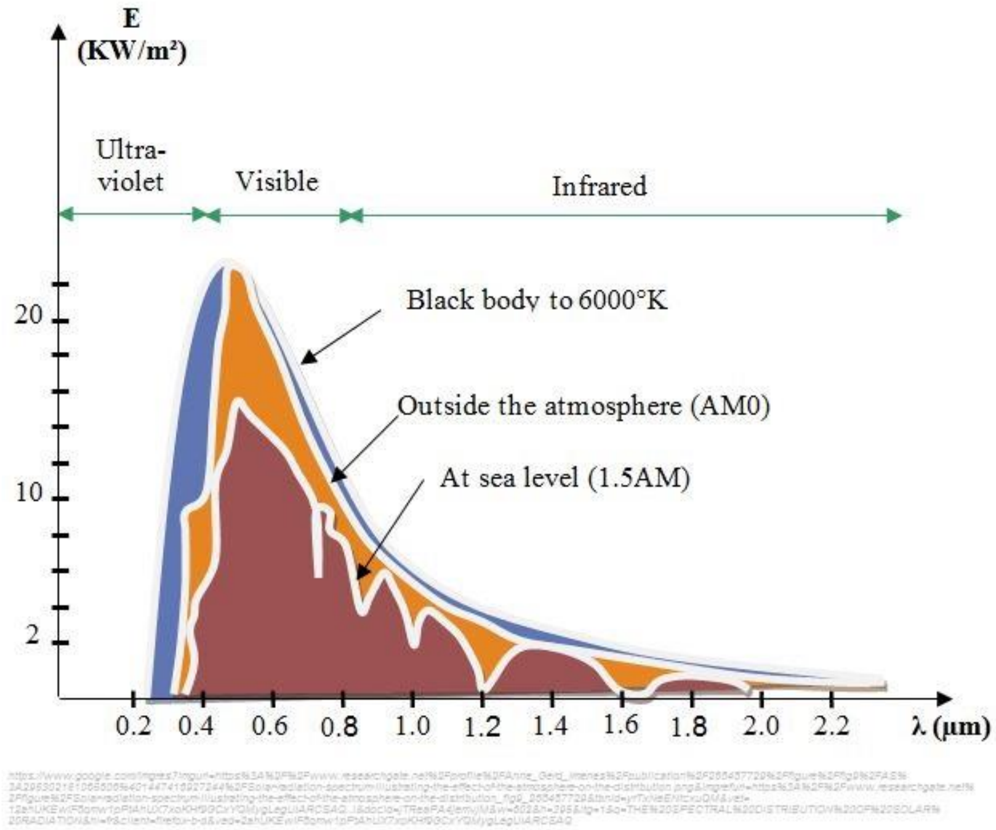


Figure.I.2: *The spectral distribution of solar radiation.*

I.2.4 Duration of Sunstroke:

The duration of insolation is the number of hours in the day, between sunrise and sunset, where it is clearly visible. The survey is made by means of the Campbell-Stokes heliograph in which a crystal sphere concentrates the sun's rays on a paper which it burns while moving. Thus, only the moments when the sun is clearly visible are recorded; this is known as actual or actual insolation duration and depends on whether the sun is visible from the observation point or hidden by the clouds.

In the absence of the heliograph, it is possible from the calculation of the relative astronomical movement of the sun and the earth to evaluate the theoretical duration of the day; that is to say, that which would be if the clouds did not hide the sun. This duration is calculated according to the latitude of the site and the apparent declination which itself depends on the period of the year considered.

I.3 Photovoltaic system:

The term "photovoltaic" comes from the Greek (phos) meaning "light", and "voltaic", meaning electrical, from the name of the Italian physicist Volta, after whom the unit of electrical potential, the volt, is named.

A photovoltaic system, also PV system or solar power system is a power system designed to supply usable solar power by means of photovoltaic. It consists of an arrangement of several components, including solar panels to absorb and convert sunlight into electricity, a solar inverter to convert the output from direct to alternating current, as well as mounting, cabling, and other electrical accessories to set up a working system. It may also use a solar tracking system to improve the system's overall performance and include an integrated battery solution, as prices for storage devices are expected to decline. Strictly speaking, a solar array only encompasses the ensemble of solar panels, the visible part of the PV system, and does not include all the other hardware, often summarized as balance of system (BOS). As PV systems convert light directly into electricity, they are not to be confused with other solar technologies, such as concentrated solar power or solar thermal, used for heating and cooling. [13]

PV systems range from small, rooftop-mounted or building-integrated systems with capacities from a few to several tens of kilowatts, to large utility-scale power stations of hundreds of megawatts. Nowadays, most PV systems are grid-connected, while off-grid or stand-alone systems account for a small portion of the market.

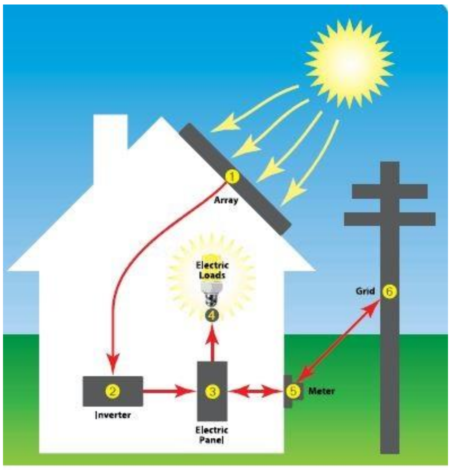


Figure.I.3: *The Photovoltaic System.*

I.4 Photovoltaic effect:

Photovoltaic cell (*PV cell*) is a device based on semiconductor materials (s / c) for the direct conversion of light energy into electrical energy. This particular transformation of energy from one form to another goes through the two steps described below:

Step_1 : The photon / semiconductor interaction :

During this step the photons, constituting the light, interact with the (s / c); those with an energy **E = h * σ** greater than its gap will be absorbed and their energy will be transferred to the electrons of the valence band. With this extra energy a valence electron can escape from its normal position in the atom creating a hole, a neighbouring electron fills this vacancy leaving behind a hole, so we have established a hole current in the valence band and an electron current in the conduction band. So the photon / electron interaction results in the generation of electron / hole pair that modifies the conductivity of the material.

Step_2 : Collecting electrical charges generated in the material :

To be able to generate the stream of carriers thus created, it must be possible to separate them in order to avoid their recombination. This is only by the application of an electric field created by a PN junction made by doping the material constituting the cell. This doping is of two types: N type doping [addition of phosphorus (p)] and P type doping [addition of boron (B)].
Incident photons create carriers in the (N) and (P) zones and in the space charge area. The behavior of the photo carriers differs according to the region, thus giving a generation photocurrent and a diffusion photocurrent. These two conditions are added to give a current I_{ph} proportional to the luminous intensity.

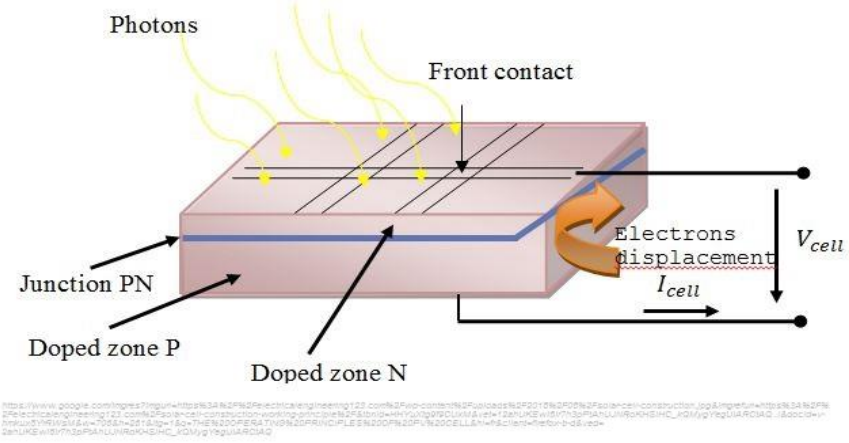


Figure.I.4: *The operating principle of a PV cell.*

I.5 The Future of Renewable Energy in Algeria:

The fiscal dependence of Algeria from the export of its massive oil and gas **reserves**, combined with the fact that over 90% of the country's electricity generation is based on this resources, poses serious problems in facing the growing residential electricity demand. Moreover, the slump in prices of oil since the third quarter of 2014 has nearly halved Algeria's foreign currency reserves.

In 2016, in order to avoid other risks derived from fossil fuels price fluctuation, the Prime Minister launched an ambitious set of reforms aimed at diversifying away from oil and boosting sectors in Algeria such as manufacturing, agriculture, renewable energy, information and communications technology (ICT) and tourism.

The Renewable Energy and Energy Efficiency Development Plan**,** launched with its first version in 2011 and updated in 2015, has put greater focus on deployment of large-scale solar photovoltaic installations and onshore wind in Algeria due to large technology costs decrease as well as introduction of biomass, cogeneration and geothermal technologies into the mix until 2020.

The updated version of the Program aims to install 4,500 MW of new projects until 2020 and overall of 22,000 MW until 2030 Algerian capacity, splitted as follow:

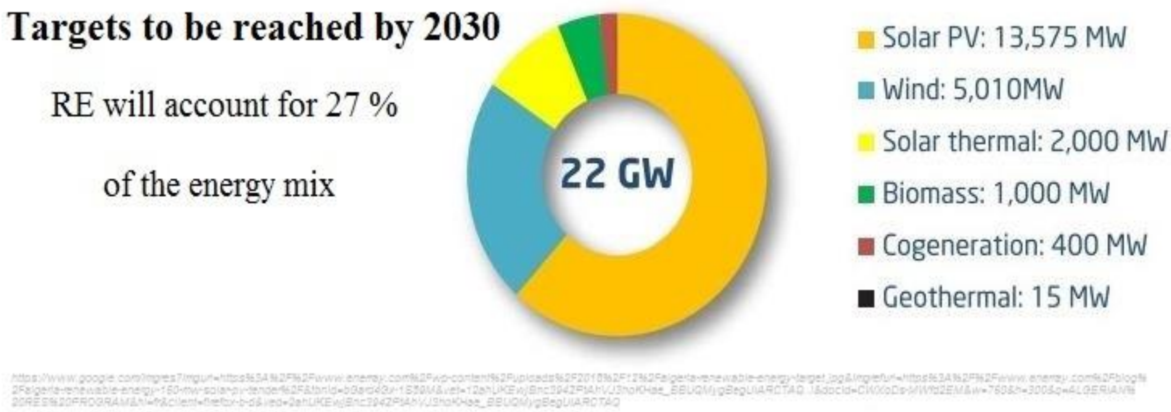


Figure.I.5: *Algerian RES Program.*

The implementation of this solar program has recently been clarified through Executive Decree No. 17-98 of 26 February 2017, which provides the legal basis for tendering of renewables and cogeneration energies**,** as well as its integration into the national electricity supply system. Selected renewable energy projects had to be owned and developed by special purpose companies, which were also responsible for financing, EPC works, grid-connection and the sale of power. These vehicles had to be owned 51% by a domestic investor and 49% by an international partner. The government indicated CREG as responsible for the tendering process rather than the new born Ministry of Renewable Energy which will manage small plants and rooftop plants.

The renewable source with the largest potential in Algeria is solar PV. The solar potential accounts for 3,000 hours of insolation per year and covers a surface area of 2,381,745 km2. This potential is mostly located in the southern part of the country, with an insolation ranging from 1,800 to 2,400 kWh/m2 (GHI – Global Horizontal Irradiance). Since 2015, about twenty solar photovoltaic facilities, with a total capacity of **343 MW**, have been in operation in the regions of the Hauts-Plateaux and the south of the country. [14]

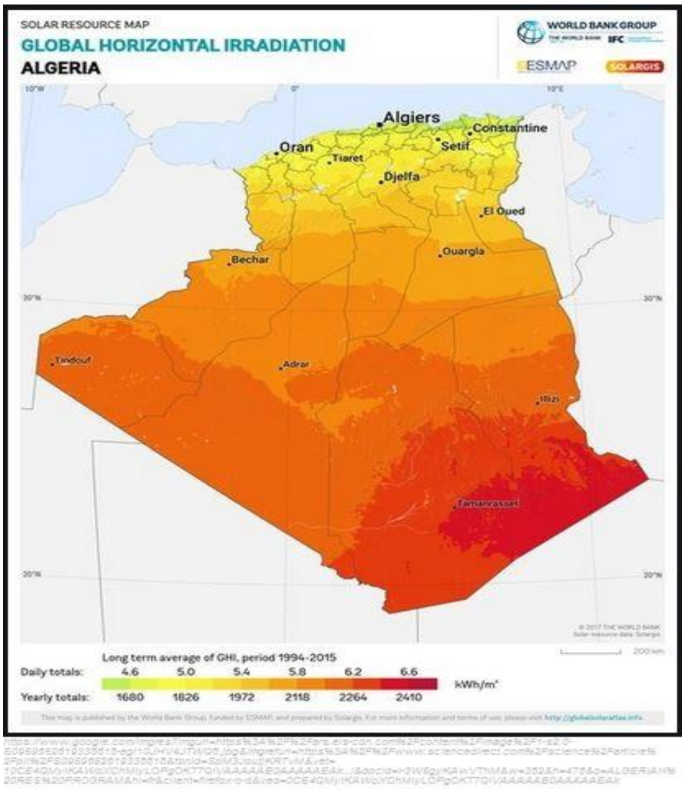


Figure.I.6: *The Global Horizontal Irradiation*

The Algerian government issued the first solar tender in November 2018. Through the tender, the Algerian Government will select IPP solar projects with a capacity range of **10-50 MW**, for a total capacity of **150 MW**. The solar PV plants will be located in the centre and northern part of Algeria, in the regions of **Ghardaïa, Biskra, Ouargla, El Oued, Tendala and Nakhla**.

All the projects will be developed on a build-own-operate basis (BOO) and will be awarded 20-year power purchase agreements (PPAs)**.** Domestic content rules require the use of solar modules assembled in Algeria, as well as locally manufactured mounting structures and cables.

The Algerian Minister of Energy said that the reference price for this first round of the upcoming auction is not expected to surpass 4 DZD/kWh (approximately $0.04/kWh).

A second 50 MW tender, which will be held by Algerian state-owned power and gas provider, Sonelgaz through its unit SKTM, is in program for the development of off-grid hybrid gas/diesel and solar projects in early June 2019. This project will drastically lower the cost of existing power generation stations in the south of Algeria, which are mostly based on fossil fuels. [14]

Chapter II

Organic Photovoltaic (OPV)

Resume:

The purpose of this chapter is to introduce the Organic Photovoltaic (OPV) devices and how it is offer great technological potential to make renewable source of electrical energy. The potential of organic photovoltaic resides in their low cost, not because of the low price of the materials applied, but due to the printing techniques applied for their fabrication. Among the challenges to overcome for this technology are the improvement of solar cell efficiency and lifetime limitation resides in the degradation of the organic semiconductors due to presence of oxygen or moisture from the atmosphere, thus encapsulation of these devices is required.
Several attempts have been made in order to find new electron transport materials with better transport properties and higher stability towards oxygen.

« You must understand the process before you can control it &
the simplest control system that will do
the job is the best. »
William L. Luyben (1990)

II.1 Introduction:

An Organic solar cell or Organic Photovoltaic (OPV) cell is a photovoltaic cell that uses organic electronics-a branch of electronics that deals with conductive organic polymers or small organic molecules for light absorption and charge transport. The plastic used in OPV cells has low production costs in high volumes. Combined with the flexibility of organic molecules, OPV cells are potentially cost-effective for photovoltaic applications. The optical absorption coefficient of organic molecules is high so a large amount of light can be absorbed with a small amount of materials. [15] The main disadvantages associated with organic photovoltaic cells are low efficiency, low stability and low strength compared to inorganic photovoltaic (IPV) cells. A fundamental difference between solar cells based on organic materials and conventional IPV cells are that light absorption results in the formation of exciting in molecular materials, rather than in free electrons and holes. Due to its electrical neutrality and the strong binding energy between the hole and the electron it can be regarded as a mobile excited state.

Solar cells in which exciting are generated due to light absorption, here after denoted as OPV cell will be discussed and describe the working principle of OPV cell. Also we will go through the different generation's types of OPV from the first generation to the next one.
At the end, the improvement of organic photovoltaic in the future will be discussed from its efficiency and life time duration.

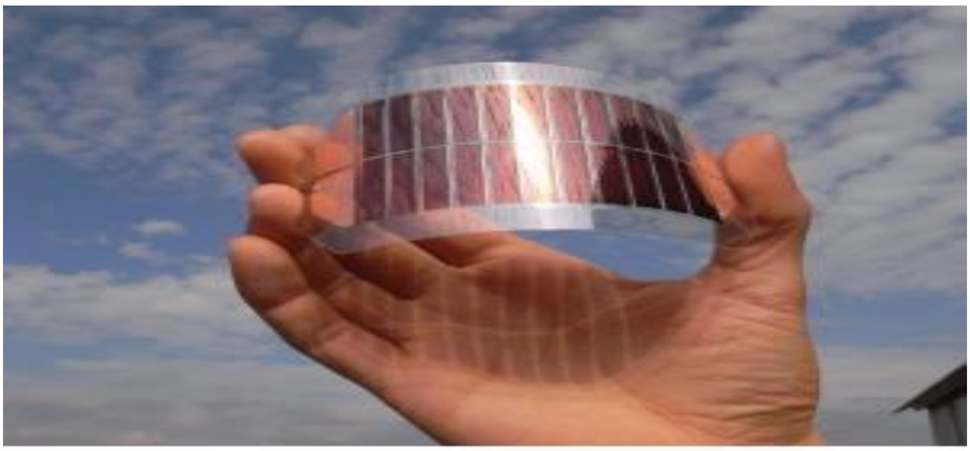


Figure II.1. *Organic Solar Cell*

II.2 History of OPV cells:

Solar photovoltaic energy conversion is one-step conversion process, which generates electrical energy from light energy. The photovoltaic effect was first reported by *Edmud Becquerel* in 1839 when he observed that the action of light on a silver coated platinum electrode immersed in an electrolyte produced an electric current. Forty years later the first solid state photovoltaic devices were constructed by workers investigating the recently discovered photoconductivity of selenium. In 1876 *William Adams* and *Richard Day* found that a photocurrent could be produced in a sample of selenium when contacted by two heated platinum contacts. In 1894, *Charles Fritts* prepared what was probably the first selenium solar cell, obtaining an efficiency of 1 % selenium [16]. Phillip Lenard discovered the role of the frequency of light regarding the energy of the emitted electrons in 1904 [17]. In the late 1950 and early 1960, the laboratories Bell Telephone and Hoffman Electronics increased the efficiency of inorganic silicon solar cells from 4 % to 14 %. In the 70's (semi)conducting polymers were discovered [16, 17]. Organic semiconductors are carbon-based materials possessing semiconductor characteristics. *Ching Tang* in 1986 publishes his work *two layer organic photovoltaic cell* [08] and reported an efficiency of 1%. Tang described a two-layer device that employed copper phthalocyanine (CuPc) as the donor and a perylene tetra carboxylic derivative (PV) as the acceptor.

In 1990 the “bulk-heterojunction” (BHJ) approach was developed [07], which consist on the blend of both donor and acceptor materials into a single active film, thus increasing efficiencies.

In 2000 year Allan J. Heeger, Alan G. MacDiarmid, and Hideki Shirakawa received the Nobel Prize in chemistry for the discovery and development of these conductive polymers.As an alternative to conventional organic cells, based on semi-conductor materials they are hybrid cells. Devices employing dye-sensitized, nanocrystalline inorganic materials based on a photo electrochemical process that was first developed by Grätzel in 1991.

In 2012 it was reported for the first time a Hybrid organic-inorganic perovskite solar cell with a PCE 21% was shown in 2016. See ***Figure II.2***.

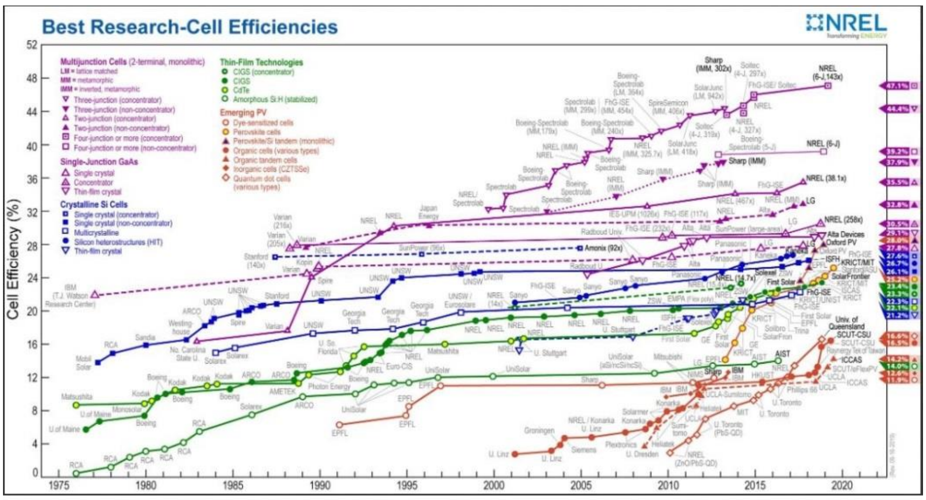


Figure II.2. *NREL Best research in cell Efficiencies*

In the following years, several organic photovoltaic devices were reported [11, 18]. Recently, OPVs efficiency reached 13% [06]. The reason for this boom can be found in the expected high potential of organic semiconductors, which are either small molecules or polymers. Several techniques and a variety of materials have been used to accomplish the architecture of the devices. The most common technique is simply to disperse fullerene, or one of its derivatives, in a conjugated polymer and then spin-coated the solution onto the device.
Nerveless, OPVs deteriorate because the organic materials are by nature more susceptible to chemical degradation by oxygen and water molecules than inorganic materials, which lead to a reduced reliability and lifetime of devices under normal environmental conditions. For this reason it is important the study of more stable photoactive layers through the introduction of additives, optimization of polymer synthesis routes to minimize incidence and concentration of impurities, and post-synthesis purification treatments and very remarquable: the development of superior quality encapsulation technologies to limit oxygen and moisture permeation from the environment into device layers [08].
Organic encapsulation materials offer significant advantages including flexibility in the synthesis of the organic, which allows parameters such as the molecular weight, energy levels, bandgap and solubility to be altered [17, 09].

II.3. Organic Solar Cell Structure:

A solar cell is a device by which electrical energy can be obtained directly, and by its nature, is modeled as a current generator. Light is made up of packets of energy, called photons, whose energy depends only upon the frequency, or color, of the light. The energy of photons in the visible region of the radiation is sufficient to excite electrons; photons are given up to excite electrons to higher energy states within the material. The process of converting light into electric current in an organic photovoltaic cell is accomplished by four consecutive steps: *Absorption* of a photon leading to the formation of an excited state, the electron-hole pair (exciton), *Exciton diffusion* to a region, where the *charge separation* occurs and finally the charge transport to the anode (holes) and cathode (electrons), to supply a direct current for the consumer load.

An OPV is generally composed of five layers (***Figure II.3***) staked on the surface of a supporting substrate, which is normally a piece of glass or transparent plastic, these five layers include a transparent conductive electrode (anode), a hole transport layer, one photoactive layer composed of an electron donor and an electron acceptor, an electron-transport layer, and a top metal electrode (cathode).

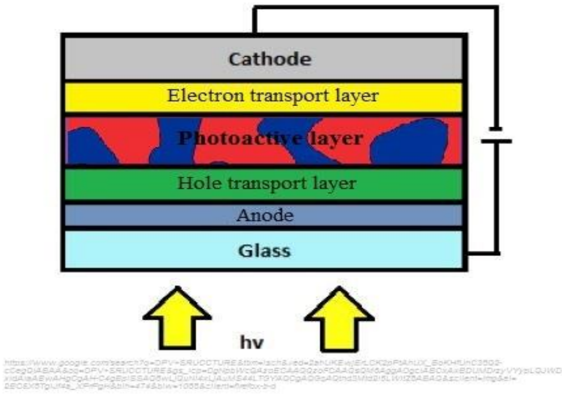


Figure II.3. *Organic Solar Cell Structure*

When a photon strikes an organic material and the frequency of the photon is appropriate, photon energy is absorbed by one of the electrons of the material reaching an excited state forming a pair of charges (electron and hole) inside the material. The bound state of the electron and hole is called exciton. Excitons are not stable states and only exist for short periods of time before recombined and release the absorbed energy in the form of another photon. OPVs absorb most of the incident radiation to form excitons to separate after these excitons. ***Figure II.4*** represent the overall functioning for load generation, it is when photo-excited electrons remain loosely bounded to the positive charges (holes) even after being excited, needing another stimulus to completely separate the charges. This stimulus is provided by the electric field appearing at the interface of the two electron-donor (conjugated polymers) and electron-acceptor (fullerenes) materials, which drives the movement of electrons and holes in opposite directions, breaking the bound and directing them towards different electrodes.

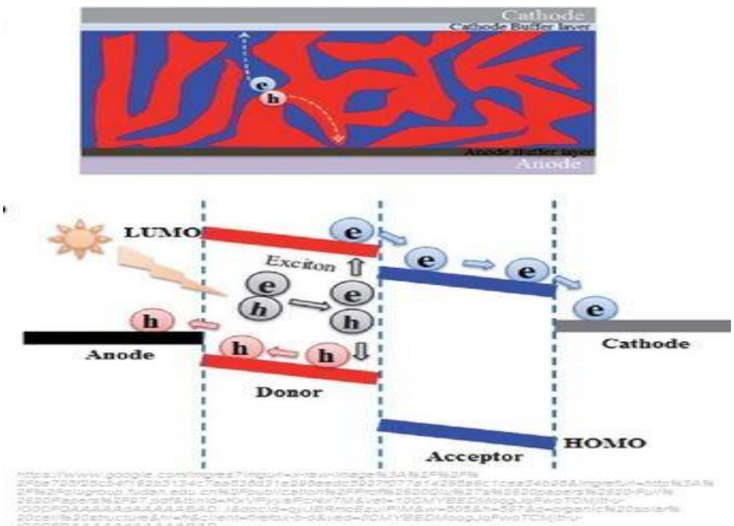


Figure II.4. *Cell process model of charge generation*

In amorphous organic materials like the ones used for solar cells, the absence of crystalline structure implies there is no conduction and valence bands like happens with their inorganic counterparts, nevertheless, energetic levels known as LUMO (lowest unoccupied molecular orbital) and HOMO (highest occupied molecular orbital) plays in organic materials a similar role to the conduction and valence bands in inorganic materials respectively [19, 20].

The HOMO and LUMO of organic semiconductors refer to energy bands that correspond to different hybridization states of the p-bonds, which will result in different energy levels of an organic semiconductor. When an electron is excited from the HOMO to the LUMO of an organic semiconductor, the molecule itself is excited into a higher energy state, as opposed to the actual excitation of a free electron from the valence band to the conduction band in inorganic semiconductors [19].

II.4 Photovoltaic cell Generations:

Today, four generations of solar cells are available, thus, enabling the use of different types of solar cells according to our needs and preferences.

II.4.1 First generation of Organic photovoltaic cells:

Traditionally, the first-generation (1G) PV technology is known to comprise of photovoltaic technology based on thick crystalline films (mainly Si) which not only leads to high efficiency, but also high cost. These were the first generation PV cells and silicon continues to rule in the commercial market due to its dominant qualities.
Typically, these cells are made with crystalline silicon wafer.

Figure II.5. *Mono Crystalline Solar Cell*

II.4.2 Second generation of Organic photovoltaic cells:

The second-generation (2G) solar cells were developed with the aim of reducing the high costs prevalent in 1G through the utilization of thin film technology; the idea being to save on bulk material cost with a significant reduction in the quality and quantity of the material used and the challenge of increasing the thin film absorption to compensate for the reduced thickness in the photoactive layers. This 2G thin film technology was based on PV materials identified during the development of 1G PVs and was extended to include amorphous or polycrystalline Si, CIGS, and CdTe. While the 2G PV family addresses the cost issues associated with thick films, the performance of such 2G solar cells is known to be poor compared to their 1G counterpart. Therefore, the challenge was to improve the efficiency as much as possible within the inexpensive material envelope that encouraged the chemical vapor deposition of thin films and thermal crystallization, where appropriate. In the case of amorphous materials, to compensate for the significantly reduced active volume, an intrinsic layer was grown to produce p–i–n devices where photo generated carriers could be swept to the doped materials by the built-in field. The key factor that worked in favor for 2G PV cells was the cost per watt delivery but the need for extended surface areas to compensate for the lower efficiency was an issue. This in turn pushed the development of the third-generation (3G) solar cells, including Nano crystalline films, PVs based on active quantum dots, tandem or stacked multilayers of inorganics based on III–V materials such as GaAs/Ge/GaInP2, or novel device concepts such as hot carrier cells where the aim was to obtain higher performance than their 2G counterparts, at a lower cost. These cells were known as Plasma Enhanced Chemical Vapor Deposition (PECVD).

In this generation, four types of solar cells were introduced, including the amorphous silicon cells which can be deposited over large areas with the help of PECVD. Their band gap was about 1.7 eV and function was similar to c-SI. Polycrystalline silicon, made of pure silicon grains, works better than the previous designs because of their mobility. These can be easily moved over a large magnitude. Cadmium telluride (CdTe) cells are formed with cadmium and tellurium mixed with zinc cubic crystal structure. This material is cheaper than silicon but not as efficient as silicon. Copper indium gallium diselenide (CIGS) alloy cells are deposited on glass or stainless steel and are a complex model. Their band gap is about 1.38 eV.

Figure II.6. *CdTe Solar Cell*

II.4.3 Third generation of Organic photovoltaic cells:

Thereafter began a true race to design materials at the Nano scale and scale-up to the macroscopic areas. For the first time, significant attention was paid to the charge and energy transfer processes and the respective routes to optimize charge collection, thereby enhancing the energy capture within the solar spectrum. With the introduction of organic materials exhibiting photovoltaic properties, their potential for low cost and high optical absorption placed them as a 3G technology. In addition to organic (or polymer) solar cells, another candidate that grew to dominate 3G PV technologies is dye or semiconductor sensitized solar cells (DSSCs). Despite the reasonable success of 3G cells, significant improvements in device performances and disposable at any molecular level. They have little negative impact on the environment. In turn, these 3G cells offer significant cost improvements on first and second generation solar cells based on crystalline and polycrystalline silicon which are still responsible for over 90 per cent of the solar power being generated today.

Figure II.7. *DSSC: Dye Sensitized Solar Cells*

II.4.4 Fourth generation of Organic photovoltaic cells:

The fourth generation (4G) of PV technology which combines the low cost/flexibility of polymer thin films with the stability of novel inorganic nanostructures was introduced with the aim of improving the optoelectronic properties of the low-cost thin film PVs. These device architectures are meant to maintain the inexpensive nature of a solution process able PV device structure; but incorporate inorganic components to improve on energy harvesting cross-sections, the charge dissociation, and charge transport within the PV cells. While the previously introduced microscopic solar cells may be considered as a 4G technology due to the incorporation of an inorganic component (usually titania), especially when combined with a polymer or organic layer as a solid-state DSSC, this inorganic component is a requirement for the functionality of the cell and does not introduce additional benefits as for the inorganics-in-organics architectures. till date, the most effective polymer solar cells (pscs) have been based on the bulk heterojunction (bhj) concept.

The 4g solar cells are a hybrid that combine the low cost and flexibility of conducting polymer films (organic materials) with the lifetime stability of novel nanostructures (inorganic materials). this inorganics-organics technology improves the harvesting of solar energy and its conversion into electricity, offering better efficiency than the current 3g solar cells while maintaining their low cost base. These new generation materials for solar cells have been truly engineered at the Nano scale. they are designed to maximize the harvesting of solar radiation, and thereby efficiently generate electricity.

It is believed that 4g solar cells will be the technology for future photovoltaic energy sources. This generation brings most successful types of solar cells for mankind and those were hybrid Nano crystal cells. For generation of these cells polymers and nanoparticles were mixed to make on layer which can help electrons and protons to move for producing better voltage and good quality of direct current.

The fourth generation (4g) of PV technology which combines the low cost/flexibility of polymer thin films with the stability of novel inorganic nanostructures was introduced with the aim of improving the optoelectronic properties of the low cost thin film pvs. these device architectures are meant to maintain the inexpensive nature of a solution-process able PV device structure; but incorporate inorganic components to improve on energy harvesting cross-sections, the charge dissociation, and charge transport within the PV cells.

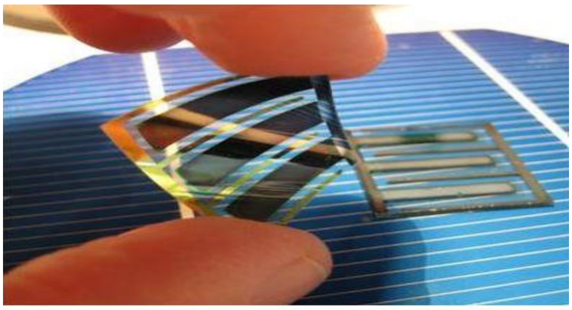


Figure II.8. *Organic Heterjunction Solar Cells*

II.4.5 Next generation of Organic photovoltaic cells:

So far, most of the solar cells are entirely made of inorganic semiconductors, usually silicon, but these materials are not as energy efficient as organic semiconductors. The new method lies in the groundwork for building a new generation of solar cells made up of both organic and inorganic material. In silicon solar cells, every single particle of light (photon) can excite one electron only, but with a new material (naturally present in green leaves), the same quantity of light releases not one but two electrons, doubling the energy capacity of the semiconductor. This improves the energy efficiency ratio to up to 95 per cent, a figure impossible to reach with conventional, inorganic semiconductors. The process ‘clears the way for hybrid solar cells which could far surpass current efficiency limits’.

The next generation solar cells could be infinitely more useful, thanks to a newly discovered nanotube structure capable of transporting electrical charges 100 million times higher than previously measured. Most solar cells currently use silicon to absorb light; however, inefficiencies in the material have led scientists to develop carbon nanotubes that can be implemented to enhance the light absorption capabilities of current cells. However, until now the nanotubes have been randomly placed within the solar cells in suboptimal structures as they are difficult to arrange. Scientists are able to manipulate the carbon nanotubes using controlled, nano-scale dimensions inside a polymer matrix.
This method allowed rearranging the nanotubes into complex networks that reduced the cost of nanotubes needed. Extremely small amounts of nanotubes can be used less than 1 per cent and still produce efficient devices leading to lower material cost. Solar cells made of these materials are solution process able, implying that do not require expensive equipment and yet increase the conductivity within the cell. The resulting Nano networks possess exceptional ability to transport charges up to 100 million times higher than previously measured carbon nanotube random networks produced by conventional methods.

However, photovoltaic cells continue to depend on light to produce electricity, and so,generate a negligible amount of power when there are clouds overhead. But, researchers wondered whether it would be possible to create all-weather solar cells. Rain helps solar cells operate efficiently by washing away dust and dirt that block the sun’s rays. Solar cells could someday generate electricity even during rain showers with the help of graphene. Raindrops contain salts that split up into positive and negative ions. In order to manipulate that bit of chemistry, researchers turned to graphene, the one-atom-thick sheet of carbon. Graphene’s electrons can attract the positively charged ions, such as sodium, calcium, and ammonium, resulting in separated layers of positive and negative ions that act much like a capacitor to store energy. With that in mind, scientists added graphene to a dye-sensitized solar cell, a kind of inexpensive thin-film solar cell, thereafter placed these on a flexible, transparent backing of indium tin oxide and plastic. The resulting flexible solar cell demonstrated a solar-to-electric conversion efficiency of up to 6.53 per cent, and generated hundreds of microvolts from slightly salty water that was used to simulate rain water. Therefore, future solar cells may produce electricity in all-weather conditions with high efficiency, desired geometry and long life span.

II.5 Dye-Sensitized solar cells:

The dye-sensitized solar cell (O’Regan and Grätzel, 1991) has its foundation in photochemistry rather than in solid-state physics. In this device, also called the “Grätzel cell” after its Swiss inventor, organic dye molecules are adsorbed on a Nano crystalline titanium dioxide (TiO_2) film, and the Nano pores of the film are filled with a redox electrolyte. The dyes absorb solar photons to create an excited CdTe PV cells require a small amount of semiconductor, and the production can be automated, which can increase its yield.

CIS has higher efficiency and has the capability to be made on a flexible substrate, but large-scale production might be limited to the availability of indium. molecular state that can inject electrons into the TiO_2. The electrons percolate through the Nano porous TiO_2 film and are collected at a transparent electrode. The oxidized dye is reduced back to its initial state by accepting electrons from the redox relay via ionic transport from a metal counter-electrode; this completes the circuit, and electrical power is delivered in the external circuit. Dye-sensitized solar cells are very attractive because of the very low cost of the constituent materials (TiO_2 is a common material used in paints and toothpaste) and the potential simplicity of their manufacturing process. Additionally, sensitized solar cells are tolerant to impurities, which allow ease in scaling up the production. Laboratory-scale devices of 11 percent efficiency have been demonstrated, but larger modules are typically less than half that efficient. Stability of the devices (e.g., dye materials and electrolyte) while maintaining high efficiency is an ongoing research issue (DOE, 2007k).

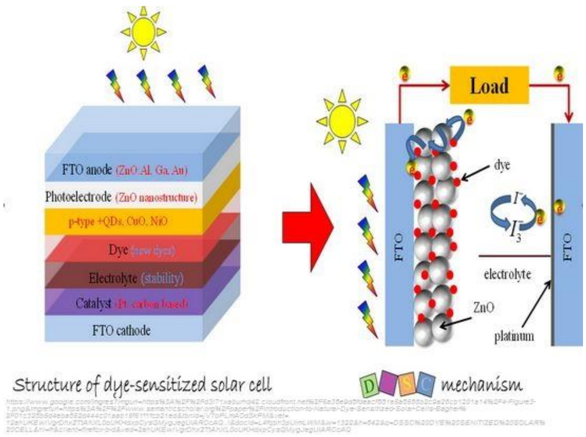


Figure II.9. *Structur of Dye Sensitized Solar Cells*

II.6 Perovskite solar cells:

A perovskite solar cell is a type of solar cell which includes a perovskite structured compound, most commonly a hybrid organic-inorganic lead or tin halide-based_material, as the light-harvesting active layer. Perovskite materials, such as methyl ammonium lead halides and all-inorganic cesium lead halide, are cheap to produce and simple to manufacture. Solar cell efficiencies of devices using these materials have increased from 3.8% in 2009 to 25.2% in 2019 in single-junction architectures, and, in silicon-based tandem cells, to 28.0%,[21] exceeding the maximum efficiency achieved in single-junction silicon solar cells. Perovskite solar cells are therefore the fastest-advancing solar technology to date.[2] With the potential of achieving even higher efficiencies and very low production costs, perovskite solar cells have become commercially attractive.

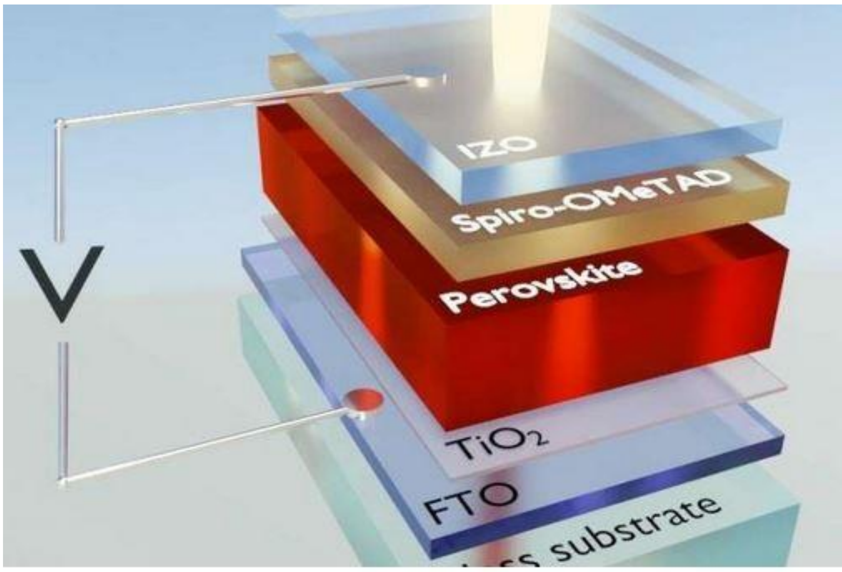


Figure II.10. Perovskite *Cell*

Latest advances have shown a great potential for organic solar cells compared to conventional silicon cells. Their versatility in production methods, properties and applications looks very promising for the future of solar energy.

II.7. The Future of OPVs:

Whilst a large majority of OPV literature remains focused on efficiency values, the main issues restricting OPV commercialization are scalability and long-term stability. Indeed, some literature has suggested that the current efficiencies obtained could be competitive with other technologies if scaled appropriately. At present, there is little consideration of the synthetic complexity of materials or suitable scalable deposition techniques, so these are likely to be an area of focus in the future along with greener solvent systems. OPVs have struggled with long-term stability, mostly due to damage from water and oxygen ingress. Improvements in this area are likely to be found with better understanding of NFAs (*Non-Fullerene Acceptors*) [22], as this group of materials has shown significant promise in terms of long term stability. [23].

II.8. Organic Photovoltaic Applications:

An organic solar cell or plastic solar cell is a type of photovoltaic that uses organic electronics, a branch of electronics that deals with conductive organic polymers or small organic molecules. [24] for light absorption and charge transport to produce electricity from sunlight by the photovoltaic effect. Most organic photovoltaic cells are polymer solar cells.

The molecules used in organic solar cells are solution-process able at high throughput and are cheap, resulting in low production costs to fabricate a large volume. [25] Combined with the flexibility of organic molecules, organic solar cells are potentially cost-effective for photovoltaic applications. (*See the below examples of OPVs Applications*).

Figure II.11. Example_1

Figure II.12. Example_2

Figure II.13. Example_3

Figure II.14. Example_4

Figure II.15. Example_5

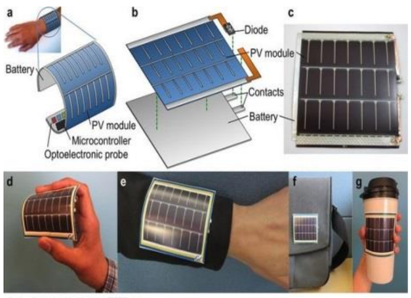


Figure II.16. Example_6

Chapter III

Equivalent Circuit Model for Organic Solar cells

Resume:

The purpose of this chapter is to design or implement an equivalent circuit for OPV cell in order to get a good idea on the electrical behavior and observe how the device parameters changes with any kind of applied treatment (Temperature, illumination, etc.) to the device, it is modeled with discreet electrical components such as voltage or current sources, diodes and resistors. It provides a scientific and realistic physical explanation for the Photovoltaic cells behavior.

« You must understand the process before you can control it &

the simplest control system that will do

the job is the best. »

William L. Luyben (1990)

III.1 Introduction:

In order to understand the electrical behavior and observe how the device parameters changes with any kind of applied treatment (bias, illumination, etc.) to the device, it is necessary to be modeled with discreet electrical components such as voltage or current sources, diodes and resistors.
It provides a scientific and realistic physical explanation for the OPV cells behavior.

III.2 Representation of Equivalent Circuit Model:

To represent the electrical circuit of an OPV photovoltaic cells there are two models.
The single diode model and *the two diode model*, but in general the single diode model is the most useful one to represent the equivalent circuit of PV cells.

III.2.1. The Single Diode Model:

PV solar cells typically can be represented by an equivalent circuit consisting of a single diode as shown in ***Figure.III.1***. The resistor and current values depend on the illuminated area. But the dark current depends on the actual device area.
Assuming that, for voltage dependence of the current the Shockley diode equation can be used and I_D is the current through the ideal diode *D* then applying Kirchhoff's current and voltage laws in currents nodes and voltage loops we can formulate the following equation:

$$I = \left(I_L - \frac{V}{R_{SH}} \right) \frac{R_{SH}}{R_{SH} + R_S} - I_0 \left[\exp\left(\frac{V + IR_S}{nkT/q} \right) - 1 \right] \cdot \frac{R_{SH}}{R_{SH} + R_S} \quad \text{(Eq.III.1)}$$

Where:

$$V_T = \frac{K*T}{q}$$

I : The current supplied by the cell.
I_L : The photo current generated by light (I_{ph}).
Is : Diode saturation current.
I_D : Current flowing through the diode.
V : The voltage at the terminal of the cell.
V_T : The potential thermodynamics.
R_{sh} : The Shunt Resistance.
Rs : The Series Resistance.
n : The ideality factor of the junction between 1 & 2.
k : Constant of Boltzmann (1.38×10^{-23} J / K).
T : The effective temperature of the cell in Kelvin.
q : The charge of the electron (1.6×10^{-19} C).

Now, considering an ideal solar cell that comprises only ideal [26] diode D in the dark so that $R_{SH} = \infty$ and $R_S = 0$ then Equation (Eq.III.1) can be rewrite as:

$$I_D = I_0\left[\exp\left(\frac{V}{nkT/q}\right)-1\right] \quad \text{(Eq.III.2)}$$

Under illumination, the light generates a photo current I_L which is simply added with the normal rectifying characteristics of the diode D:

$$I_D = I_0\left[\exp\left(\frac{V}{nkT/q}\right)-1\right]-I_L \quad \text{(Eq.III.3)}$$

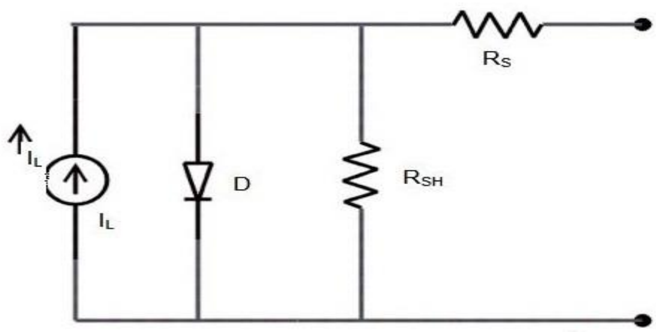


Figure.III.1*.The single diode model equivalent circuit.*

By setting the output current to zero (I = 0) in Equation (Eq.III.1), we obtain:

$$V_{OC} = \frac{nkT}{q}\ln\left(\frac{I_L - V_{OC}/R_{SH}}{I_0}+1\right) \quad \text{(Eq.III.4)}$$

III.2.2. The Two Diode Model:

The two-diode model can be described from the lumped parameters of ***Figure.III.2***. Using the Shockley diode equations, we obtain:

$$I=\left(I_L-\frac{V}{R_{SH}}\right)\frac{R_{SH}}{R_{SH}+R_S}-I_{01}\left[\exp\left(\frac{V+IR_S}{nkT/q}\right)-1\right]\frac{R_{SH}}{R_{SH}+R_S}-I_{02}\left[\exp\left(\frac{V+IR_S}{nkT/q}\right)-1\right]\frac{R_{SH}}{R_{SH}+R_S} \quad \text{(Eq.III.5)}$$

Setting I = 0, we get the equation for VOC which is:

$$V_{OC}=\frac{nkT}{q}\ln\left(\frac{I_L-V_{OC}/R_{SH}}{I_{01}-I_{02}}+1\right) \quad \text{(Eq.III.6)}$$

Lower mobility and smaller charge carrier concentration lead to considerably smaller currents in most organic solar cells. In fact, both the dark and light currents are about 1000 times smaller; hence, the light current in these devices is about as large as the dark current in silicon devices. The dark current is still about 900 times smaller and according to Equation (Eq.III.6) a similar V_{OC} is expected.

As result and according to Equation (Eq.III.6), both the ideal diode D and R_{SH} are now the components that determine V_{OC}. This as-sumes that R_{SH} is not very high and the device is in the dark and by applying a positive voltage across the cell electrodes a voltage drop can be created across R_{SH} which equal to the voltage V_D across the ideal diode D. The current that can pass through the diode D at V_D is determined by its I-V characteristic. The sum of the currents through D and R_{SH} yields the current through the electrodes of the solar cell for a given applied voltage. Upon illumination, the current source generates the current I_L some of which passes through the diode where a voltage drop is generated that is big enough to allow the rest of I_L to go through R_{SH} if the electrodes are open. The same voltage can be measured with a voltmeter with high internal resistor across the device electrodes and is then termed open circuit voltage V_{OC}.

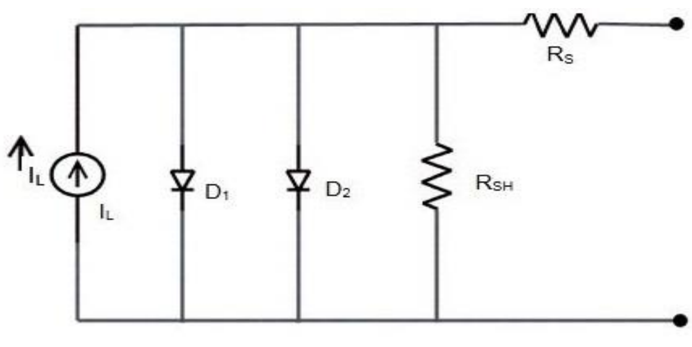


Figure.III.2. *The two diode model equivalent circuit.*

III.3.Equivalent Circuit Model parameters:

The equivalent circuit of an OPV cell it contains the following parameters:

III.3.1. Open Circuit Voltage (Voc):

The open circuit voltage is obtained when the current flowing through the cell is zero. It depends on the energy barrier and shunt resistance. It decreases with temperature and varies little with light intensity.
We can write:

$$Voc(I = 0) = AV_T \mathbf{ln}\left(\frac{I_L}{I_s} + 1\right) \qquad \text{(Eq.III.7)}$$

III.3.2. Short Circuit Current (Isc) :

This is the current obtained by shorting the terminals of the cell (taking V = 0) in the equivalent diagram). It grows linearly with the illumination intensity of the cell and depends on the illuminated surface, the wavelength of the radiation, the mobility of the carriers and the temperature.
We can write:

$$I_{sc}(V = 0) = I_L \qquad \text{(Eq.III.8)}$$

III.3.3.Fill factor ($\boldsymbol{FF}$):

In order of improving the efficiency of organic solar cells, the most critical factor for a large impact on the different strategies depends on better fill factor FF which is given by the following relation:

$$FF = \frac{V_{max}}{V_{oc}} \frac{I_{max}}{I_{sc}} \qquad \text{(Eq.III.9)}$$

Where: Vmax and Imax are the voltage and at maximum awarded by the cell extract of the characteristic I (V) of the PV cells.

Also the maximum theoretical power produced could be obtained from the product of Imax and Vmax (the current and voltage at the maximum power point of the I-V power curve of solar cells).

$$\boldsymbol{P_{max} = I_{max}.V_{max}} \qquad \text{(Eq. III. 10)}$$

III.3.4. Power Conversion Efficiency (*PCE*):

Defined as the ratio of outgoing electrical power to the incoming solar power, PCE is the product of three parameters: open circuit voltage (V_{OC}), short circuit current (I_{SC}), and fill factor (*FF*).
The V_{OC} is the maximum voltage that a solar cell can generate, I_{SC} is the maximum current it can generate, and *FF* is a parameter that describes the maximum power it can generate.

All three factors: V_{OC}, I_{SC}, and *FF* depend heavily on electrode/organic interfaces. With the incorporation of a metal oxide buffer layer at electrode/organic interfaces, these three factors can be optimized to boost an OPV's performance. [27].

III.3.5.Efficiency of organic solar cells:

The efficiency of organic solar cells is one of the factors limiting there Commercialization. It is given by:

$$\eta = \frac{I_{sc} \cdot V_{oc} \cdot FF}{P_{in}} \qquad \text{(Eq.III.11)}$$

Where: **Pin** is power of the incident light. It is directly related at the open circuit Voltage and the Short current circuit.

III.4.THE *IV* Curve of a solar cell:

The output characteristics of a solar cell are described by the current – voltage (I –V) curve. The test circuit used in order to produce the output characteristics is shown in ***Figure III.3.*** The IV curve is produced by varying *RL* (load resistance) from a small to a large value and measuring the current and voltage. Typical current-voltage (I-V) and power-voltage (P-V) characteristics of a photovoltaic device are shown in
Figure III.4.

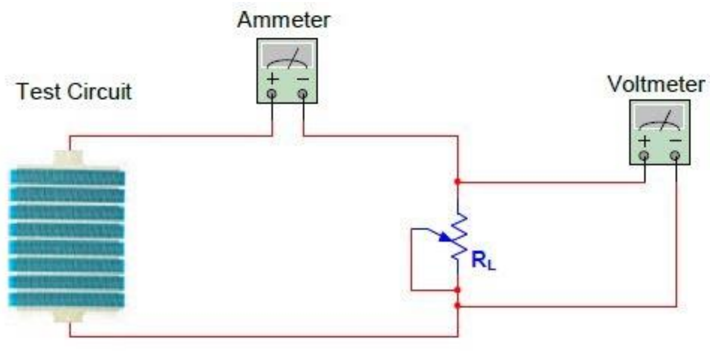


Figure III.3. *Test circuit to produce the output characteristics.*

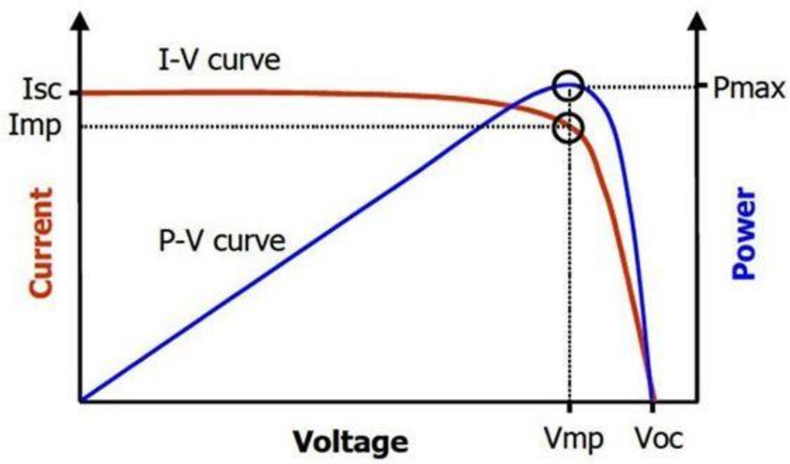


Figure III.4. *Typical Solar cell (I-V, P-V) Curve.*

The maximum power rectangle is defined by the voltage and current values (V_{mpp} and I_{mpp}) at the maximum power point, which is reached by optimizing the resistance of the load to draw the maximum power from the circuit. The ratio of the area of the maximum power rectangle to the area of the $V_{oc}\ I_{sc}$ rectangle is termed the *fill factor* (*FF*) and the closer this value is to unity, the better the quality of the solar cell [28].

III.5.The Efficiency and the Stability of OPVs:

A photovoltaic device should be exposed to sunlight for a period large than 10 years in order to become competitive alternative to silicon. That is more than 10 000 hours of sun; this is not an easy assignment. The causes of degradation have different origins:

- Photochemical: it can be intrinsic property of the molecules or an extrinsic one (Photo oxidation with oxygen for instance);
- Electrochemically: ionic impurities or water may promote redox reactions at the Electrodes;
- Structurally: low transition temperature (Tg) may reorganize, recrystallize, or diffuse one into another owing to repeated heating and cooling in out door conditions;
- Electrodes: they can react with molecules, metal diffusion from ITO into polymers for instance. [26]

III.6. Improvements for the stability of organic photovoltaic cells:

Organic photovoltaic (OPVs) have been pursued as a next generation power source due to their light weight, thin, flexible, and simple fabrication advantages. Improvements in OPV efficiency have attracted great attention in the past decade. Because the functional layers in OPVs can be dissolved in common solvents, they can be manufactured by eco-friendly and scalable printing or coating technologies. In this review article, the focus is on recent efforts to control nano morphologies of photoactive layer and discussion of various solution-processed charge transport and extraction materials, to maximize the performance of OPV cells. Next, recent works on printing and coating technologies for OPVs to realize solution processing are reviewed. The review concludes with a discussion of recent advances in the development of non-traditional lamination and transfer method towards highly efficient and fully solution-processed OPV. [29,30]

Chapter IV

Optimal Results and Data Analysis by using *RTO* Algorithm

Resume:

The purpose of this chapter is to introduce the new method for optimization which is called Root Tree Optimization algorithm (**RTO**), this algorithm improved its robustness and efficiency which is validated on nonlinear functions and compared to recent methods addressing the same problem; simulation results confirm its efficiency and reliability during the search of Optimal value for Maximum Power Point (MPP_{opt}) of solar cells.

« You must understand the process before you can control it &
the simplest control system that will do
the job is the best. »
William L. Luyben (1990)

IV.1 Introduction:

The Root Tree Optimization algorithm (**RTO**),is a new method which improved its robustness and efficiency during simulation results, and it is validated on nonlinear functions and proposed for solving complex optimization problem in term of solution quality and convergence characteristic has been applied to a various test systems and the simulation results obtained are compared with other results which is recently developed methods available in the literature, from numerical results, it is found that this algorithm provide better solution than other reported techniques in terms of speed and robustness than most of the existing algorithms used in this study.

Unlike classical search and optimization methods, RTO starts its search with a random set of solutions (group of roots), instead of a single solution just like GA. Each population member is then evaluated for the given objective function and is assigned fitness. The best fits are entertained for the next generation while the others are discarded and compensated by a new set of random solutions in each generation. The far solution from the water place is omitted or replaced by a new roots oriented randomly, also it is replaced by roots near from the best root of the previous generation. The only stopping criterion is the completion of maximum number of cycles or generations. At the end of the cycles, the solution of the best fitness is the desired solution.
In this study we are going to present the use of the RTO technique to find the Optimal value of Maximum Power Point MPP_{opt} for PV cells, the RTO method has been proposed to solve this issue and its results compared to another method known as P&O (Perturb and observe) to show its robustness and efficiency specially on nonlinear functions.

IV.2 Perturb and Observe Algorithm Method (P&O):

In Perturb and Observe P&O method, the algorithm is based on the “Hill-Climbing” techniques which are the most popular MPPT methods due to their ease of implementation and good performance when the irradiation is constant. The advantages of this method is the simplicity and low computational power they need. The shortcomings are also well-known: oscillations around the MPP and they can get lost and track the MPP in the wrong direction during rapidly changing atmospheric conditions. The P&O algorithm is based on moving the operation point of the PV cells in the direction in which power increases. The tracker operates by periodically incrementing or decrementing the solar cells voltage. If a given perturbation leads to an increase in the output power of the PV, then the subsequent perturbation is generated in the same direction and vice versa [31]. The process is repeated until the maximum power point has been reached.
Actually, the system oscillates about the MPP. Reducing the perturbation step size can minimize the oscillation. However, small step size slows down the MPPT. For different values of irradiance and cell temperatures, the PV array would exhibit different characteristic curves. Each curve has its MPP. [31].

IV.2.1 Perturb and Observe Principle:

The principle of this command is to generate perturbation by reducing or increasing the duty cycle D and to observe the effect on the power delivered by the PV generator. The algorithm of this command is presented in ***Figure.IV.1***.

*****If dpv / dVpv >0, the voltage is increased, this induces an increase in the duty cycle

D (k) =D (k-1) +ΔD.   ΔD being an accretion constant.

*****If dpv / dVpv <0, the voltage is reduced, which means a decrease in the duty cycle

D (k) =D (k-1) - ΔD.

IV.2.2 Perturb and Observe Flow chart:

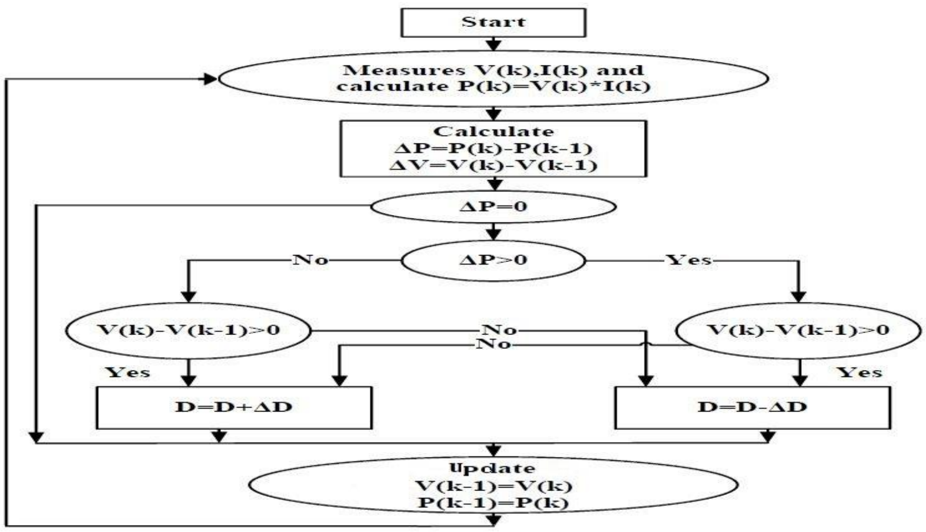


Figure.IV.1*. Perturb and Observe Flow Chart.*

IV.3 Roots Tree Optimization Algorithm Method (RTO):

IV.3.1 The roots look for water:

One root has a limited capacity, but a group of roots can find together the best issues to get water, and the majority of them are located around this issue or around the way that links the plant with the resource of water. To create the algorithm, we add a hypothetical behavior which is the way how the roots decide together to choose the orientation according to the wetness degree where the root head is located, these ones move randomly but when they find the wetness they contact between them to intensify their existence around this way, so it becomes a new start point for the majority of the root group to get the original place of water.

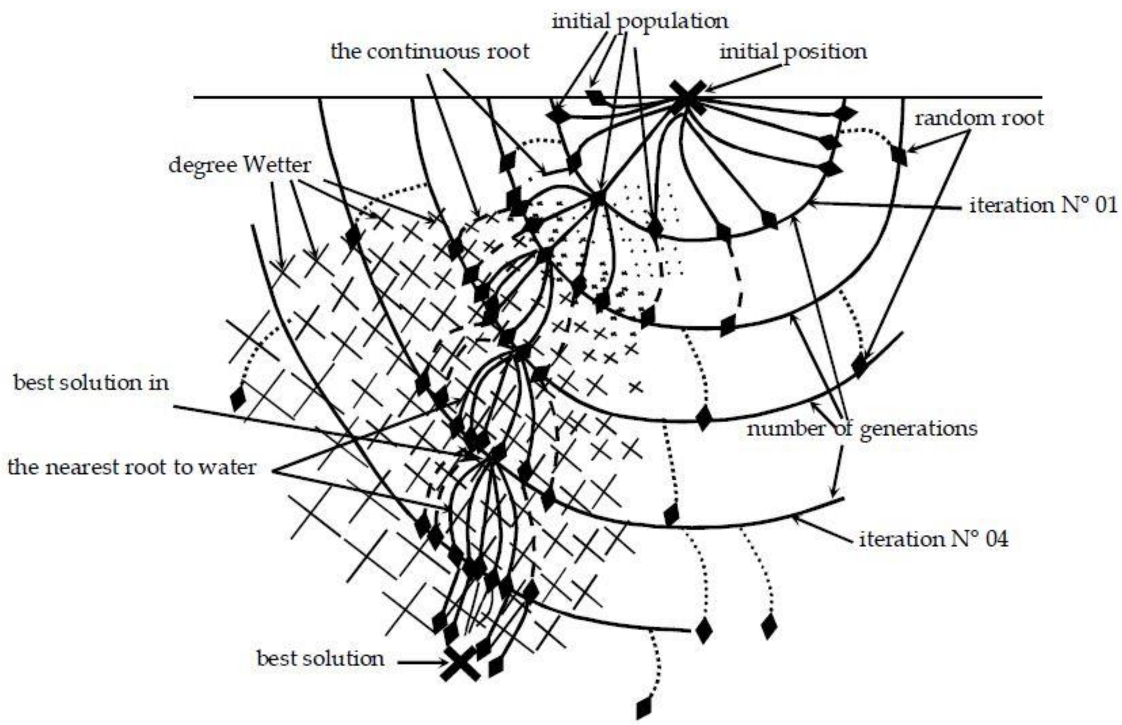


Figure.IV.2.*the roots of plants behavior when they look for water (the solution).*

The ***Figure IV.2:*** presents the way how the roots of plants behave when they look for water -the solution- according to what we have talked about in RTO, where we find that the far solution from the water place (which has a less witness degree) is omitted or replaced by a new roots oriented randomly, also it is replaced by roots near from the best root of the previous generation, whereas the roots which have a considerable witness degree preserve their orientation, where we remark that the majority of roots gather at the last step next to the best solution- resource of water-
.

IV.3.2 Rooted Tree Optimization Method:

The proposed method is similar to the most other methods it begins by creating an initial population randomly. But before that, we will introduce some terms which will determine the method of moving from initial population to the new population:
- Root: is a candidate or the suggested solution.
- Degree Wetter D_W: it is a term that evaluates the candidate and gives him his Optimization degree between the rests of population, it seems to the mechanism fitness, it is calculated using the equation (Eq.IV.4).

*A. The rate of the nearest root to water **Rn***

It is the rate that represents the number of candidates according to the total population that should gather around the witness or the water place (the best solution to the previous generation). It will be the successor of the roots which were in dry places (so the witness is weak) from the previous generation. The new population of the nearest root to water is calculated according to the formula:

$$x^{new}(i, It+1) = x^{best}(It) + c_1 \times D_w(i) \times randn \times l/(N \times It) \qquad \text{(Eq.IV.1)}$$

Where It is the iteration step, x^{new} (It +1) is the new candidate for the iteration (It +1), x^{best} (It) is the best solution to the previous generation, *i* is the number of candidate, N is the population scale, *l* is the upper limit of the parameter and *randn* is a normal random number between [-1, 1]. Then new point x new is upper and lower bounded.

*B. The rate of the continuous root in its orientation **Rc***

It is the rate of the members that continued the previous way because it appears near from water. The new population of the random root is calculated according to the formula:

$$x^{new}(i, It+1) = x(i, It) + c_2 \times D_w(i) \times rand \times (x^{best}(It) - x(i, It)) \qquad \text{(Eq.IV.2)}$$

Where x(It)is the previous candidate for the iteration It and rand is random number between [0, 1].

*C. The rate of the random root **Rr***

It is the rate that represents the number of candidates according to the total population that we want that they spread randomly in the research field in order to increase the rate of getting the global solution, it replaces also the roots in the wetness degree is so weak (weak candidates) from the last generation. The new population of the random root is calculated according to the formula:

$$x^{new}(i, It+1) = x_r(It) + c_3 \times D_w(i) \times randn \times l/It \qquad \text{(Eq.IV.3)}$$

Where x_r is individual randomly selected from the previous generation, c_1, c_2 and c_3 is the adjustable parameters. The rates R_n, R_r and R_c are determined by the experiments according to the exposed problem, these rates are considered as variables which affect the convergence and how to find solution. The rate R_r is always small in comparison with the rest because it aims to reserve the random in order to be far from the local, its role can be presented as a mutation in the genetic algorithm.

We put the D_W value in the research functions of the roots in order to determine a space research according to the candidate power. When his power increase (presented by the D_W values), our goal is to, assure the step and the type of the used relation to create a new generation.

IV.3.3. The Algorithm RTO:

Summarizing the steps in RTO yields to:

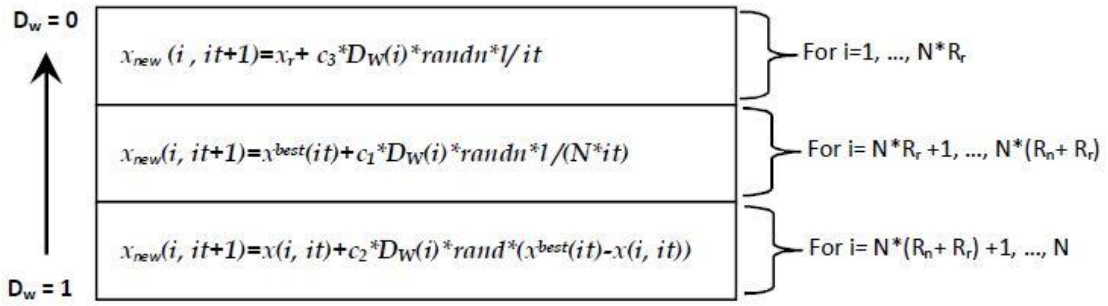
Step 1: Creation of primary generation randomly which is composed from N candidate with the respect of the variables limits in the research space, and the determination of the rates values R_n, R_r and R_c.

Step 2: We evaluate all the population members in order to measure the witness degree D_W by using the objective function following this formula:

$$D_w(i) = \begin{cases} \dfrac{f_i}{\max(f_i)} & \text{for the maximum objective} \\ 1 - \dfrac{f_i}{\max(f_i)} & \text{for the minimum objective} \end{cases}, \quad i = 1,2,\ldots,N \qquad \text{(Eq.IV.4)}$$

Or we use directly the fitness regardless of the suitable formula.

Step 3: Reproduction and replacement by the new population;
We reorder the population according to the degree wetter D_W in order to replace them by the new population according to R_n, R_r and R_c as the following:



Where $R_n + R_r + R_c = 1$. We start by the candidate which has the less D_W till we get at the one who has a degree wetter equivalent 1.

Step 4: Return to step 2 if the stopping criteria is not realized.
The RTO algorithm is a method based on the most of the meta-heuristic algorithms; it is a simple evolutionary algorithm that creates new candidate solutions by integrating the parent individual

with several other individuals in the same population. All candidates replace the parent; the rooted tree optimization algorithm is written as the Algorithm represents the recreation of new generation concerning RTO algorithm.

RTO Algorithm

//Initialization:
Set the rates R_n, R_r and R_c parameters;
Give the maximum number of iterations, MaxIte, the population scale is theRTOsize;
Set iteration counter it =1;
For *i=1* **to** *theRTOsize***do**
    Generate the initial population X_i randomly within the search range of ($X_{\min}$, $X_{\max}$);
end for
Evaluate the fitness for each individual D_{W_i} ;
Reorder the population according to the witness degree;
Identify the candidate according the wetness place (the best solution) X_{best};
//Loop:
While *(stop criterion is not satisfied & it < MaxIte)* **do**
    For i *=1* **to** $R_r \times$ *theRTOsize***do**
        Selected individual X_r^{it} randomly from the current population;
        $X_i^{it+1} = X_r^{it} + c_1 \times D_{W_i} \times randn \times \mid X_{\max} - X_{\min} \mid / (it);$
    end for
    For $i = R_r \times$ *theRTOsize+1* **to** $(R_r + R_n) \times$ *theRTOsize***do**
        $X_i^{it+1} = X_{best} + c_3 \times D_{W_i} \times randn \times \mid X_{\max} - X_{\min} \mid / (theRTOsize \times it);$
    end for
    For $i = (1 - R_c) \times$ *theRTOsize+1* **to** *theRTOsize***do**
        $X_i^{it+1} = X_i^{it} + c_1 \times D_{W_i} \times rand \times (X_{best} - X_i^{it});$
    end for
    Evaluate fitness D_{W_i} for each candidate;
    Update X_{best} ;
    it = it + 1;
end while

From the ***Figure. IV.2*** we remark the change of the parameters x_1 and x_2 according to the generation number where the three kinds of roots appear, these kinds represent the random roots, and the roots which meet together till they stop these ones represent the near roots from the solution, the rest kind represents those groups which cease when they become weak in comparison with the other roots of the same generation. It appears so clear in the ***Figure. IV.4*** which represents evaluation the **Rastrigin function** (N=2) (where N is the number of dimension) where the majority of roots gather in the solution –resource of water-.

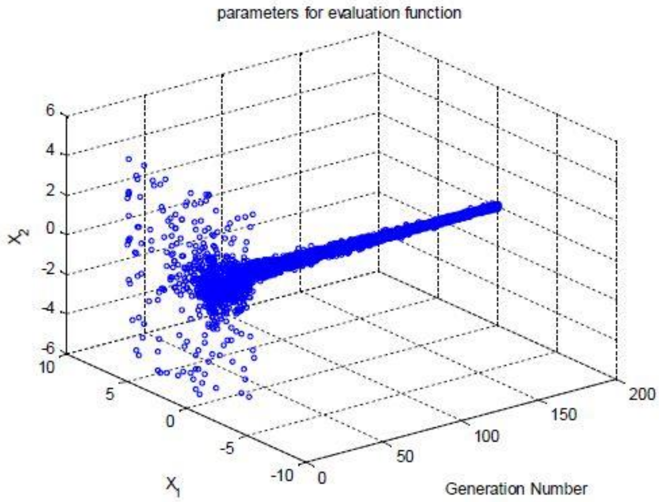


Figure. IV.3: *The parameters and the roots for 200 iterations (the Rastrigin function (N=2)).*

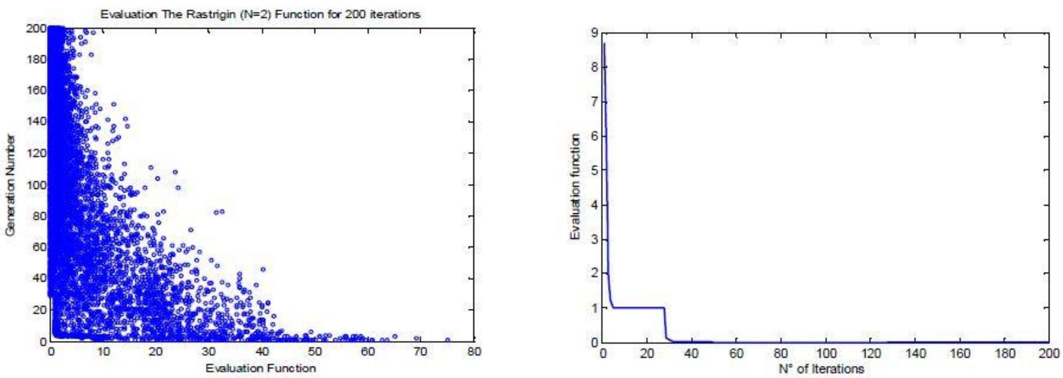


Figure. IV.4: *Evaluation the Rastrigin function (N=2) for 200 iterations.*

We remark in the ***Figure. IV.5*** the concentration of the roots (candidates) with the different rates R_n, R_c and R_r where we can see how every kind looks for water through changing the rates values, so the convergence to the solution has a strong relation with the different behaviours movements of the roots kinds between them as we have listed previously.

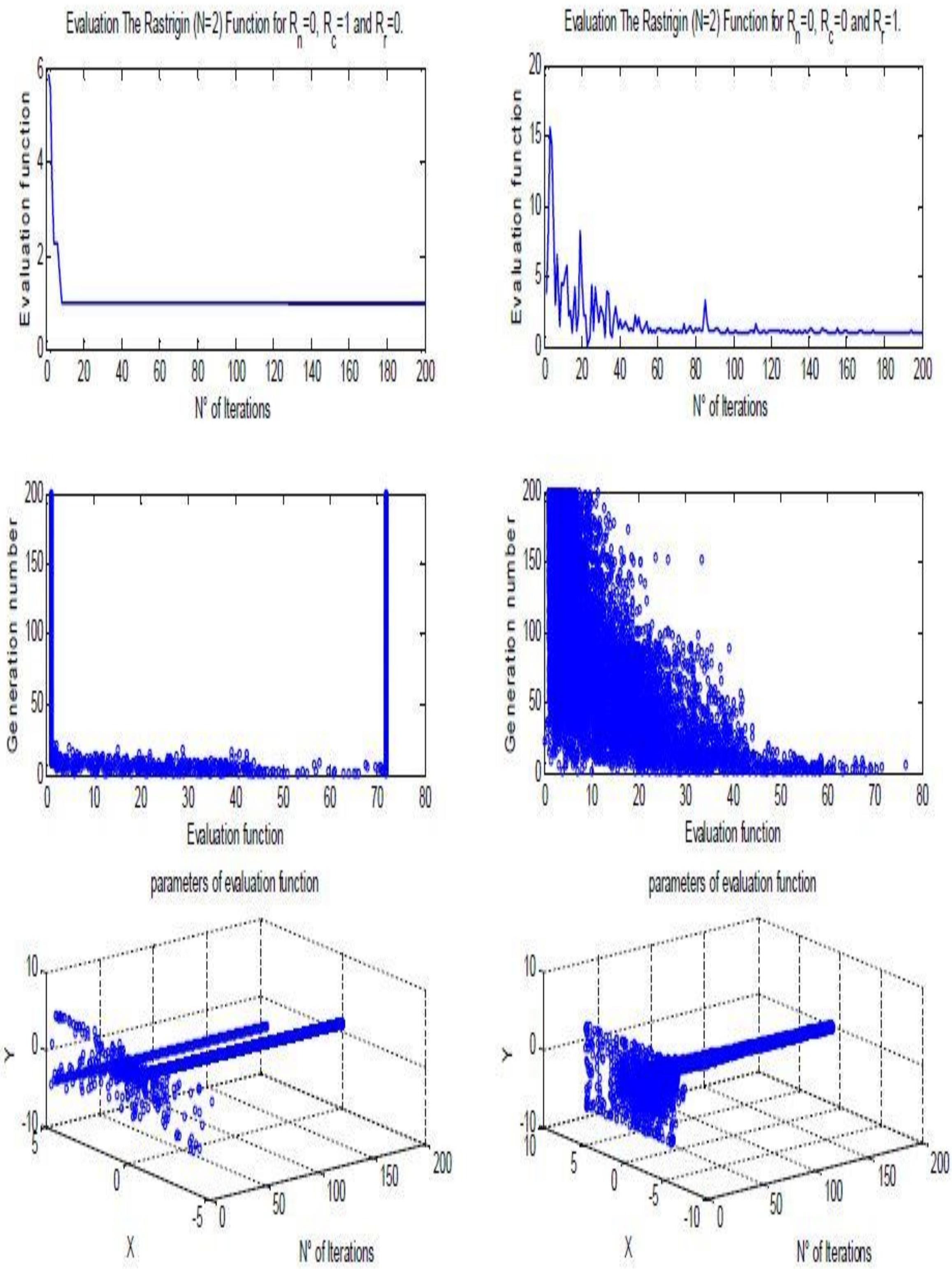


Figure. IV.5: *Evaluation the Rastrigin function for different rates parameters R_n, R_r and R_c.*

IV.4. Experimental Results and Data Analysis:

The calculation program for Optimization was developed and executed under the MATLAB® environment. The results obtained after the optimization by means of the calculation code (or program) are reported in Tables 1 and 2.

These result tables consider several examples of execution (samples) of the Optimization technique by Root Tree Optimization (**RTO**). We can clearly see the variation of the maximum power (MPP_{opt}) with respect to the ambient temperature and / or the sunshine with a good precision (***Figure.IV*.6**, **7** and **8**), Then, applying the above algorithm in search of the maximum power point (MPP) for this day.

IV.5. Influence of Temperature and Illumination

To explain the influence of the ambient temperature and the intensity of the solar irradiance for a given day on the power, the current or the voltage, one traced the curves of these last ones for various sunshine with constant ambient temperature, and for various ambient temperatures with constant sunlight.

It is found that for variable sunshine and at constant room temperature the I_{SC} current is a strong function of the change of sunshine, while the V_{OC} voltage remains substantially constant, unlike the V_{OC} voltage is influenced by changes in the ambient temperature while the I_{SC} current remains confined within a narrow range.

- **Effect of Temperature:**

It is important to perform the same test of the two above-mentioned digital techniques for different ambient temperature values ranging from 0 ° C to 100 ° C while maintaining the illuminance at the constant value of 1000 W / m2. [32].

Table.1: Result of Optimization with variable temperature and illumination of 1kW / m^2.

	V_{Opt} [V]		I_{Opt} [A]		MPP_{opt} [W]	
Temperature [°C]	***RTO***	***P&O***	***RTO***	***P&O***	***RTO***	***P&O***
100	11.5169	10.5000	3.5157	3.7460	**40.4902**	39.3325
75	13.3147	12.5000	3.5465	3.7134	**47.2206**	46.4170
50	15.1511	14.5000	3.5573	3.6787	**53.8965**	53.3406
25	17.0174	16.5000	3.5536	3.6419	**60.4728**	60.0906
0	18.9080	18.5000	3.5390	3.6030	**66.9145**	66.6549

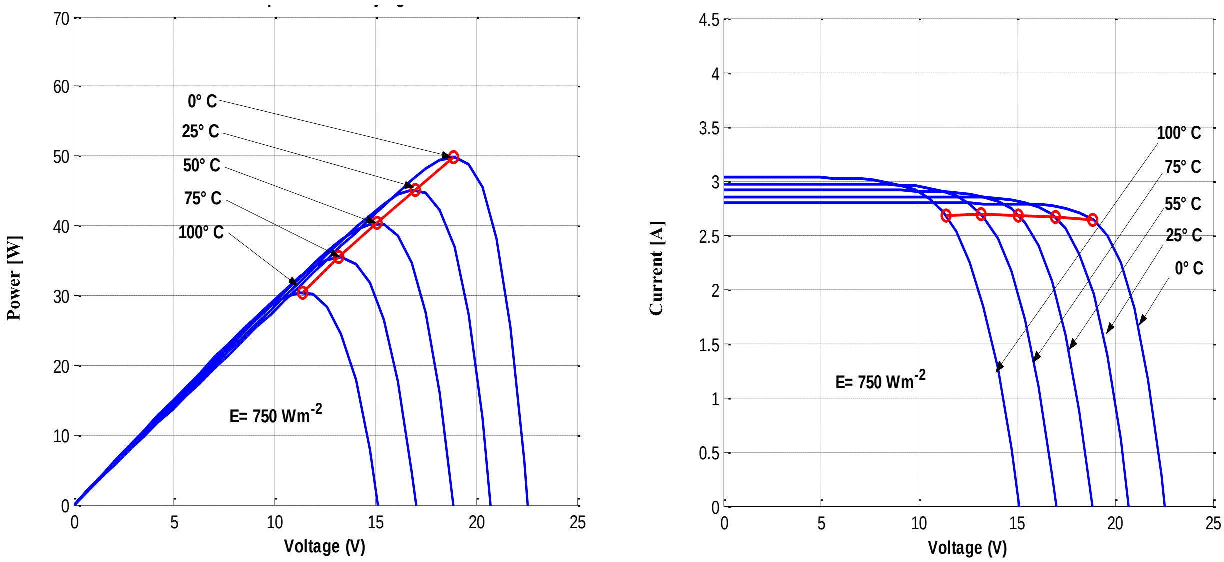


Figure.IV.6: *Variation of the MPP$_{opt}$ with the ambient temperature.*

*** Effect of Illumination:**

A comparison was made of two numerical techniques used to determine the optimum values of the PV system characteristics for a change in sunshine from 100 to 1000 W / m² whose temperature is kept constant at 25 ° C.

Table.2: Optimization results with different illumination and constant temperature at 25 ° C.

	V$_{Opt}$ [V]		I$_{Opt}$ [A]		MPP$_{Opt}$ [W]	
Illumination [w/m^2]	***RTO***	***P&O***	***RTO***	***P&O***	***RTO***	***P&O***
1000	17.0173	16.5000	3.5536	3.6419	60.4728	60.0906
900	16.9959	16.5000	3.1992	3.2759	54.3728	54.0528
600	16.8372	16.5000	2.1341	2.1713	35.9317	35.8258
500	16.7355	16.2500	1.7784	1.8206	29.7619	29.5848
300	16.3797	15.5000	1.0664	1.1063	17.4667	17.1479
100	15.4117	14.5000	0.3543	0.3687	5.4605	5.3455

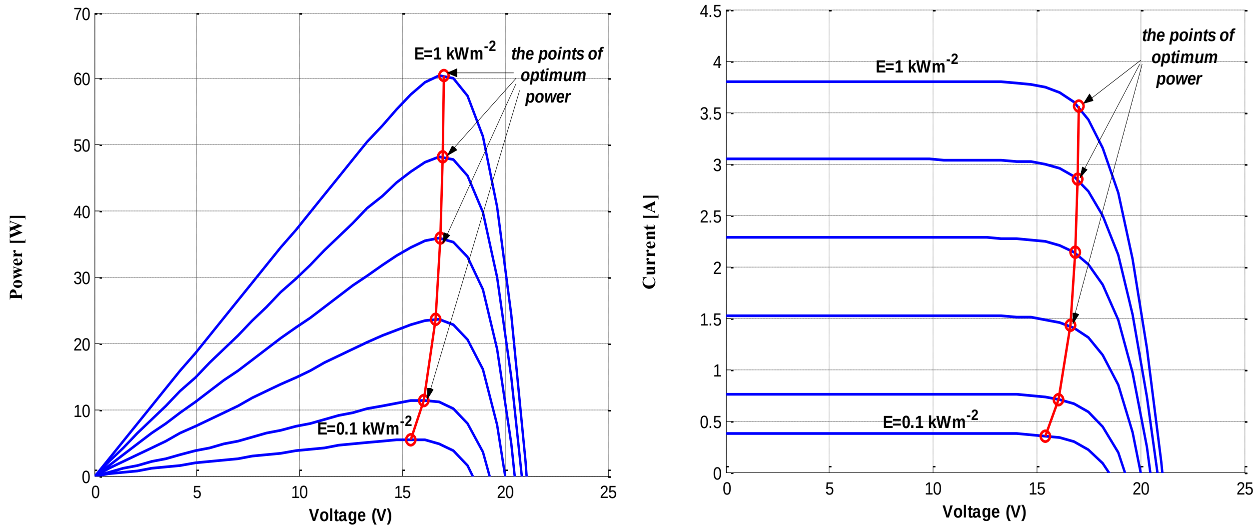


Figure.IV.7: *Variation of the MPP $_{opt}$ with sunshine of this day.*

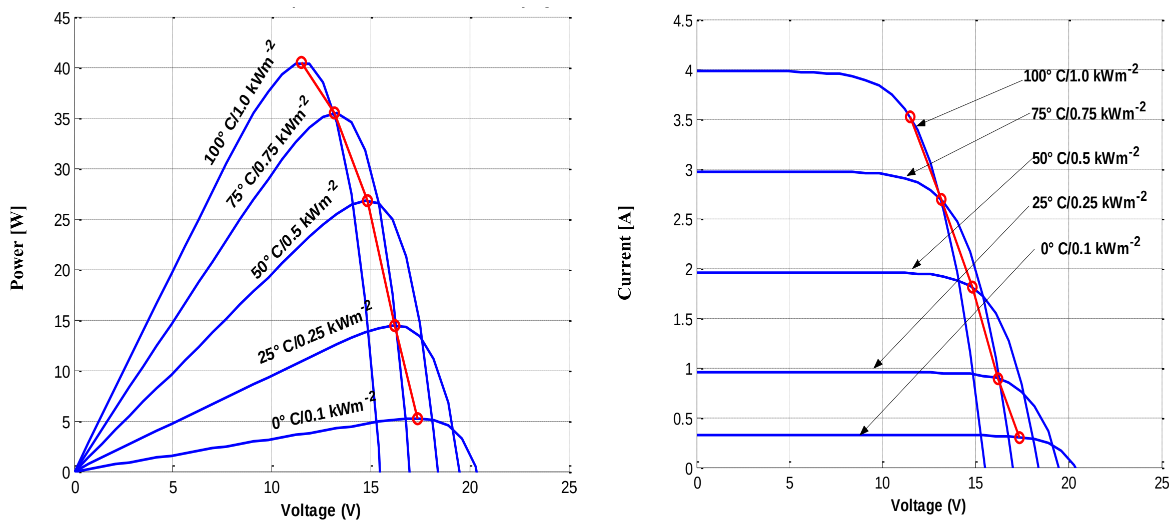


Figure.IV.8: *Variation of the MPP $_{opt}$ with sunshine and ambient temperature at the same time from the PV characteristics.*

It can be clearly seen that the results presented highlight the advantages and the precision of the application of the procedure adapted to the inspection of the effects of temperature and sunshine on the characteristics of the PV system studied.

In order to clearly see the results of this Optimization study, ***Figure.IV.6 to 8*** show the parametric variations of current and power with respect to the voltage. The MPP_{opt} maximum power operating point of each curve is represented by a small circle symbol, which indicates the maximum power value (current and voltage) that the PV module can provide instantaneously under different metrological conditions.

IV.6. MPP Optimization by using RTO Algorithm:

Our goal here is to solve an optimization problem where we look for an optimal solution in terms of variables of the problem (current and voltage) by imposing the constraints on the current and the voltage which should be at the same time greater than zero.
To find the optimal decision variables, we should optimize the objective function and satisfy the constraints, the variables are limited to the limits. (Eq.IV.5) gives a function defined in to take into account variable bounds.

***Random solution generation**

The generation of solution was created randomly as below.

$$P\_i = P\_imin + rand(0,1) \cdot (P\_imax - P\_imin) \quad \text{(Eq.IV.5)}$$

$$D = \sum_{i=1}^{N} P_i - P_D - P_L$$

$$\forall\, i, j \in \left[1,2,3, \dots \dots n_g\right]$$

Where P_{imin} and P_{imax} are the lower and upper limits of the variable Pi. In (Eq.IV.5) rand (0,1) represents a random number between 0 and 1.
The solution is represented as a matrix as below:

$$X_i = \left[P_1 P_2 P_3 P_4 \dots P_{ng}\right] \quad \text{(Eq. IV. 6)}$$

Similarly, $[X_1 X_2 X_3 X_4 \dots X_n]$ are the set of all the solutions chosen at random which satisfy all the defined constraints.

***Assessment of the suitability of solutions**

Likewise, Fitness is assigned to each solution, which represents the quality of each solution.

$$Fitness(i) = \frac{1}{(1 + \sum F_i)} \quad \forall\, i \in \left[1,2,3, \dots \dots n_g\right] \quad \text{(Eq. IV. 7)}$$

$\sum F_i$: represents the total cost of production fuel.

A mutant solution is generated for each solution using its randomly selected neighbor and the parameter to be modified.

$[X_1 X_2 X_3 X_4 \dots X_n]$ is the defined solution where each solution $X = \left[P_1 P_2 P_3 P_4 \dots P_{ng}\right]$ is represented as a random variable of all *ng* variables is chosen and a neighbor of all neighbors n-1 is chosen randomly and a mutant solution is produced as shown below.

$$X_{1mutant} = X_1(i) + \left(X_j(i) - X_1(i)\right).(2.rand - 1) \qquad \text{(Eq.IV.8)}$$

Where (i, j) are randomly chosen parameter and neighbor respectively.
A greedy selection between mutant and original solutions takes place, leading to the rejection of the worst solution. This selection process is repeated for each solution. The solution of which the mutant is less fit increases its test and can lead to the dissertation if the test leads to a threshold limit.

Minimized F equals getting a maximized fitness value in the search process. The purpose of the RTO method must be changed to maximize the ability to be used as follows:

$$fitness = \begin{cases} P(V,I); & if \quad V > 0 \wedge I > 0 \\ 0\ ; & otherwise \end{cases} \qquad \text{(Eq.IV.9)}$$

The steps described above illustrate how RTO evolves during its execution. It is noted that all the parameters involved in the optimization algorithm by the root tree optimization method can be predefined according to the nature of the problem considered.
The RTO operator gives the user a great deal of control over the direction of the search, also giving a better average performance of the optimal computation speed as well as good direction of research.

Beforehand, it is necessary to use the actual sunshine data and the ambient temperature of a specific geographical position during a day in order to simulate the system in question. The latter makes it possible to test the model satisfactorily. For this, we have chosen the real data of the region of Algiers.

Throughout the selected day with small variations in light irradiation between noon and 13:00 and between 14:00 and 17:00. ***Figure.IV.9*** and **10** respectively show the evolution of the optimal voltage and current and the power calculated via the MPP-RTO method during the day.

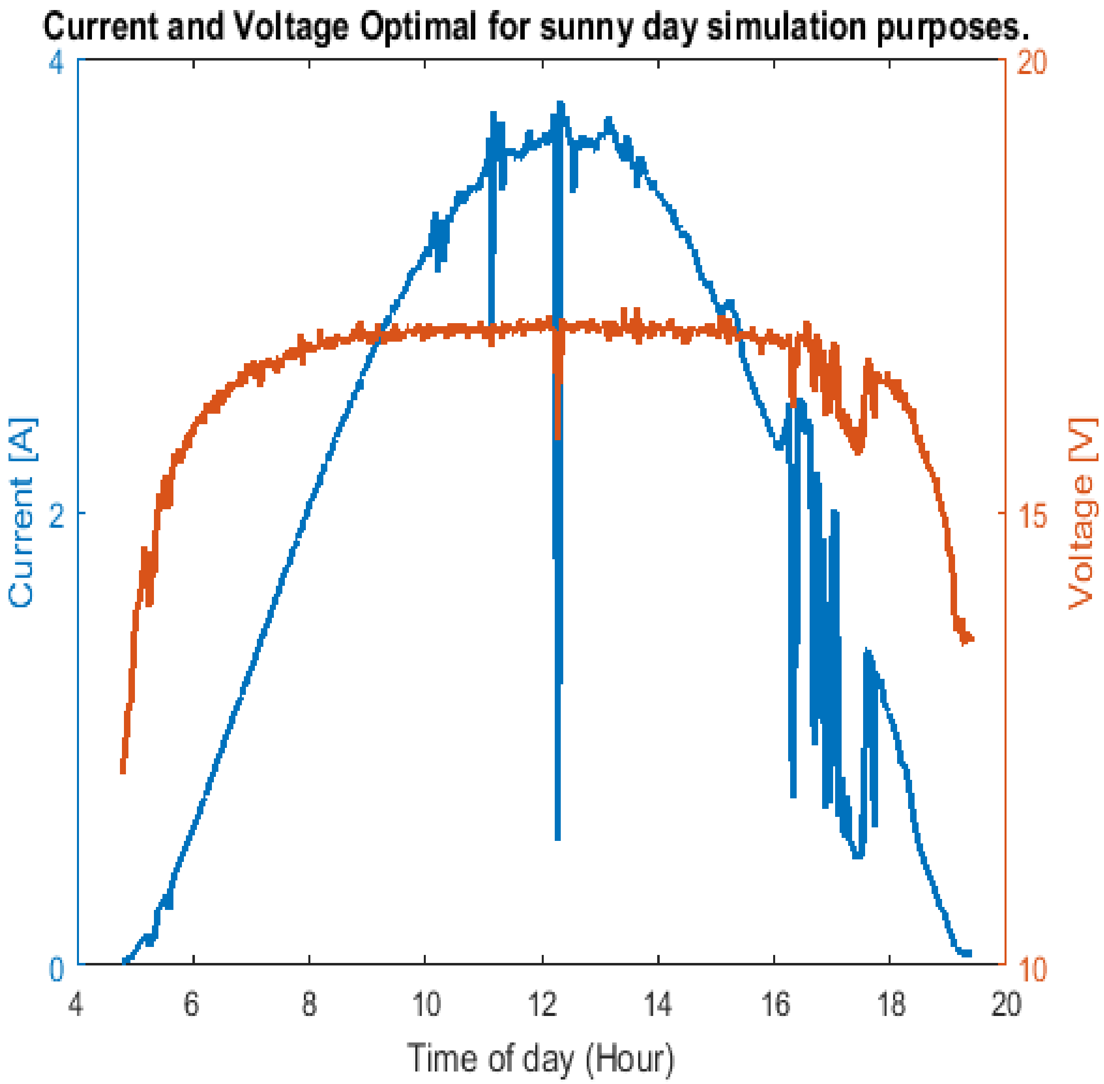


Figure.IV.9: *Optimal Current and Voltage of a sunny day.*

Figure.IV.9 shows the close dependence of the electric current on illumination (solar irradiation) directed towards the PV module presented by the red curve, thus presenting the same pace along the considered day. Furthermore, it can be seen in Figure.IV.9 that the electric voltage increases sharply at the beginning of the day to reach its maximum value, then remains almost constant by making fluctuations around this value until the evening when the solar irradiance is reached. Weakened after sunset about 17h45 local time.

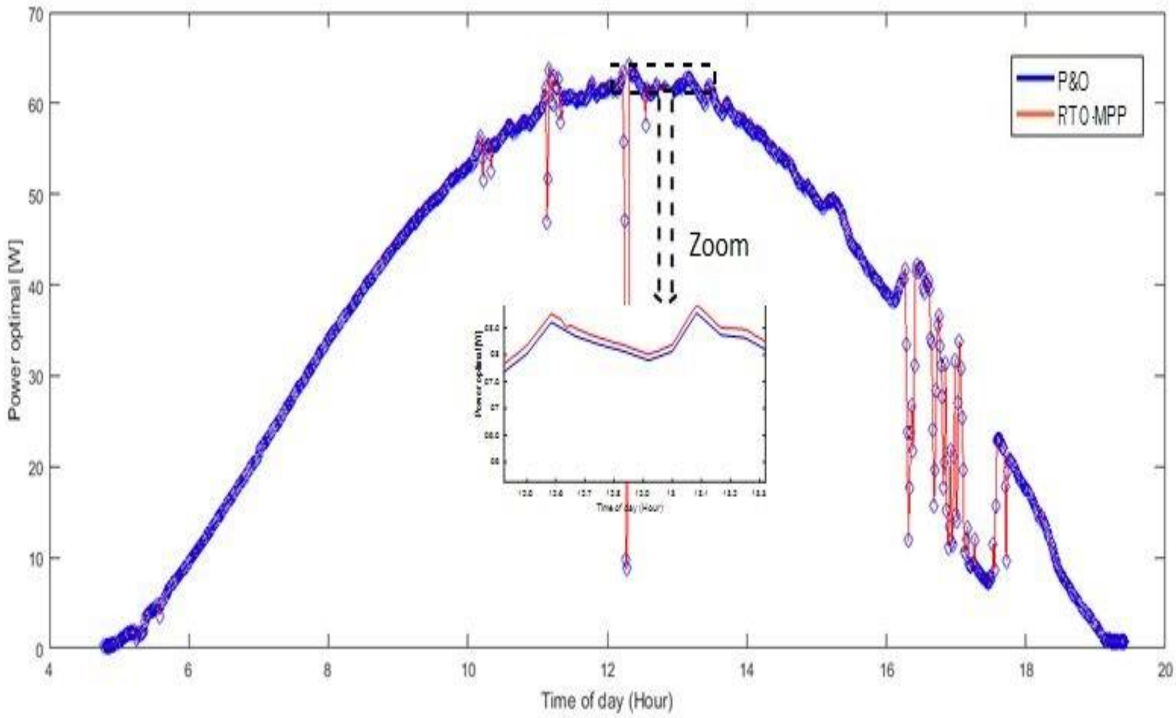


Figure.IV. 10: Optimum power of a sunny day.

We can see in ***Figure.IV.10*** that the curve of the Optimal power sees its value increasing gradually according to the intensity of the radiation (of sunshine) until reaching a maximum lying between 12h06 and 13h01 for a maximum power of P_{max} = 58.75 W and a maximum calculated from the Optimization method RTO of P_{max} = 58.90 W (I_{max} = 3.27 A, V_{max} = 18.0 V) under the following locally measured mean weather conditions: E = 589.58 W / m², Ta = 12.7 ° C before decreasing until evening with a significant power drop between 13h30 and 17h15. Then, the discontinuity clearly observed on the measured power signal may be due to a measurement fault or a disturbance related to a cloudy passage.

General Conclusion

The Photovoltaic cells is one of the most powerful renewable energies; alternatives to fossil energy resources; today invades several domains and finds a wide range of applications.

The efficiency of converting solar energy into electrical energy of the first PV cells was very low. But the industrial and technological development that the world has experienced in the last decade has accelerated the development phases of PV cells, improve the quality of the materials used for their manufacture and consequently increase their conversion efficiency.

Despite the efforts made in this area to lower the overall cost of PV systems which focuses mainly on the manufacturing costs of solar modules, their price remain high. For this reason the applications of PV solar energy remain; until now; particularly limited to isolated sites and mountainous areas where the extension of power lines is often expensive.

In order to make up this high cost, the solar electricity user must think about the new nanotechnology of photovoltaic cells which is called *Organic Photovoltaic (**OPV**)* where the plastic used in OPV cells has low production costs in high volumes. Combined with the flexibility of organic molecules, OPV cells are potentially low cost-effective for photovoltaic applications.
In this research work the focus has been on maximizing the power and gets its Optimal value through the use of the new algorithm called *Root Tree Optimization (**RTO**).*

We started first, in the first chapter, by giving an introduction to the renewable energy and how we can benefit from the energy of the sun.

During the second chapter we introduced the different notions allowing the understanding of the principle of the Photovoltaic cells as well as the various types of solar cells then introduce the new nanotechnology of PV cells called Organic *Photovoltaic cells (OPV)* and listed the advantages of OPV cells than the traditional PV cells.

In the Third chapter we implemented an equivalent circuit for OPV cell in order to get a good idea on the electrical behavior and observe how the device parameters changes with any kind of applied treatment (Temperature, illumination, etc.) to the device, it is modeled with discreet electrical components such as voltage or current sources, diodes and resistors. It provides a scientific and realistic physical explanation for the Photovoltaic cells behavior.

In the Fourth chapter we introduced the concept of the maximum power point, the search strategy and the use of ***RTO*** to extract this point, the simulations carried out allowed us to observe the advantages offered by this technique and Compared to the other method (***P&O***), it gives us a good results well as the robust and the simplicity of its search strategy for the Optimal maximum power point (MPP_{opt}).
The results obtained by the application of the root tree optimization algorithm (***RTO***) for solving MPP_{opt} problem, comparatively to recent methods that treat the same problem, showed a fast and better solution quality time to reach the Optimal solution.

At the end, the challenges to overcome for this technology are the improvement of solar cell efficiency and lifetime limitation resides in the degradation of the organic semiconductors due to presence of oxygen or moisture from the atmosphere, thus encapsulation of these devices is required.

Annex

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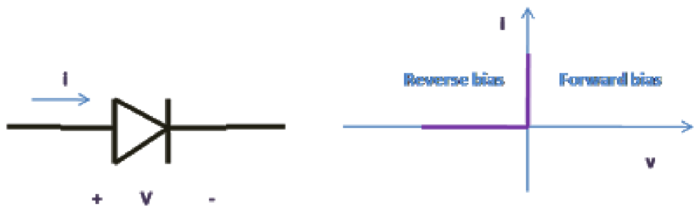
Diode-Circuits

Diode Convention:

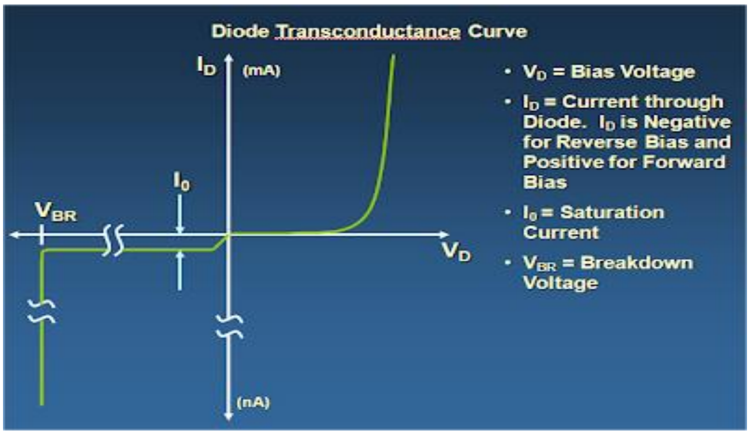
- Positive terminal of the diode is called Anode
- Negative terminal of the diode is called Cathode.
- If a negative voltage applied to the diode , no current flows and diode behaves like open circuit. This mode called Reverse bias.
- If a positive voltage applied to the diode , current flows and diode behaves like short circuit. This mode called Forward bias.



Ideal Diode

Practical Diode Characteristics:

- Reverse saturation current is interdependent of the applied reverse bias.
- Cut in voltage: In forward bias, voltage below the Cut in voltage, diode forward current is very small.
- Cut in voltage for Germanium =0.2V, Silicon=0.7V.
- Reverse saturation current is 1000 times more in Germanium when compared to Silicon diode.
- At higher currents diode behaves like a resistor than a diode and current increases linearly rather than exponentially with applied voltage.



- The reverse saturation current approximately doubles for every 10 degree C temperature rise for both Si and Ge materials.
- The p-n junction voltage decreases by about 2.5mV/degree C with rise in temperature.

Diode equation

Reverse Bias:

When the diode is reverse-biased, a very small drift current due to thermal excitation flows across the junction. This current (reverse saturation current, I_0) is given, according to the Boltzmann equation, by the formula:

$I_0 = K_0 \exp^{-eV_0 / kT}$

Where K0 is a constant depending on the pn junction geometry and V_0 is the built-in Voltage of the diode.

Forward Bias:

When the diode is forward-biased through a voltage V, a small drift current flows again
across the junction. In that case, however, there is an additional component, the diffusion
current V_d, given by the formula:

$I_d = K_0 \exp^{e(V - V_0) / kT}$

These two currents have opposite directions; the total current is therefore given by:

$I = I_d - I_0 = K_0 \ \exp^{-eV_0 / KT} (\exp^{eV / KT} - 1) = I_0 (\exp^{eV / KT} - 1)$.

Bibliography and used References

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[01] Dr S S Verma, "Next generation solar cells, The future of renewable energy", Department of Physics, S.L.I.E.T., Longowal, Sangrur District, Punjab, India ,2016.

[02] M.Askari. Bagher, "Introduction to Organic Solar Cells." Sustainable Energy, vol. 2, no. 3 (2014).

[03] Cheng, Y.J.; Yang, S.H.; Hsu, C.S. Synthesis of conjugated polymers for organic solar cell applications. Chem. Rev. 2009.

[04] S.V.D. Prasad, V.Krishnanaik, K. R Babu "*Analysis of Organic Photovoltaic Cell"* International Journal of Science and Modern Engineering (IJISME) ISSN: 2319-6386, Volume-1, Issue-9, August 2013.

[05] M.B Askari "*Introduction to Organic Solar Cells"* Department of Physics Azad University, North branch, Tehran, Tehran, Iran Revised April 28, 2014; Accepted April 28, 2014.

[06] Heliatek press release, Heliatek consolidates its technology leadership by establishing a new world record for organic solar technology with a cell efficiency of 13.02%, 2016.

[07] H. Cao, et al. *"Recent Progress in Degradation and Stabilization of Organic Solar Cells",* J. Power Sources 264: 168-83, 2014.

[08] C. W. Tang, et al. *"Two-Layer organic photovoltaic cell,"* Appl. Phys. Lett. 48, 2:183–5, 1986.

[09] T. L. Benanti, et al. "*Organic Solar Cells: An overview focusing on active layer morphology"*, Photosynth Res. 87: 73–81, 2006.

[10] International Energy Agency, *"CO2 Emissions from fuel combustion highlights"*, 2015.

[11] H. S. Jung, et al. *"Perovskite Solar Cells: From Materials to Devices",*Materials Views 11: 10-25, 2015.

[12] Web site: https://www.pveducation.org/

[13] Web site: https://en.wikipedia.org/wiki/Photovoltaic_system.

[14] Web site: https://www.enerray.com/blog/algeria-renewable-energy-150-mw-solar-pv-tender/

[15] M.Askari. Bagher, "Introduction to Organic Solar Cells." Sustainable Energy, vol. 2, no. 3 (2014).

[16] A. Luque and S. Hegedus, *"Handbook of Photovoltaic Science and Engineering"*, Wiley, Great Britain, 2003.

[17] Wolfgang Tress, *"Device Physics of Organic Solar Cells"*, 1-384, 2011.

[18] C. Frederik et al. "*25th Anniversary Article: Rise to Power – OPV-Based Solar Parks"*, Adv. Mater. 26: 29–39, 2014.

[19] J. C. Jean-Luc, et al. *"Molecular understanding of organic solar cells: The challenges,"* Acc. Chem. Res., 42: 1691–99, 2009.

[20] B. Kippelen, et al. *"Organic photovoltaics,"* Energy Environ. Sci, 2: 251–61,2009.

[21] Web site: https://www.nrel.gov/pv/assets/pdfs/best-research-cell-efficiencies.20190802.pdf

[22] C. Yan, *et al.* Non-fullerene acceptors for organic solar cells. *Nat. Rev. Mater.* **3,** 72–83 (2018).

[23] H. Cha, *et al.* An Efficient, 'Burn in' Free Organic Solar Cell Employing a Nonfullerene Electron Acceptor. *Adv. Mater.* (2017).

[24] *L.D. Pulfrey, Photovoltaic Power Generation. New York: Van Nostrand Reinhold Co. ISBN 9780442266400. (1978).*

[25] *N., Jenny "Polymer:fullerene bulk heterojunction solar cells". Materials Today.* ***14*** *(10): 462–470. doi:10.1016/S1369-7021(11)70210-3 (2011-10-01).*

[26] Web site: https://www.pnas.org/content/105/8/2783.

[27] Web site: https: //www.laserfocusworld.com/detectors-imaging/article/16549532/organic-photovoltaics-transition-metal-oxides-increase-organic-solarcell-power-conversion.

[28]. W. X. Chaoxu and L. Tang," Advanced Control Techniques for PV Maximum Power Point Tracking", Advances in Solar Photovoltaic Power Plants, 2016.

[29].*Article in* *Chemical Society Reviews* *"Stability of organic solar cells: Challenges and strategies" February 2016.*

[30] J.M. Nunzi, '*Organic Photovoltaic Materials and Devices*', Comptes Rendus de Physique, Vol. 3, N°4, pp. 523 – 542, 2002.

[31]. M. A. Elgendy," Comparative investigation on hill climbing MPPT algorithms at high perturbation rates", *Renewable Energy Congress (IREC), 2016 7th International*, MAR. 2016.

[32]. L'ensoleillement de la journée du 03/01/2015 de la région de Bouzzereah – Alger .