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Photovoltaic Generator power Enhacement Competence using square technique

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DEDICATION

I dedicate this humble work

to my dear parents who have supported me throughout my life studies, may ALLAH preserve them.

To my dear brothers and sisters

For all my family and friends.

Fatima

DEDICATION

I dedicate this work
To the most precious person in my life to whom everything was in my life and who still is,…my dear father.
To the souls who left us one day… mother and my grandmother.
(God have mercy on them).
To my dear sisters
To my dear brothers
To my father's wife, and my brother's wife and children.

SARA

Abstract

Recently, the increasing interest in solar energy has led to the development of large scale solar arrays. Although the most commonly used TCT (total cross-connection) interconnection scheme minimizes mismatch losses. However, the shading in large PV arrays can significantly reduce the power output and cause multiple power peaks in the P-V characteristics. In order to avoid the problem of multiple peaks, PV arrays are reconfigured using electrical or physical reconfiguration techniques. For this purpose, the physical repositioning method proved to be effective and economical in achieving better shadow dispersion, as it neither requires complex switch arrangements or expensive controllers for reconfiguration compared to electrical methods. Therefore, this graduation thesis introduces an innovative Competence Square (CS) technology for the physical rearrangement of photovoltaic panels in a TCT interconnection scheme.

ملخص

في الآونة الأخيرة ، أدى الاهتمام المتزايد بالطاقة الشمسية إلى تطوير مصفوفات شمسية واسعة النطاق. على الرغم من أن مخطط التوصيل البيني TCT (إجمالي التوصيل المتقاطع) الأكثر استخدامًا يقلل من خسائر عدم التطابق. ومع ذلك ، فإن التظليل في المصفوفات الكهروضوئية الكبيرة يمكن أن يقلل بشكل كبير من خرج الطاقة ويسبب قمم طاقة متعددة في خصائص P-V. من أجل تجنب مشكلة القمم المتعددة ، يتم إعادة تكوين المصفوفات الكهروضوئية باستخدام تقنيات إعادة التكوين الكهربائية أو الفيزيائية. لهذا الغرض ، أثبتت طريقة إعادة الوضع المادي أنها فعالة واقتصادية في تحقيق تشتت ظل أفضل ، حيث إنها لا تتطلب ترتيبات تبديل معقدة أو وحدات تحكم باهظة الثمن لإعادة التكوين مقارنة بالطرق الكهربائية. لذلك ، تقدم أطروحة التخرج هذه تقنية مربعة الاختصاص (CS) مبتكرة لإعادة الترتيب المادي للألواح الكهروضوئية في مخطط ربط TCT .

SUMMARY

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Cs: competence square.

Ns: number of cells in series.

Np : number of cells in parallel.

Voc: Open circuit voltage.

Isc : Short-circuit Current.

MPPT : Maximum Power Point Tracking.

MPP: Maximum Power Point.

Ipv: current generated by the module.

Vpv: is the PV voltage.

I_0:saturation current.

Iph :photoelectric current.

Rs: series resistance.

G: Solar radiation.

FF: fill factor.

ML: mismatch loss.

PSC : partial shading condition.

AM: Air mass.

UV : ultraviolet (10–400 nm) radiation .

UVA : ultraviolet A (315–400 nm) radiation.

UVB : ultraviolet B (280–315 nm) radiation.

UVC: ultraviolet C (200–280 nm) radiation.

SW : schort wide.

GENERAL

INTRODUCTION

Electrical energy is now essential for many human activities. Electricity production is increasing fast, while fossil fuel used for electricity generation is limited. Moreover, the emission from fossil fuel strongly causes the environmental problem. Therefore, renewable energy such as hydro energy, solar energy, and wind energy which are clean and no cost of resource are widely promoted for electricity generation, especially, solar energy. Due to its inexhaustible and environmentally friendly energy, the research in solar energy has become an increasingly important topic in recent years. It is envisaged to become one of the most important renewable energy sources. It is one of the most promising alternatives for conventional energy sources. Due to this, photovoltaic solar energy has been increasingly used to generate electric power[1][2].

Photovoltaic solar energy comes from the direct transformation of a part of the solar radiation into electrical energy. This energy conversion is carried out by means of a cell called photovoltaic (PV) based on a physical phenomenon called the photovoltaic effect.

The PV system efficiency is subject to various factors such as working condition changes (solar radiation, temperature, dust, shade) and ageing. These effects become serious challenges that deteriorate the PV system output power since the PV array is composed of interconnected PV modules that can have different conditions [9]. As result, the efficiency decreases due to mismatch losses. Indeed, interconnections of solar cells (or modules) that do not have the same properties or that are under different meteorological conditions from one another yield to a deteriorated efficiency. In practice, mismatch issue, is reflected reduction of the current or/and the voltage of the concerned module. Another key point to remember, the partial shading is just a part of mismatch issue and is not the only phenomenon influencing power generation. The temperature of the solar cells is a very important parameter that cannot be neglected in the behaviour of solar modules[3].

PV modules need to be operated at the maximum power point (MPP) at varying heat, insolation and load levels for an efficient use. One way of increasing the PV array efficiency is to use maximum power point tracker (MPPt) . In this thesis we are interested in studying the effects of shading on the production of electrical energy and how to limit its impact on the PV field by the CS topology[4].

The first chapter presents an overview of PV solar energy as well as the different solar cell technologies and their operating principles. At the end of this chapter, we will highlight the advantages and disadvantages of this system.

In the second chapter, we will focus into the effect of partial shading on energy output of different Solar Photovoltaic Array (SPVA) configurations and to mitigate the losses faced in

Solar Photovoltaic (SPV) systems by including bypass diodes, and we will explain the various architectures of the PV array.

In the last chapter, we will present a novel competence square (CS) method based physical array reconfiguration strategy for the PV output power optimization. Moreover, we will tested by simulation on a PV array consisting four different shade patterns are analyzed to create the partial shading conditions (PSC).

Finally, a general conclusion will be presented to summarize the main points raised in this work.

CHAPTER I

GENERALITY OF

PV SYSTEME

I.1. Introduction

The exploitation of solar energy has been widely spread in several countries of the world in recent years .This exploitation is mainly done in two ways:

- Thermal transformation: By exploiting the heat of solar radiation in order to heat a fluid (liquid or gas)
- Photovoltaic transformation: it is the transformation of a part of the light of the solar radiation towards an electric energy, thanks to the PV panel formed by semiconductor cells.

In this chapter, we present general information's about solar energy and explain how solar cells function and their characteristics. In addition, we provided a PV system and their types, finally, and then we present the advantages and disadvantages of photovoltaic cell.

I.2. Solar Energy

Solar energy is the proportion of electromagnetic energy that comes from the sun and passes through the atmosphere, which absorbs some of the energy before reaching the Earth's surface. Solar energy is derived from nuclear fusion that happens in the Sun's core. It travels through the solar system and the cosmos primarily as electromagnetic radiation of photons and infrared radiation. At a speed of 300 000 km/s, 98 percent of the energy released by its light is in the wavelength region between 0.25 and 3 µm[5].

This energy can be used in thermal or electrical form:

- Solar thermal energy.
- Photovoltaic energy.

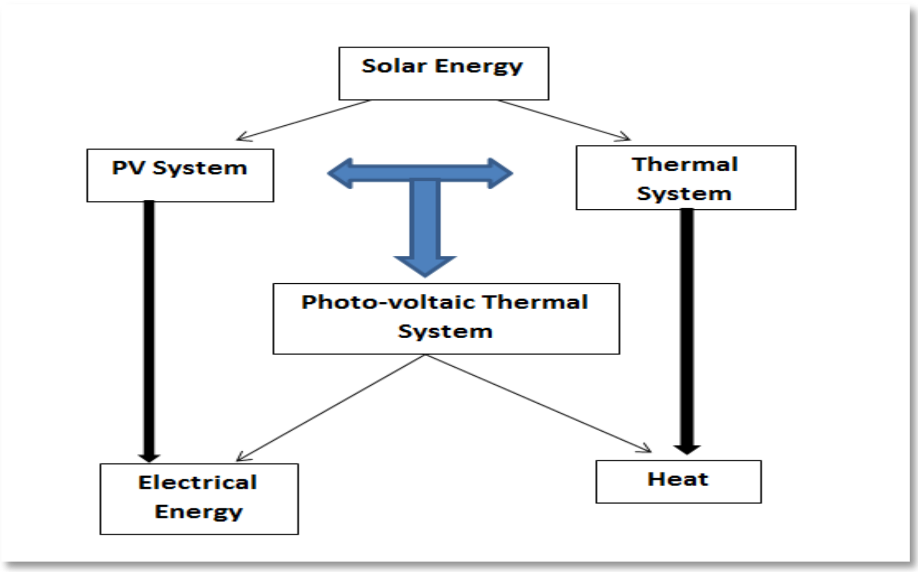


Figure.I.1 Types of solar energy.

I.2.1. Solar irradiation

The sun continuously discharges a huge amount of radiant energy into the solar system; the earth intercepts a very small part of the solar energy radiated into space. An average of 1367 watts reaches each square meter of the outer edge of the Earth's atmosphere (for an average Earth-Sun distance of 150 million km), this is called the solar constant equal to 1367W/m². The energy emitted by the Sun is primarily in the form of electromagnetic radiation, which together form the solar radiation, which is the only significant external source of energy for the atmosphere. This solar radiation propagates at the speed of light c; it therefore takes an average of 499 seconds, or 8 minutes and 19 seconds, to reach our atmosphere . The amount of energy received on the surface of the earth depends on the thickness of the atmosphere to be crossed .This is characterized by the number of air masses AM. The radiation that reaches the sea level at noon in a clear sky is 1000 W/m2 and is described as the radiation of air mass "1" (or AM1). As the sun moves lower in the sky, the light passes through a greater thickness of air, losing more energy. Since the sun is only at its zenith for a short time, the air mass is therefore permanently larger and the available energy is therefore less than 1000 W/m2[6].

I.2.2. Different components of solar radiation

When solar radiation propagates through the atmosphere, it interacts with the atmosphere's gas constituents as well as all suspended particles (aerosols, water droplets, and ice crystals). The particles discussed here range in size from a hundredth of a meter to several hundred meters. Solar radiation can be reflected, dispersed, or absorbed[7].

a. Direct radiation:

We call direct solar radiation that which reaches the ground without having undergone diffusion. The spectrum of direct solar radiation received at the earth's surface. It moves away in a notable way from the radiation reaching the upper limit of the atmosphere, in particular because of the absorption by the gaseous constituents of the atmosphere[7].

b. Diffuse radiation:

Diffuse Radiation The solar radiation received from the sun after its direction has been changed by scattering by the atmosphere. (Diffuse radiation is referred to in some meteorological literature as sky radiation or solar sky radiation; the definition used here will distinguish the diffuse solar radiation from infrared radiation emitted by the atmosphere[8].

c. Reflected radiation:

Reflected by the earth's surface, i.e. reflected in a privileged direction (known as specular reflection) or in a diffuse way. The ground reflects the radiation in a diffuse and anisotropic way[7].

d. Global radiation:

The solar radiation reaching the ground has several components to be treated differently: a direct component I, a diffuse component D, and the Albedo, all forming the global radiation G.

I.2.3. Radiation spectrum

The spectral distribution of the solar radiation reaching the surface of the Earth depends on a number of factors, Solar radiation reaching the Earth's atmosphere is mainly. in the wavelength range 200–4000 nm. Radiation below 400 nm is called UV radiation and is usually divided into UVC (200–280 nm), UVB (280–315 nm) , and UVA (315–400 nm)[9].

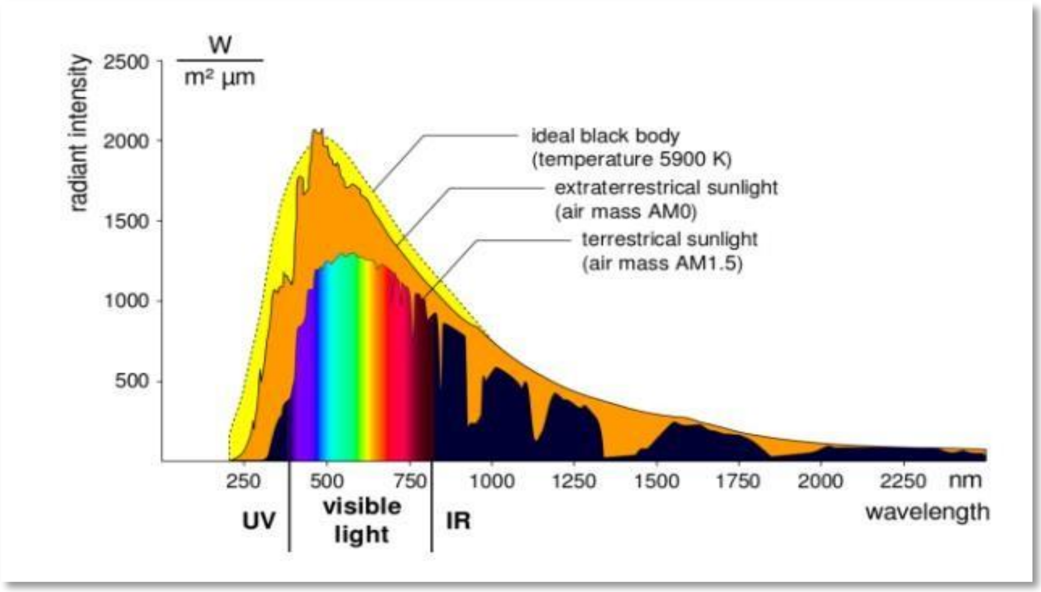


Figure.I.2 The solar spectrum from extreme UV to far infrared.

I.3. Photovoltaic energy

Photovoltaic solar energy is generated by converting a portion of the sun's rays with a photovoltaic cell. A solar panel is made up of many cells that are linked together (or module). A photovoltaic field is made up of many modules that are placed together in a solar photovoltaic power plant. The term photovoltaic can refer to either the physical phenomena - the photovoltaic effect - or the technology linked with it**.** For the past 40 years, photovoltaic systems have been employed. The applications began with the space program for satellite radio broadcasting. They continued with the beacons at sea and the equipment of remote places across the planet, employing batteries to store electrical energy during the hours when there was no sun[6].

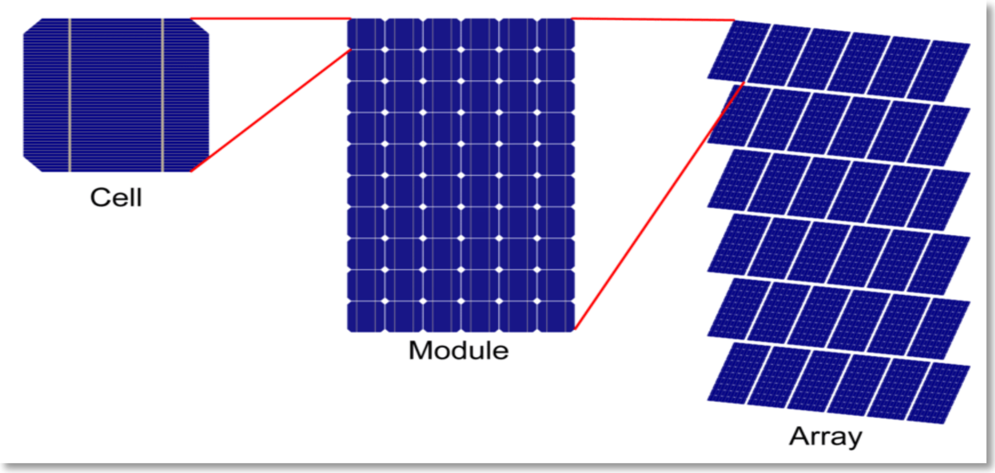


Figure.I.3 solar cell, solar PV module, and solar PV array.

I.3.1. Types of PV Systems

Based on the electric energy production, PV modules can be arranged into arrays to increase electric output. Solar PV systems are generally classified based on their functional and operational requirements, their component configurations. It can be classified into grid-connected and stand-alone systems.

- **Grid-connected PV system**

Grid-connected or utility-interactive PV systems are designed to run in parallel with and be linked to the power grid. The inverter, or power conditioning device, is the most important component in grid-connected PV systems (PCU)[10].

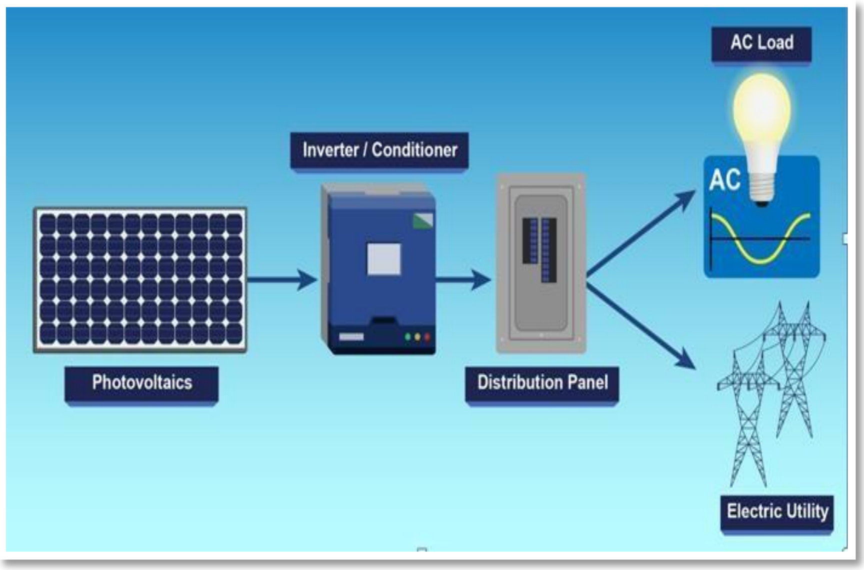


Figure.I.4 Grid-connected PV system

- **Stand-alone PV systems**

Stand-alone PV systems are intended to function independently of the power grid and are often built and scaled to serve specific DC and/or AC electrical needs. These systems may be powered solely by a PV array, or they may include wind, an engine-generator, or utility electricity as an auxiliary power source in what is known as a PV-hybrid system. A direct-coupled system is the most basic sort of stand-alone PV system, in which the DC output of a PV module or array is directly linked to a DC load Figure I.5[10].

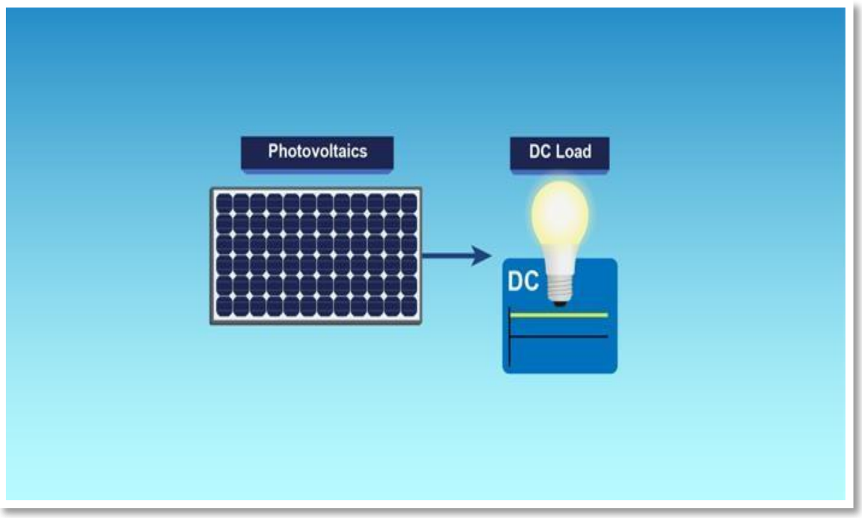


Figure.I.5 Direct-coupled PV systems

In many stand-alone PV systems, batteries are used for energy storage. The figure I.6 below show two possible configurations[10].

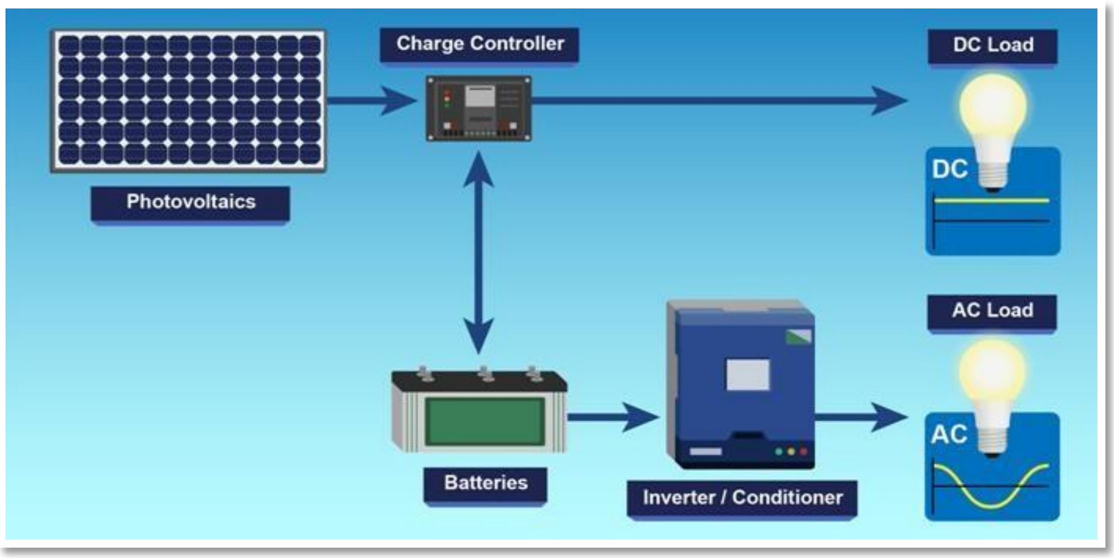


Figure.I.6 Stand-alone PV system with battery storage powering DC and AC loads

- **Hybrid systems**

Hybrid systems generally refers to the combination of any two input sources, here solar PV can be integrated with Diesel Generator, Wind Turbines, Bio-mass or any other renewable on non-renewable energy sources[10].

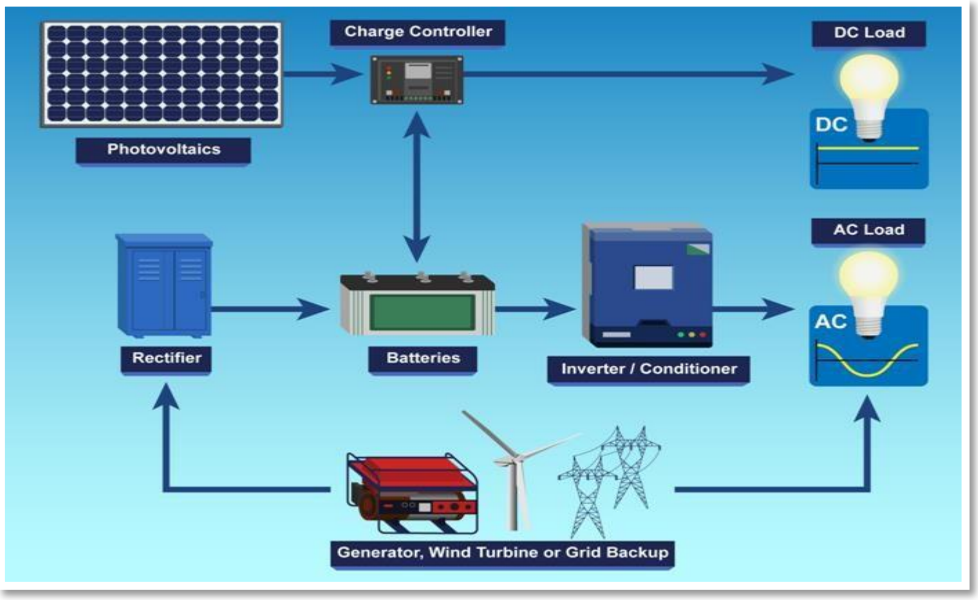


Figure.I.7 Hybrid PV system

I.3.2. Photovoltaic energy advantages:

The Photovoltaic energy has several advantages such as listed as below:

- They are non-polluting with no discernible emissions or odors. They can be stand-alone systems that operate reliably, unattended for long periods of time.
- They do not need to be connected to any other power source or fuel supply.
- They can be combined with other energy sources to increase the reliability of the system.
- They can withstand harsh weather conditions such as snow and ice.
- They do not consume any fossil fuel and their fuel is abundant and free.
- High reliability because the system has no moving parts, which makes it particularly suitable for particularly suitable for isolated areas, hence its use on spacecrafts.
- They are long-lasting.

I.3.2. Photovoltaic energy disadvantages:

Despite the various advantages listed in the last subsection, the PV energy has many disadvantages as below:

- The manufacture of photovoltaic modules is a high-tech process, which makes the cost very high.
- The actual yield of a photovoltaic module is currently around 15 to 23%.
- They are dependent on weather conditions.
- The energy from the photovoltaic generator is continuous and of low voltage. Therefore, it must be transformed through a static converter.

I.4. Photovoltaic cell

In this section, we present the working principal of PV cell, interconnection of PV cells, and various types of PV cells

I.4.1. working principal of PV cells

A photovoltaic cell is based on the physical phenomenon called photovoltaic effect which consists in establishing an electromotive force when the surface of this cell is exposed to light. The generated tension can range between 0.3 and 0.7 V depending on the material used and its location, as well as the cellule's temperature and age. The graphic depicts a typical PV cell with its detailed structure. A PV cell is made up of two layers of silicium, one doped P (doped to bore) and the other doped N (doped to phosphore), resulting in a PN junction with a potential barrier. When photons are absorbed by the semiconductor, they transmit their energy to the atoms of the PN junction so that the electrons of these atoms are released and create electrons (N charges) and holes (P charges). This creates a potential difference between the two layers. This potential difference is measurable between the positive and negative terminals of the cell. Through a DC charge, carriers can also be collected. The maximum voltage of the cell is about 0.6 V at zero current. This voltage is called open circuit voltage (V_{OC}). The maximum current occurs when the terminals of the cell are short-circuited, it is called short-circuit current (I_{SC}) and depends strongly on the level of illumination[11].

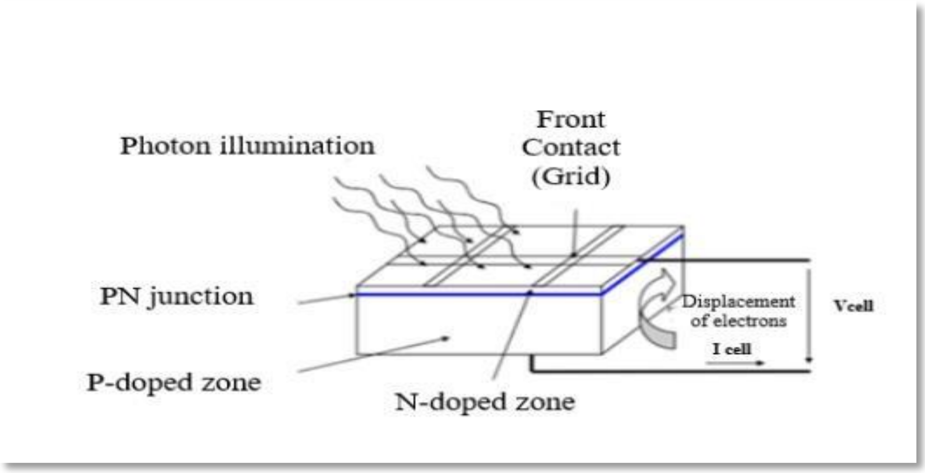


Figure. I.8 Cross section of a typical PV cell

I.4.2. Interconnections of photovoltaic cells

- **Interconnection series and parallel of PV cell:**

In a grouping of Ns cells in series, all are crossed by the same current. Figure I.9 shows the resulting characteristic (Isc, V_{OC}) of such an array under ideal conditions, obtained for ns identical cells (Isc,V_{OC}) by summing the elementary characteristics at constant current[6]

Vsoc = ns.Voc

For an array of np identical cells in parallel

$$Ipsc = np.Isc$$

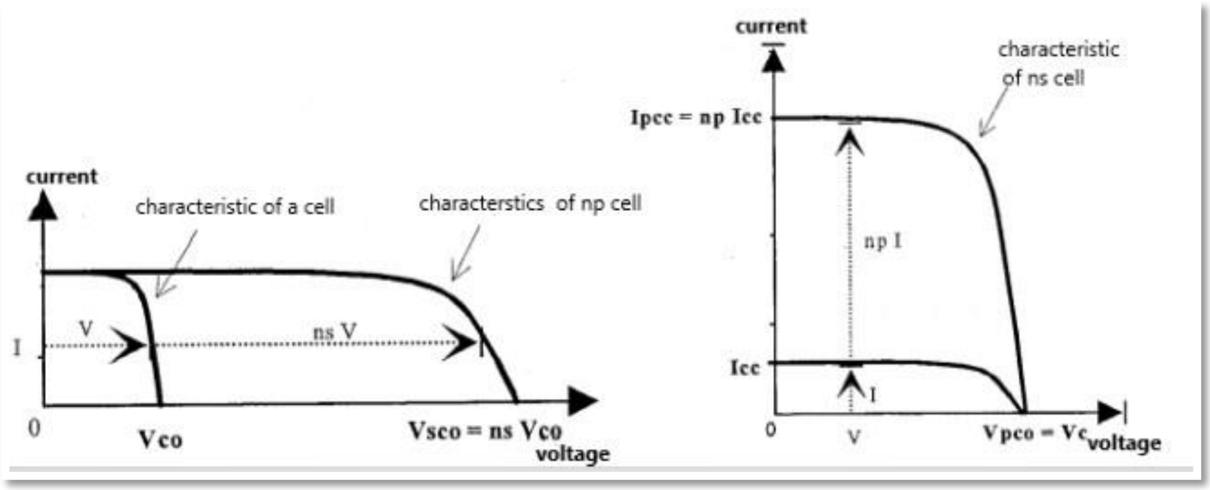


Figure. I.9 characteristic of series or parallel grouping of identical photovoltaic cells

- **Hybrid interconnection (series and parallel)**

Figure I.10 shows the resulting characteristic obtained by associating, in series ns and in parallel np, identical cells.

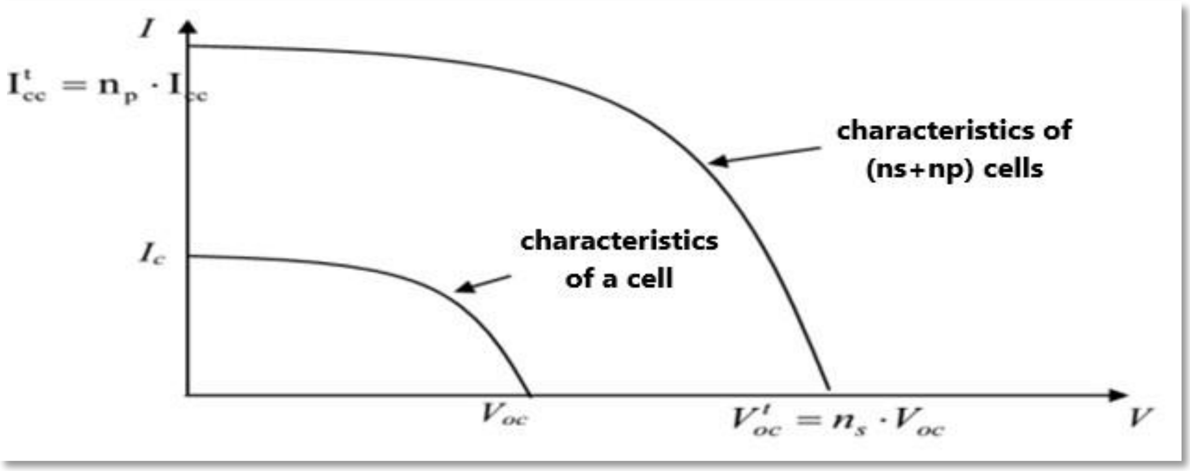


Figure.I.10 Resulting characteristic of a parallel grouping of np identical cells

I.4.3. Different types of PV cells:

- **Monocrystalline silicon:**

Monocrystalline silicon cells represent the first generation of photovoltaic generators. To manufacture them, we melt silicon in the form of a bar. During slow and controlled cooling, silicon solidifies forming only one large crystal. The crystal is then cut into thin slices which will give the cells. These cells are usually a uniform blue. Lifespan: 20 to 30 years[6].

- **Polycrystalline silicon:**

As the silicon cools in an ingot mold, several crystals are formed. The photovoltaic cell is bluish in appearance, but not uniform, we can distinguish patterns created by the different crystals[6].

- **Amorphous silicon :**

Silicon during its transformation produces a gas, which is projected onto a sheet of glass. The cell is a very dark gray color. It is the cell of so-called "solar" calculators and watches[6].

- **The advantages and disadvantages of various types of PV cell:**

Table I.1 shows the comparison of different types of PV cells .

TableI.1 PV cells type comapraison

Cell type	 **Monocrystalline silicon**	 **Polycrystalline Silicon**	 **Amorphous Silicon**
Advantages:	Good yield, from 12% to 18% Good ratio (around 150 which saves space if necessary	Square cell (with rounded corners in the case of monocrystalline Si) allowing better expansion in a module, less expensive than a monocrystalline cell.	Operates in low or diffused lighting (even on cloudy days). A little cheaper than other technologies. Integration on flexible or rigid supports.
Disadvantages:	High cost , Low performance in low light	Efficiency less good than monocrystalline cell: 11 to 15% Ratio less good than for monocrystalline (around 100)	Low yield in full sun, 6% to 8% Need to cover larger areas than when using crystalline silicon (lower ratio, around 60. Performance that decreases over time (around 7%).

I.5. Conclusion

In this chapter we have made a general description of photovoltaic solar energy, then principle operation of a photovoltaic cell and their characteristics. In addition, we have explained the different types of photovoltaic system. Finally, we finalized this chapter by talking about the advantages and disadvantages of different types of PV cells.

CHAPITRE II

OPTIMIZATION OF PV ARRAY OUTPUT POWER

II .1.Introduction

The utility of electrical energy and its demand are increasing at a quicker rate. However, the supply of conventional energy sources such as fossil fuels is dwindling. As a result, the usage of non-conventional energy sources such as solar, wind, tidal, geothermal heat, and biomass is expanding. Among all, the solar photo-voltaic (PV) energy is the most prevalent and popular source of energy. But the PV output characteristics are mainly depending on temperature and irradiance and are nonlinear in nature. There-fore, PV array characteristics greatly changes with change in the atmospheric condition. Under partial shading condition (PSC) PV modules will not receive the same amount of irradiance levels throughout the day which causes mismatch in PV module characteristics of the PV array. PSC appears in the PV array if the PV array module gets varying amounts of irradiance. The current output of the shaded module is lowered in comparison to the unshaded modules due to partial shading.

To deal with, many studies based on reconfiguring the solar PV modules have been carried in literature .The reconfiguration of solar PV arrays is a well-known and a widely used method to increase the power output and production efficiency of power generation[3].

II.2. System description and characteristics:

A PV cell is modeled as a current source shunted with a diode and represented by an equivalent circuit shown in Figure II.1. The characteristics of the module are obtained by connecting a number of such cells in series. The equation relating the output current and the voltage of a PV module can be written as

$$I_{PV}= I_{ph} - I_0 \left[exp\left(\frac{V_{PV}+R_s I_{pv}}{A}\right) - 1\right] - \left[\frac{(V_{pv}+I_{pv} R_s)}{R_{sh}}\right] \quad (1)$$

where Ipv is the current generated by the module, Iph is the photoelectric current, Io is the saturation current, Vpv is the PV voltage, and A = nkT/q. T represents the temperature of the module in Kelvin, k is the Boltzmann's constant, q is the electric charge, n is the number of cells in series, and R s is the series resistance. The nonlinear output characteristic of the PV module results in a unique MPP on its P − V characteristics[12].

a) Single diode model

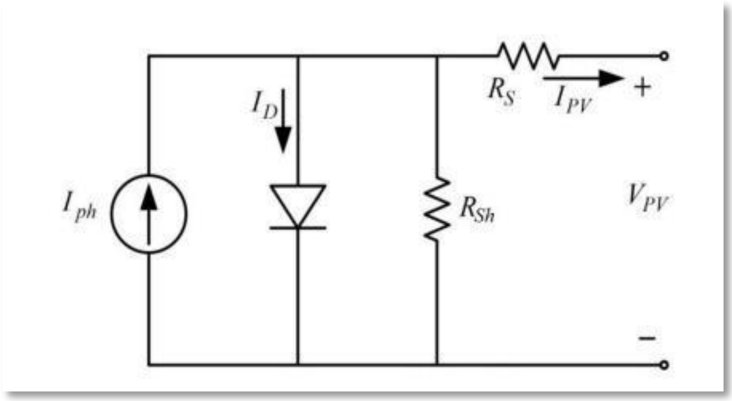


Figure II.1 Single-diode model

The characteristic curves of a PV system depend on the solar irradiance and temperature. For a given system, during uniform conditions where the solar irradiance is equally distributed among the PV modules, the output power curves depend on the PV voltage under different weather conditions are shown in Figure.II.2. During uniform conditions, only one maxima point is observed in the characteristic power curves. However, when the solar irradiance or temperature varies, the power generated by PV module becomes different and the maxima point varies according to the previous value[13].

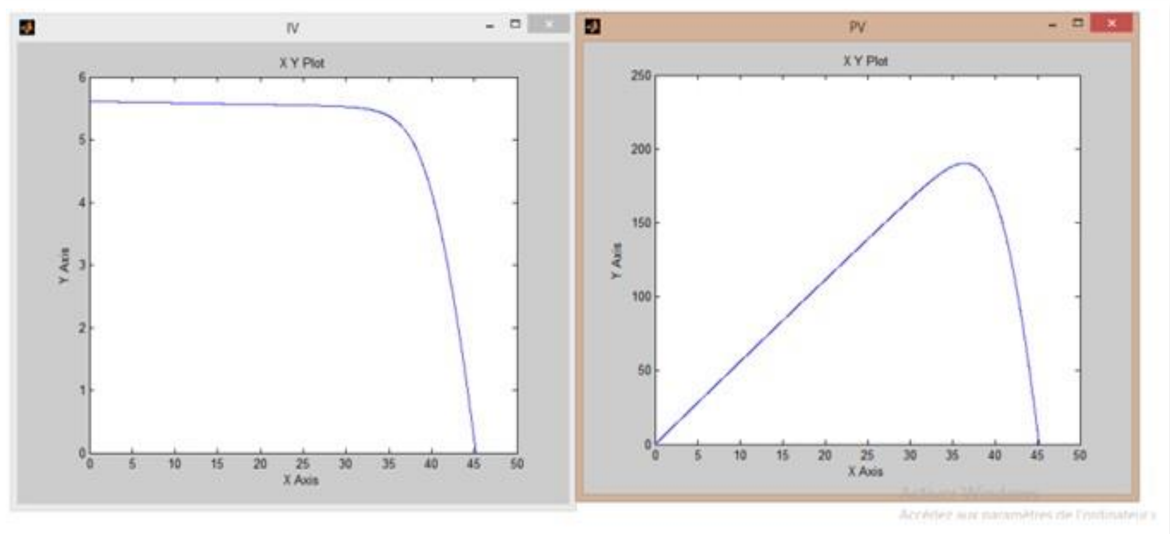


Figure .II.2 Characteristics of the pv module under matlab sumilink

II.2.1. Operating areas of the photovoltaic module:

The electrical characteristics of a photovoltaic panel vary according to the temperature, the illumination and generally the operating conditions when connected to a given load. In this section, we briefly review the behavior of the generator under various constraints. These notions are indeed necessary to understand the behavior of a PV generator and then to optimize its operation.

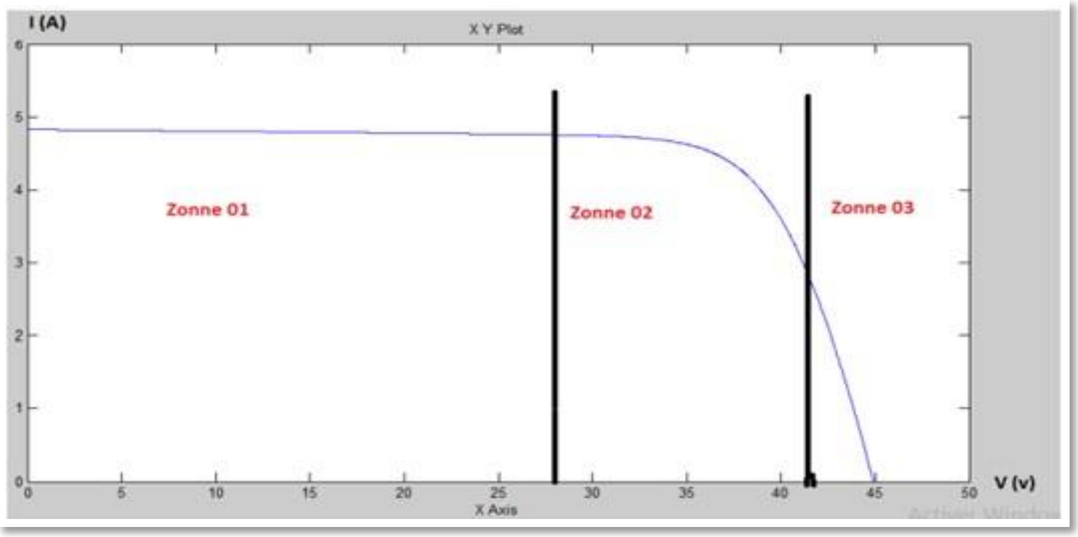


Figure .I1.3 PV module operating areas

The characteristic of a PV module made up of several cells has a general appearance similar to that of an elementary cell, provided that there is no imbalance between the characteristics of each cell (uniform irradiation and temperature). We can decompose the I(V) characteristic of a PV generator into three zones:

- **Zone-1-** : A zone comparable to a current generator Isc proportional to the irradiation, the internal admittance can be modeled by 1/Rsh .
- **Zone-2-** : A zone comparable to a voltage generator Uoc of internal impedance equivalent to the series resistance Rs.
- **Zone-3**- : A zone where the internal impedance of the generator varies very strongly from Rs et Rsh.

It is in zone 3 that the operating point is located for which the power supplied by the generator is maximum. This point is called the point of optimum power, characterized by a couple (Imax, Umax), and only a load whose characteristic passes through this point, allows to extract the maximum power available in the considered conditions.

II.2.1.1. The influence of illumination and temperature :

- **The influence of illumination :**

The following figure shows the variation of current versus voltage for different light intensities and the maximum power for each case. It can be seen that the operating points at maximum power move little and are located around the same value. We can also notice that the current is directly proportional to the solar radiation. On the other hand, the voltage is relatively little degraded. We deduce that the module can provide a correct voltage, even at low illumination.

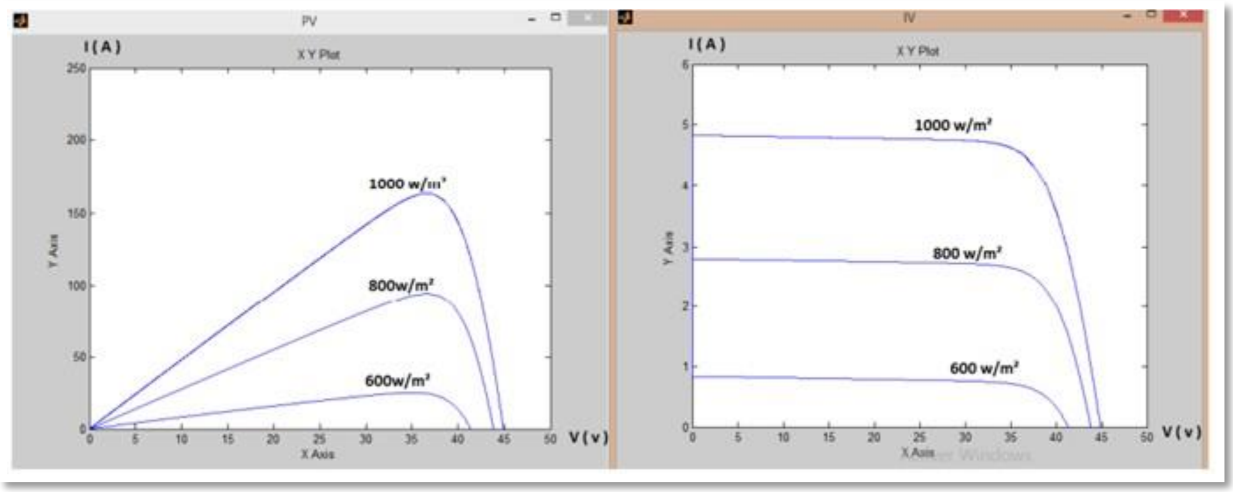


Figure.II.4. The influence of illumination

- **The influence of temperature:**

Has a significant influence on the efficiency of a photovoltaic cell. Experimentally, we notice that the short-circuit current varies little with the temperature while the open-circuit voltage is much more influenced (of the order of - 0.4%/K). The temperature has therefore a significant influence on the efficiency of a photovoltaic cell (power loss of the order of 9-15% for an increase of 30°).

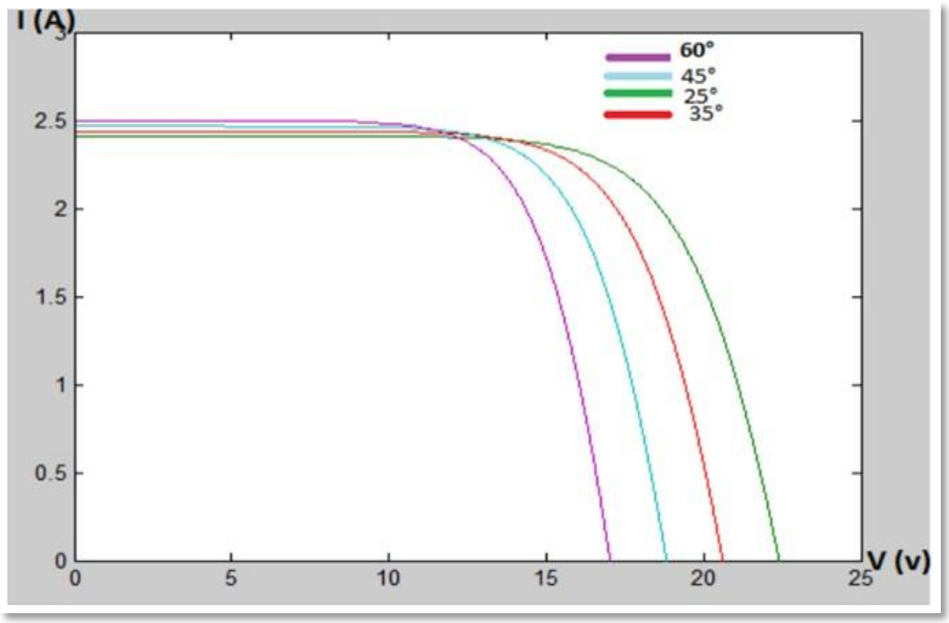


Figure.I.5 The influence of temperature

II.2.2. Optimal use of a cell, determination of the MPPT (Maximum Power Point Tracking):

From the current-voltage characteristic we can deduce the characteristic of the electrical power generated by the cell as a function of the voltage at its terminals. There is a value of photo current corresponding to a voltage at the terminals of the cell for which this electrical power generated is optimum. This point is called the MPPT (Maximum Power Point Tracking)[6].

II. 3.MPPT (Maximum Power Point Tracking):

For any PV system, the output power can be increased by tracking the MPP (Maximum Power Point) of the PV module by using a controller connected to a dc- dc converter (usually boost converter). However, the MPP changes with insolation level and temperature due to the nonlinear characteristic of PV modules. Each type of PV module has its own specific characteristic. In general, there is a single point on the V-I or V-P curve, called the Maximum Power Point (MPP), at which the entire PV system operates with maximum efficiency and produces its maximum output power. This point can be located with the help of MPPT (Maximum Power Point Trackers). PV system with MPPT controller has been shown in FigureII.6

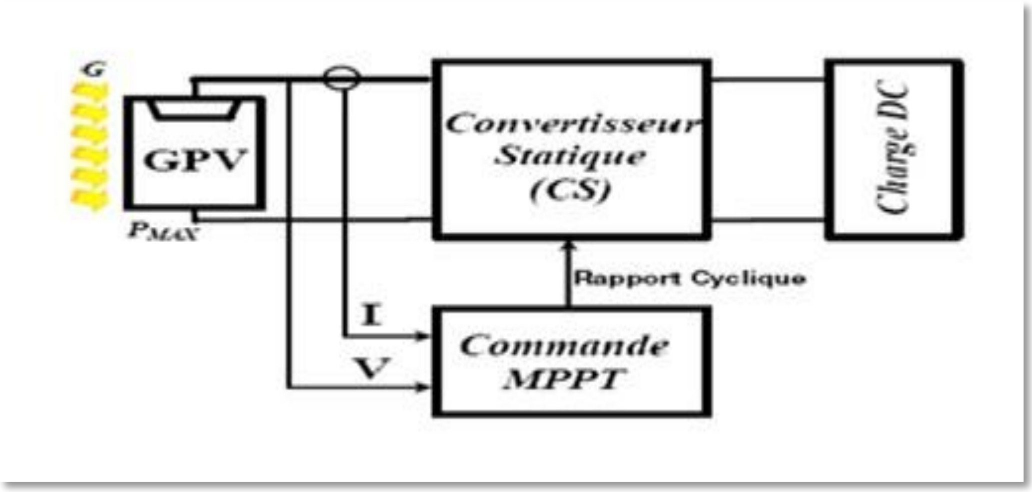


Figure.1I.6 PV system with commande MPPT

Maximum Power Point Tracker, frequently referred to as MPPT, is an electronic system that operates the PV modules in a manner that allows the modules to produce all the power they are capable of. MPPT is not a mechanical tracking system that “physically moves” the modules to make them point more directly at the sun. MPPT is a fully electronic system that varies the electrical operating point of the modules so that the modules are able to deliver maximum available power[14].

II.3.1 operating principle of MPPT:

A MPPT, is a principle allowing to follow, as its name indicates it, the point of a non-linear electrical generator. Consequently, for the same illumination, the power delivered will be different depending on the load. An MPPT controller allows control the static converter linking the load (a battery for example) and the photovoltaic the photovoltaic module so as to permanently provide the maximum power to the load at each load at any time[15] .

II.3.2 MPPT Algorithms:

Many different algorithms have been proposed for tracking MPP in the past. Commonly used algorithms are Perturb and observe method, Incremental conductance method, Constant voltage method, Constant Current method etc. Perturb & observe method is also known as P&O method. In this method voltage or current of the PV array is modified to reach the MPP. For example the voltage is kept on increasing till the power increases. Constant voltage method is one of the simplest algorithms for MPPT. This method is based on the fact that the ratio of the array's maximum power voltage, V_{MPP}, to its open-circuit voltage, Voc, is approximately constant. Constant current method is similar to constant voltage method .The choice of the algorithm depends on the complexity; the time takes to track the MPP and cost of implementation.

- **P&O Algorithm :**

In this algorithm a small error is introduced in the system due to this power of the module changes. If the change in power is positive then the perturbation is continued in that direction after point MPP, the power ate the next instant decreases, then perturbation is reversed. At steady state the algorithm oscillates around the peak point. The figure. 1I.7 shows a flowchart of Perturb & Observe (P & O) algorithm.

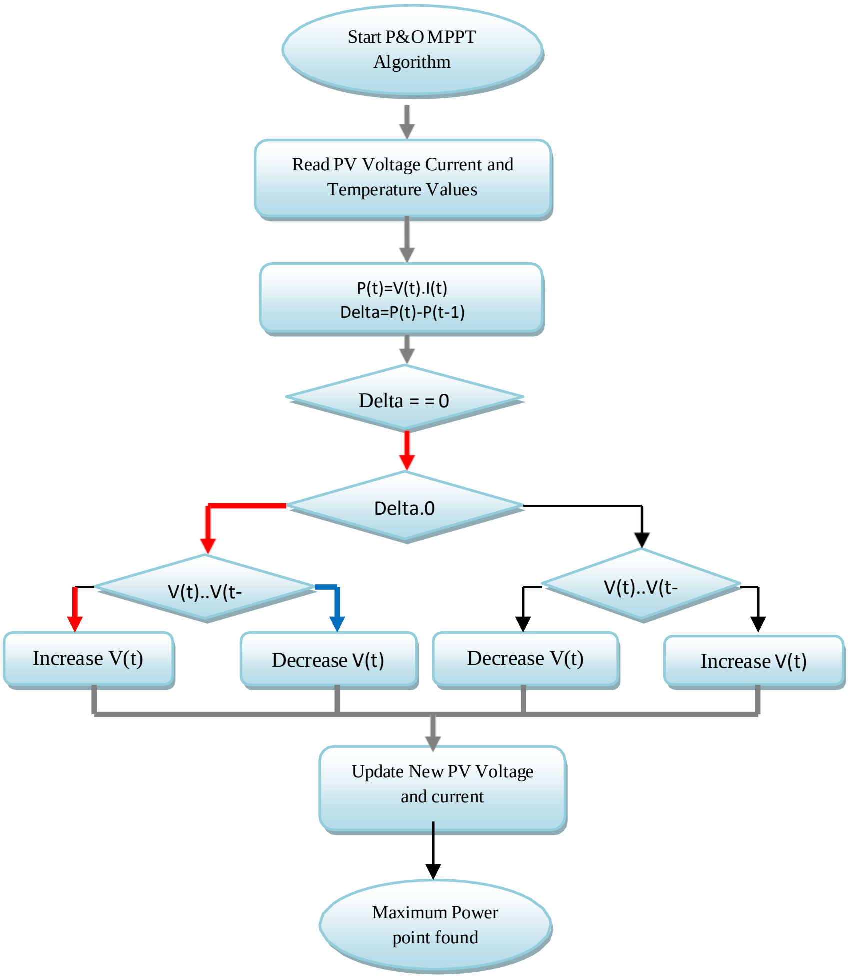


Figure. 1I.7 Flowchart of Perturb & Observe (P & O) algorithm.

II.4. Reconfigurable operation for solar PV array:

The reconfiguration of the PV modules is one of the solutions for electrical mismatch losses in an SPVS such that reconfigurable systems change the inter-connections between the solar modules in a solar PV array. Reconfiguration approach is applicable only for central inverters, string inverters and multi-string inverters. Generally, module inverters do not follow this approach since the electrical mismatch problem does not create a significant effect on these inverters. According to the configuration of connections of solar PV modules in a solar PV array, they can be categorized as, Series , Parallel , Series-Parallel Honeycomb , Total cross-tied , Bridge-linked[16] .The figure .II.8 summary of the application of reconfigurable solar PV systems.

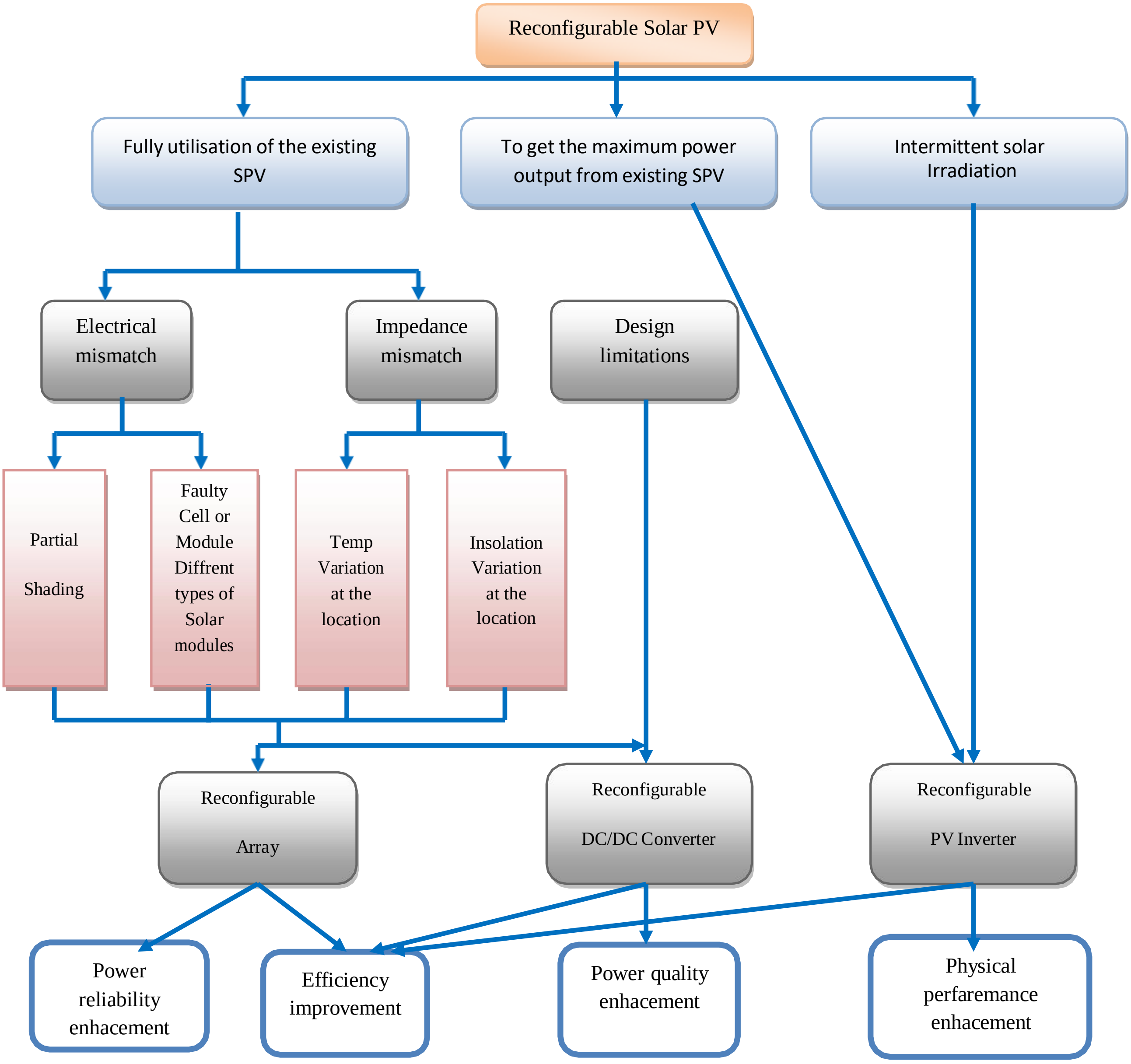


Figure .II.8 summary of the application of reconfigurable solar PV systems.

II.4. 1. Interconexion of PV module

- **Connection in parallel :**

In this topology all the PV modules are connected in parallel. In parallel configuration voltage in equal to module voltage on current in array is separate PV module is the individual PV modules . Current produces from each PV module flows without any limit in this topology regarding irradiance level. Therefore parallel interconnected PV system operates more effectively under rapidly varying solar irradiance level[17].

Vout = V1=V2=…= Vn **(2)**

$$\mathbf{Iout = I1 + I2 + \ldots + In = \sum_{i=1}^{n} Ii} \qquad (3)$$

The output power of submodule

$$Pout = Iout\ Pout = \sum_{i=1}^{n} Pi \qquad (4)$$

- **Connection in series :**

When the PV array operates under uniform irradiance condition, all the PV modules produce same short circuit current and generates the maximum power .The PV array current is restricted by the stunted irradiance on PV module. In this connection same current should flow from PV modules. Therefore, in the shaded modules production of short circuit current is equal to unshaded PV modules by the operation of reverse bias condition .This is the only reason the operation of shaded modules in reverse bias, instead of delivering power they will definitely dissipates the power as in high temperature (heat) and causes hot spots on PV modules. Straight for the guarded operation of modules from hotspot effect. Each PV module bypass diodes are connected in antiparallel .Due to the irradiances the voltage difference occur in between the PV modules under forward biases bypass diodes. These diodes share portion of the short circuit current of the shaded modules and improves the power generation capability by representing multiple MPPs on output characteristics of S- PV array[17].

- **Series-Parallel (SP) Array:**

All PV modules are first connected serially then in parallel, as shown in Fig. II.9. This type of configuration can increase the voltage and current output of the module array, and the connection scheme is simple and easy to construct. Consequently, series-parallel arrays are the most commonly employed configurations. However, when any branch of a series-parallel array experiences partial shading or malfunctions, the overall current output declines substantially[18].

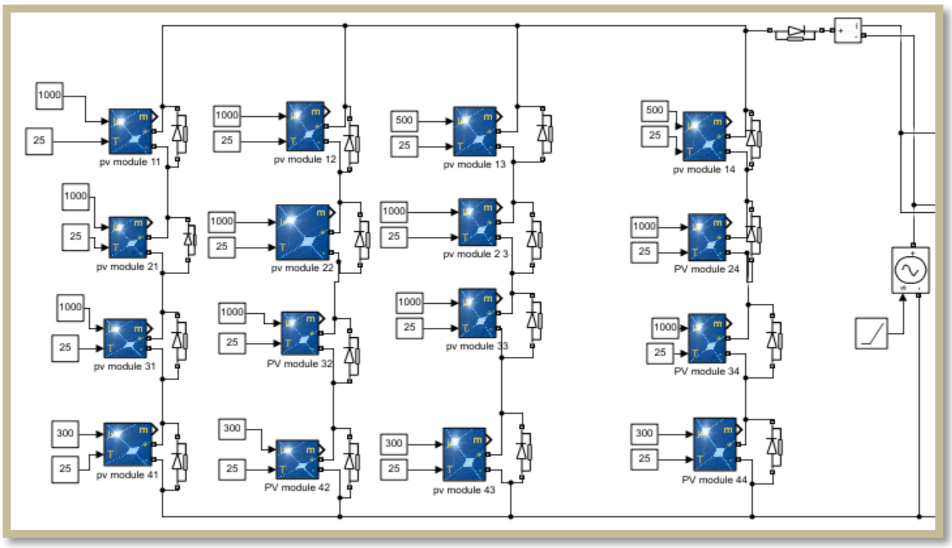


Figure.II.9. simulink Model of Serie_Parallel PV array configuration

- **Total Cross-Tied (TCT) Array:**

All PV modules are connected serially and then cross-tied in parallel, as shown in Figure II.10 This configuration involves a scheme in which the modules are connected in parallel and then in series. Multiple PV modules are first connected in parallel; these parallel modules are then connected in series. This connection scheme can resolve the disadvantages of series and parallel arrays[18].

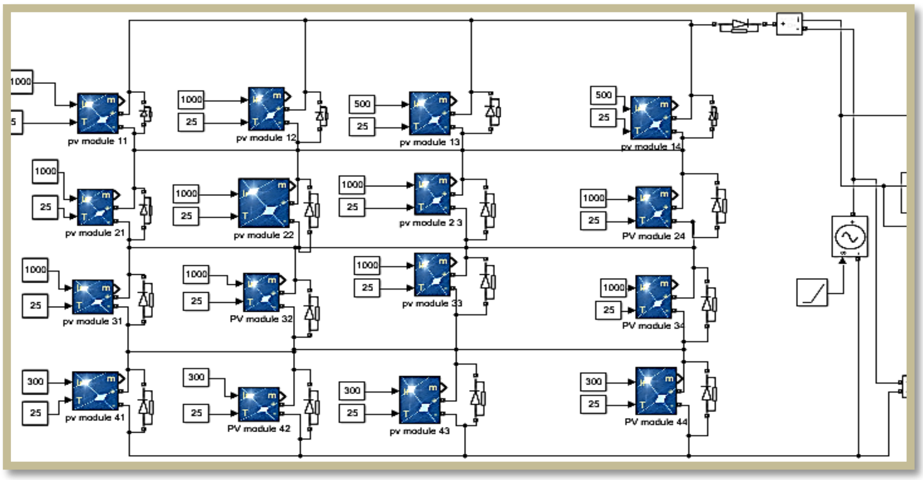


Figure. II.10 Simulink model of Total-Cross-Tied (TCT) PV array Configuration

- **Bridge-Linked (BL) Array:**

In this interconnection, all PV modules are connected using bridge architecture, as shown in Figure II.11. When configurations of this type are partially shaded, the neighboring modules are also affected, reducing the overall voltage and current output. The MPPT method proposed in cannot be applied to this connection scheme[18].

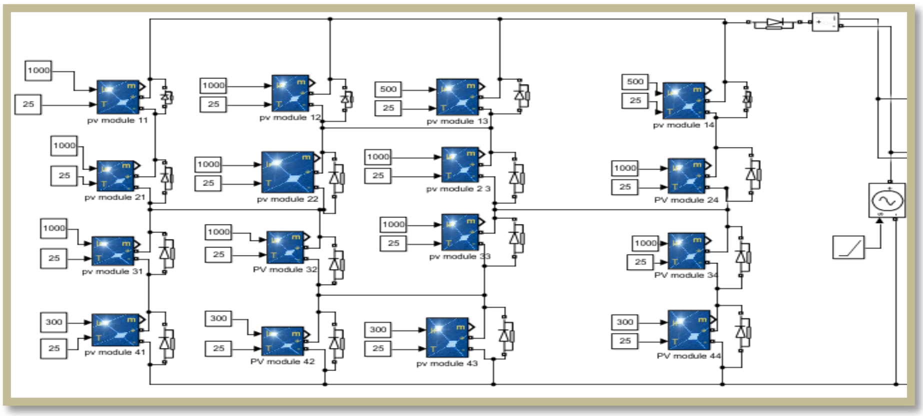


Figure. II.11 Simulink model of bridge-link (BL)PV array Configuration

Honeycomb (HC) Array:

For this interconnection, the PV modules are connected in honeycomb-like architecture, as shown in figure II.12. Such configurations can reduce power output losses in some, but not all, shading conditions. Therefore, this connection scheme possesses insufficient robustness[18].

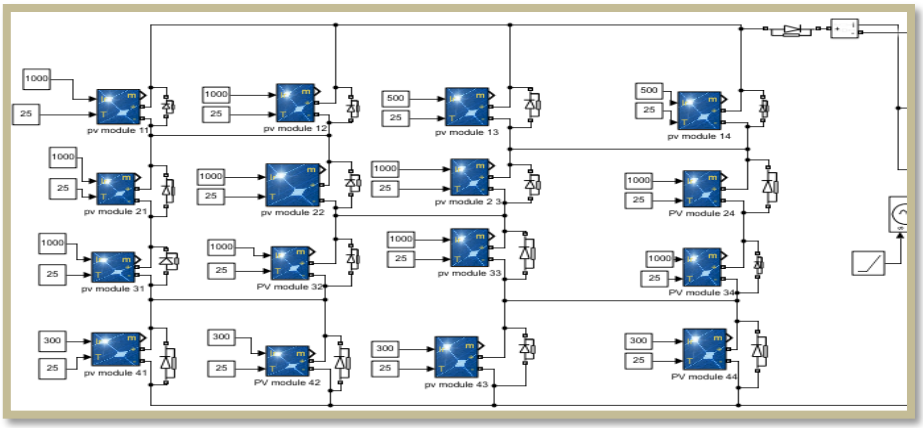


Figure.II.12 .Simulink model of Honeycomb (HC) PV array Configuration.

II.4.2. Better conventional Interconnection Schemes:

In a PV array, the interconnection scheme refers to the manner in which modules are interconnected in the array. A study on the available module interconnections and their impact on power production are reported in the literature. Comparison of different interconnection schemes based on shading conditions and shading levels reveals the influence of the interconnection schemes on generated PV power. The TCT scheme is considered to be the better scheme for reducing the losses under most of the shading conditions, although none of the schemes are found to be effective under wide shading conditions[12].

II.5. The effect of shading on PV systems:

Shading is the phenomenon in which the surface of the PV module is partially or totally blocked from the sun. This is a very serious concern in PV arrays. Under uniform conditions on the PV array, the P-V curve of the PV module is uniform, i.e. it has only one peak (PPM) .However, under non uniform conditions where the solar irradiance is unequally distributed among the PV modules, each PV module can be exposed to different solar irradiance due to the shadows of buildings, trees, clouds, birds, dirt, etc. Figure II.13 shows different partial shading scenario for a PV system. Under the partial shading conditions, if there is one module in a PV array which is less illuminated, the shaded module will dissipate some of the power generated by the rest of the modules. If there is no bypass diode which is connected to the PV cells or PV module in parallel, the shaded PV cell or PV module can be exposed to higher currents because of the unshaded cells and it can cause hotspot condition for the shaded cells which can damage to the shaded PV cells. To prevent hotspot condition for the shaded cells, parallel connected bypass diode is preferred to connect to each PV cell or PV module. However, the resulting P – V curve have multiple local peaks and single global peak due to bypass diode. Fig. 26 illustrates the P – V characteristics of PV module under non-uniform condition. This reduces the maximum available power. Also, conventional MPPT techniques cannot find true global point and it hinders the efficient MPPT operation[13].

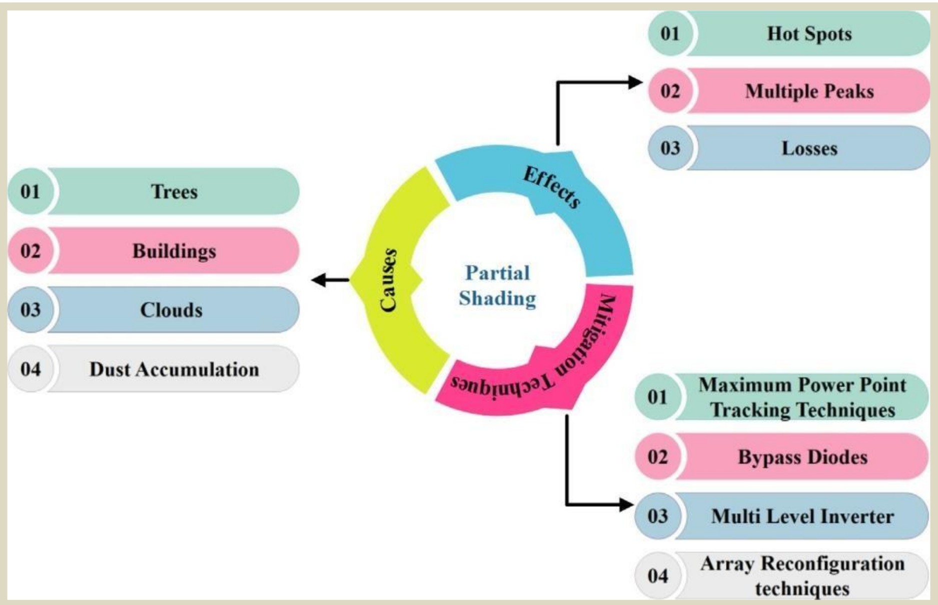


Figure .II.13 Partial shading causes, effects and mitigation techniques

The insolation on a PV module affects the module characteristic significantly. This state can be seen from the output current equation of module’s I ph-photo generated current value based on radiation [4].

$$I_{ph} = \frac{G}{G_n}(I_{scn} + K_i(T - T_n)) \quad (5)$$

As it can be seen in Eq. (5), Iph value of PV module is directly proportional to G (W/m²) which is irradiant intensity. Here, while Iscn shows short circuit current of the PV module, Gn and Tn are rated radiant intensity (1000 W/m²) and temperature values (25°)respectively. Ki is temperature coefficient of short circuit current. I–V and P–V curves for the PV module at different insolation levels at constant temperature are shown in Fig. 26. Simulated PV module parameters are Iscn = 3.74 A, Voc = 23 V, Pmax = 65 W. As it can be seen from the figure, Isc and power values of module are affected by insolation that comes to module[4].

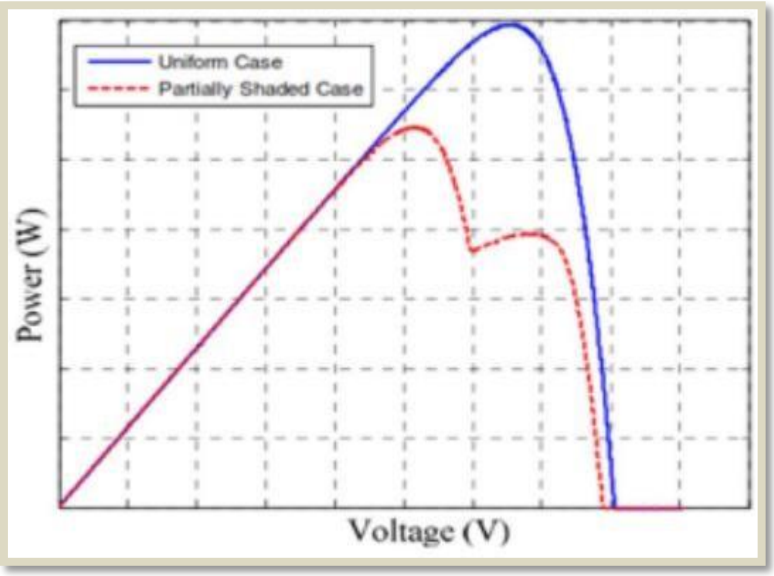


Figure. II.14 P-V curve of shaded PV array under PSC

The effect of partial shading on series connected PV modules is shown in figure II.15. Here, I–V and P–V curves of series connected two modules are shown for 1000 and 600 W/m² radiant intensity levels, respectively. In order to see the effect of bypass diodes, these curves have been drawn both when the diodes exist and when they do not exist. As it is seen, bypass diodes prevent current limiting at particular operating points and increase the available power

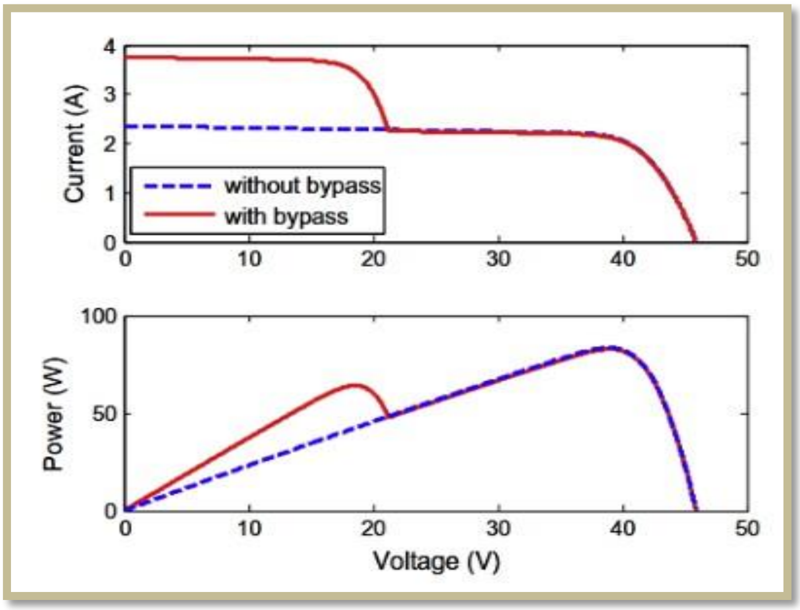


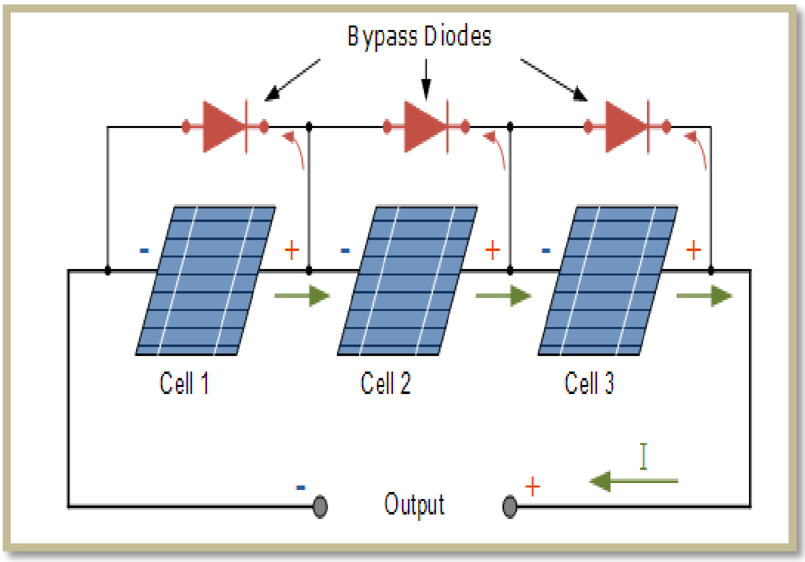
Figure .II.15 effect of bypass diodes to PV string

II.5.1. Hot-spots and diode by-pass:

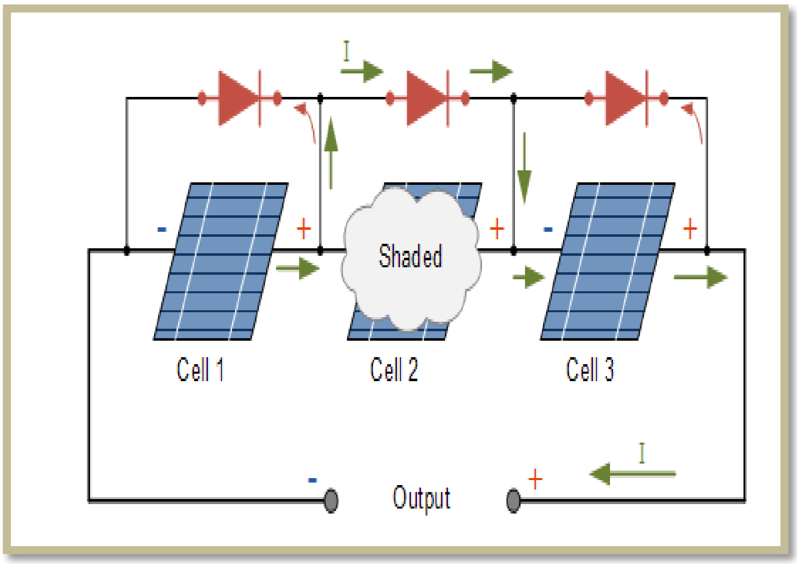
A photovoltaic system is intended to produce electrical energy for many years. Therefore, the module itself must be protected in order to increase its life span and to avoid destructive failures due to the combination of cells and their operation in the event of shading The degradation of a solar cell in series causes a sharp decrease in the solar current produced by the photovoltaic module and when the current delivered is greater than the current produced by the cell under low light conditions, the voltage of the cell becomes negative and it becomes a receiving element, which implies the dissipation of a significant amount of electrical power that could lead to its destruction. This phenomenon is known as a "hot spot".

- **Parallel diode protection (or bypass):**

Aims to protect a set of cells in the event of an imbalance linked to the failure of one or more cells in the set or to shading on certain cells. They are used to isolate a group of cells when the illumination is not homogeneous to avoid the appearance of hot spots and the destruction of poorly lit cells. This solution is effective, but it reduces the power delivered and the voltage at the panel terminals. The degradation of a single cell condemns the group of cells associated with it. Thus, this unit, shunted by the bypass diode, no longer produces power. In the figure II.17 we present a PV array without shad and without shad phenomene.



(a)



(b)

Figure.II.16 Architecture of PV array,(a) **:**PV cells with diode bypass and (b): Shaded PV cells with bypass diode protection

II.5.2. Performance parameters :

The performance evaluation of the PV array configuration is discussed in terms of the maximum power (Pgmp), fill factor (FF) and mismatch loss (**ML**).

- **Fill Factor:** It is defined as ratio between the available global maximum power from the PV array under PSC to the product of open-circuit voltage and short-circuit current of the PV array under partial shading condition .

$$FF = \frac{P_{GMP}}{I_{SC} \times V_{OC}} \quad (6)$$

- **Mismatch loss:** it is defined as the difference between the amount of available maximum power from individual PV modules to the global maximum power available from the PV array configurations under PSC[19].

$$ML = P_{ind.mpp} - P_{g\,.shade} \quad (7)$$

Here, $P_{ind.mpp}$ represents the amount of individual available maximum power from the PV modules, $P_{gmpp.shade}$ represent the global maximum power available from the PV array configurations under PSC.

II.6. CONCLUSION

In this chapter, we presented details of the PV cell model and then illustrated the different metrological effects on the PV cell. Therefore, the various architectures of PV array have been presented. Furthermore, we focus in the effect of partial shading on the energy output production, as well as how to mitigate the losses in the Photovoltaic systems by incorporating bypass diodes.

In the next chapter, we will propose a new method for optimization of PV array output power under partial shading condition (PSC).

CHAPITRE III

PROPOSED COMPETENCE SQUARE METHOD

III.1 Introduction

Making photovoltaic (PV) systems energy efficient is a serious task. Partial shadowing is one of the major factors that contribute to the lowering of PV power. The power lowering are determined by the interconnection reconfiguration and shading pattern used by the modules. To minimize the losses due by partial shade, many array reconfiguration methods evolved in the recent past made a remarkable stride in offering solutions for partial shading such as: - module array configuration in SP, TCT, BL, or HC, optimal configuration, intelligent dynamic configuration (in real time), etc.

Therefore, in this chapter we will propose an innovative technique optimization named Competence Square (CS) technique for physical rearrangement of PV panels in a TCT interconnection scheme.

III .2. Competence square method for PV reconfiguration:

A choice of 9 × 9 PV array is chosen to evaluate the performance of proposed Competence Square (CS) method. The proposed Competence Square technique adopts the following steps for rearrangement of panels in a PV array is represented in the figure III.1.

- **Proposed reconfiguration method :**

This puzzle opt a logic based number placement which locate alphabet/numbers to deal a given (m × n) matrix. Here positioning specifies the arrangements of alphabets and numbers in a sequential manner for a given matrix. For illustration, a 9 × 9 square matrix labeled with alphabetical sequence (a, b, c...i) for each row of TCT interconnection scheme is represented in the figure.III.1(a). In addition, each panel position is indicated with the suffixes of respective row and column number. For instance1, a_{12} refers to the position of the panel at first row second column. The given 9 × 9 square matrix can be modified with the aid of competence square puzzle for placing the number or alphabet by adopting four important rules[20].

Rule 1:

At first, the panel positioned in a_{11} location is moved to the location a_{55} . This movement is a random choice and the user can arbitrary choose any location over the entire array depending on the shadow patterns. The successive alphabet positioning follows the structure of letter 'L' with respect to its initial position and updated. For instance, the successive alphabet, a_{12} is placed as per the rule of wide 'L' shape and its updated position is indicated in figure.III.1(b)[20].

Rule 2:

During the alphabet placement in wide 'L' shape, if any of the alphabet encounter oversteps, i.e. ($m > 9$), resume the series from next row with second column. For example, in figure.III.1(b), it is noted that, a_{15} corresponding to ninth row and fourth column has overstepped the row limit, hence following step 2 a 16 resume its position from first row and second column in the figure.III.1(b). Similarly the modules like a_{75}, a_{85},a_{95} , a_{25} , a_{35} , a_{45}, a_{55} and a_{66} follow the same rule for positioning itself for reconfiguration process. For better understanding on rule 2,' a_{15} and a_{16} are highlighted with green color star in figure.III.1(b), [20].

Rule 3:

Likewise, during the placement of module, if any of the column limit ($n > 9$) is overstepped, resume the series from second column with next row position. For example a_{13} at seventh row and ninth columns is out stepped in column manner, therefore a_{14} takes its position at eighth row second column as indicated in figure.III.1(b).The modules that opt the rule 3 for PV positioning are 'a_{46}','a_{27}','a_{98}','a_{79}','a_{51}', 'a_{32}','a_{84}' and'a_{65}'[20].

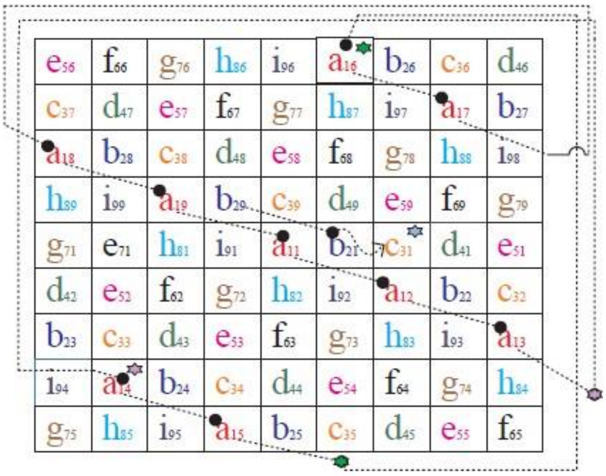
Rule 4:

Finally at the time of alphabet placement, if it occupies aposition previously placed then, place the alphabet to the nearest forward position in the same row. Following this rule, the module c_{31} which is supposed to be positioned at fifth row and sixth column has been shifted to the nearest fifth row and seventh column with arrow mark indicated in figure.III.1 (b). Rule 4 is applicable to most of the modules in the row5 highlighted with pale blue1star.

Following the above rules, each module is shuffled via competence square method to achieve physical rearrangement. A well dispersed PV array with the application of competence square method can be seen in figure.III.1(C). For clarity, the reconfiguration process with the first row alone is represented in the figure.III.1(b). Inspired by the methods performance, the analysis has been extended for 9×9 PV array. For easy understanding, a flowchart explaining the steps of CS puzzle is presented in figure III.2[20].

a_{11}	a_{12}	a_{13}	a_{14}	a_{15}	a_{16}	a_{17}	a_{18}	a_{19}
b_{21}	b_{22}	b_{23}	b_{24}	b_{25}	b_{26}	b_{27}	b_{28}	b_{29}
c_{31}	c_{32}	c_{33}	c_{34}	c_{35}	c_{36}	c_{37}	c_{38}	c_{39}
d_{41}	d_{42}	d_{43}	d_{44}	d_{45}	d_{46}	d_{47}	d_{48}	d_{49}
e_{51}	e_{52}	e_{53}	e_{54}	e_{55}	e_{56}	e_{57}	e_{58}	e_{59}
f_{61}	f_{62}	f_{63}	f_{64}	f_{65}	f_{66}	f_{67}	f_{68}	f_{69}
g_{71}	g_{72}	g_{73}	g_{74}	g_{75}	g_{76}	g_{77}	g_{78}	g_{79}
h_{81}	h_{82}	h_{83}	h_{84}	h_{85}	h_{86}	h_{87}	h_{88}	h_{89}
i_{91}	i_{92}	i_{93}	i_{94}	i_{95}	i_{96}	i_{97}	i_{98}	i_{99}

(a) 9 *9 TCT arrangement of PV array matrix



(b) Implementation steps for competence square method

56	66	76	86	76	16	26	36	46
37	47	57	67	77	87	97	17	27
18	28	38	48	58	68	78	88	98
89	99	19	29	39	49	59	69	79
61	71	81	91	11	21	31	41	51
42	52	62	72	82	92	12	22	32
23	33	43	53	63	73	83	93	13
94	14	24	34	44	54	64	74	84
75	85	95	15	25	35	45	55	65

(c) Final disposition of panels in a 9*9 PV array applying CS method

Figure. III.1. Implementation of CS method step for shade dispersion in a 9 × 9 PV array.

The proposed competence square method is exclusive and fruitful for uniform shade dispersion in a PV array is analyzed in the following section. Inspired by the puzzle, the authors correlated competence square method for reconfiguring the solar PV panel from TCT configuration is shown in Fig. 4(a)–(c) respectively [20] .

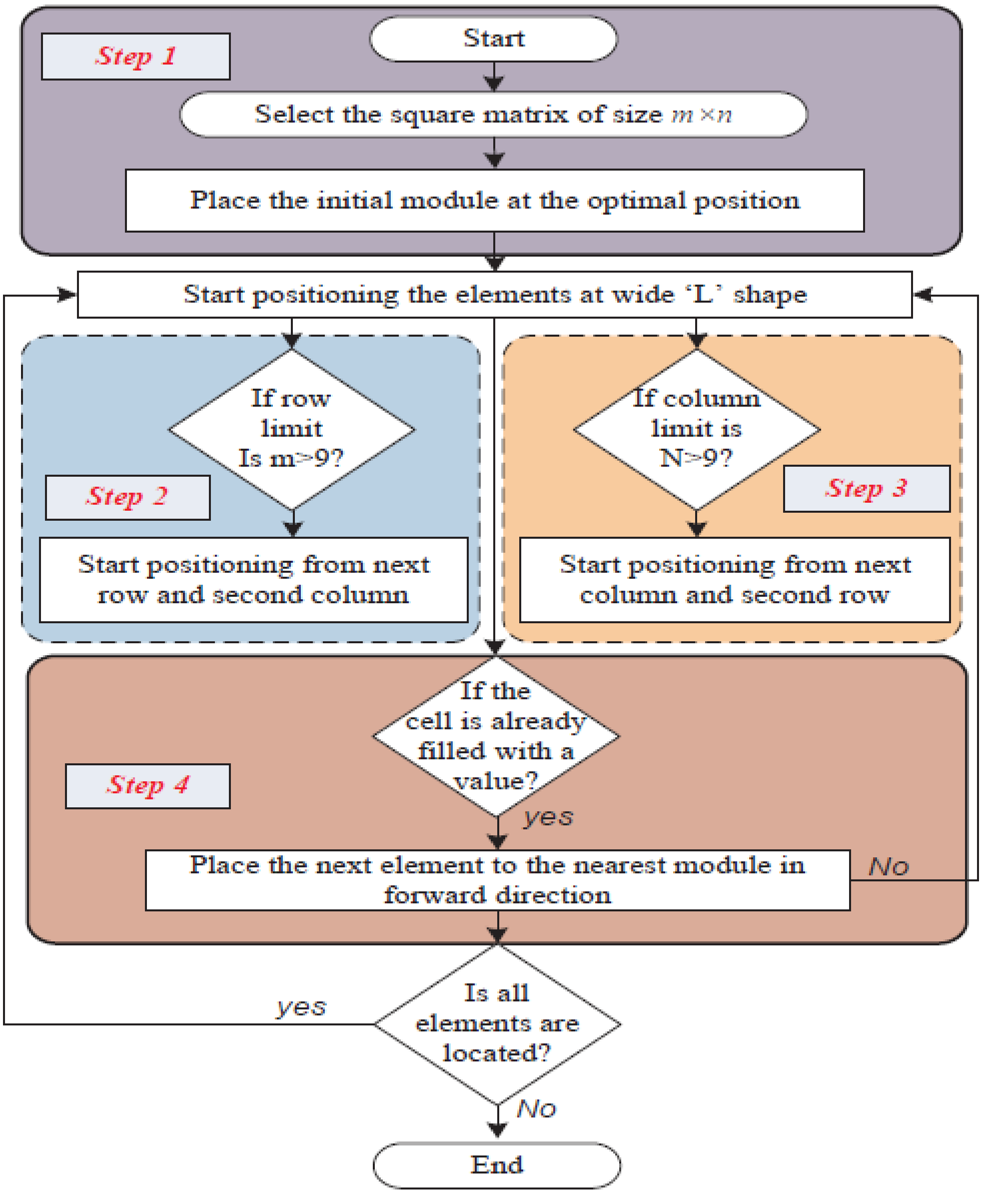


Figure.III.2. Competence square method flow chart.

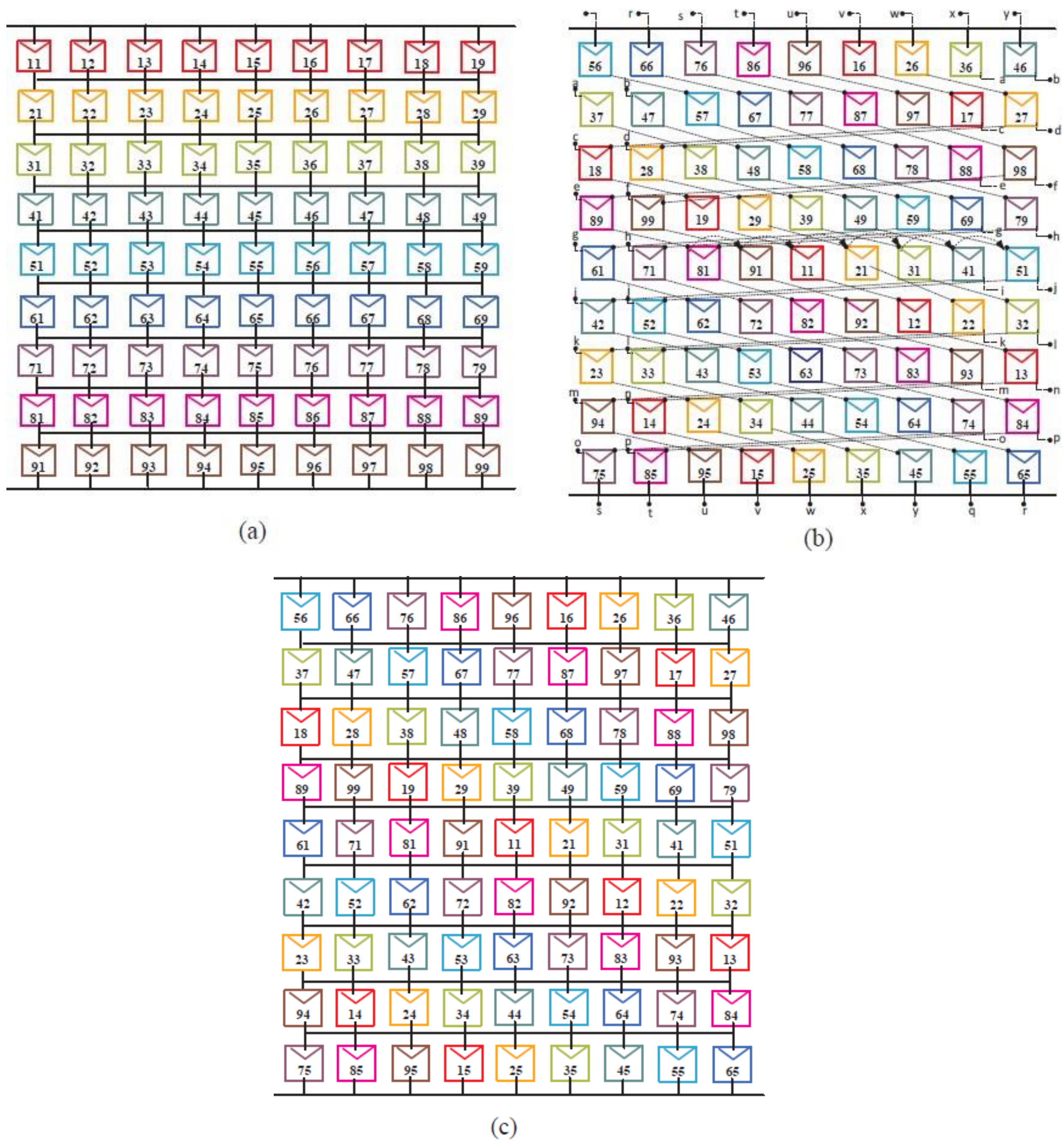


Figure.III.3. (a): Arrangement of (9×9) PV panel, (b): Reconfiguration Process, (c). Competence square set up

III.3 Simulation model presentation:

- **Materials used:**
  - 81 panels (SunPower 250 Wc).
  - 81 bypass diodes.
  - 81 current & voltage sensors.
  - I-V and P-V characteristics tracers.

- **PV panel parameters:**

In order to make this simulation, we used 81 panels type Sun Power 250Wc polycrystalline, the table III.1 and the figure III.4 shows the specification and the Simulink model parameters of the PV panel used

Table III.1 : Specification of PV panel used

Characteristics	**Specifications**
Maximum power (P_{max})	249.952
Voltage at maximum power .(Vmax)	42.8
Current at maximum power (Imax)	5.84 A
Open circuit voltage (Voc)	50.93
Short circuit current (Isc)	6.2 A
Irradiance	[100 1000]
Temperature	25 C°

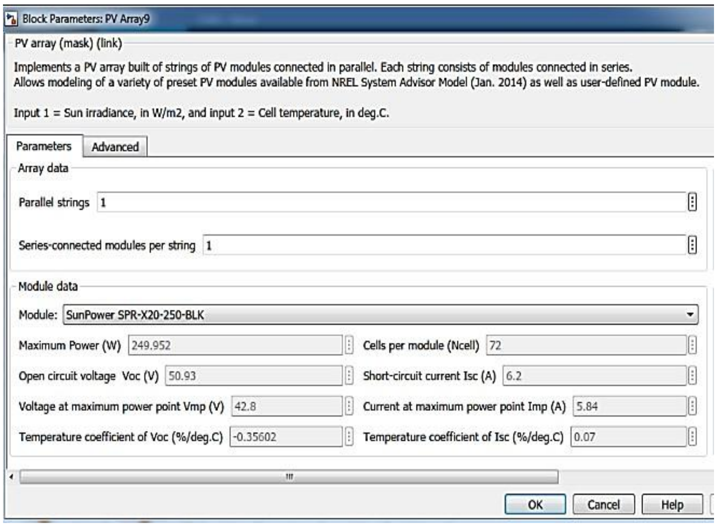
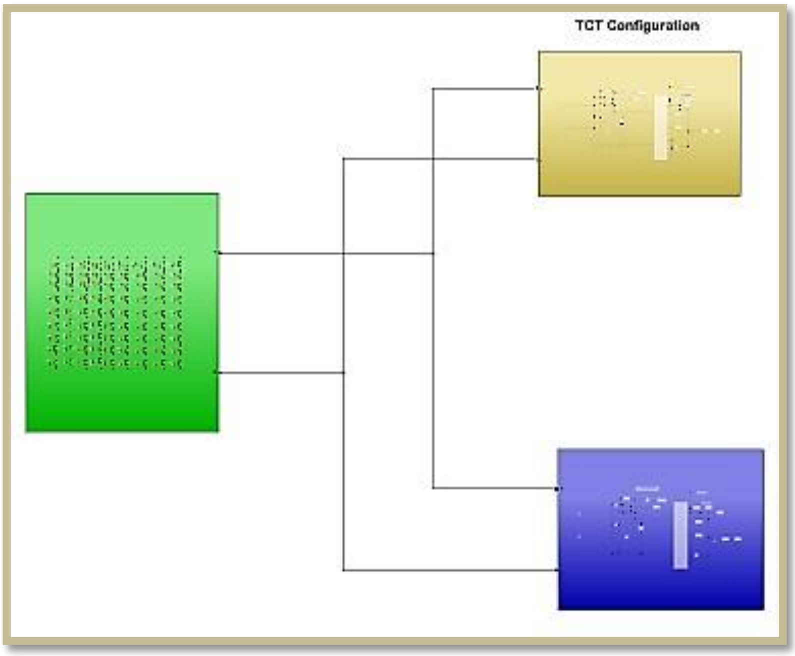
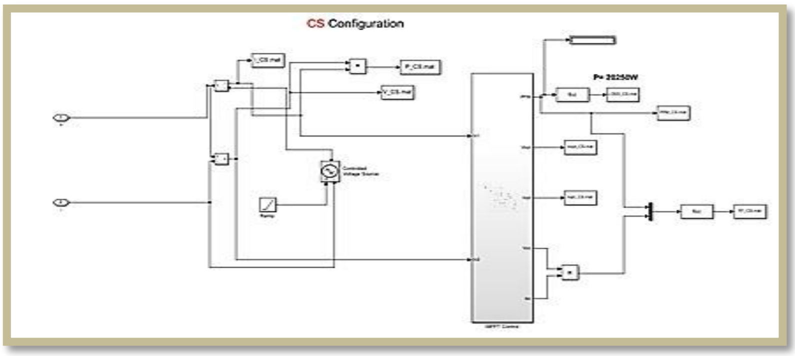


Figure.III.4 Sun power SPR -20-250-BLK 1 Simulink model parameters

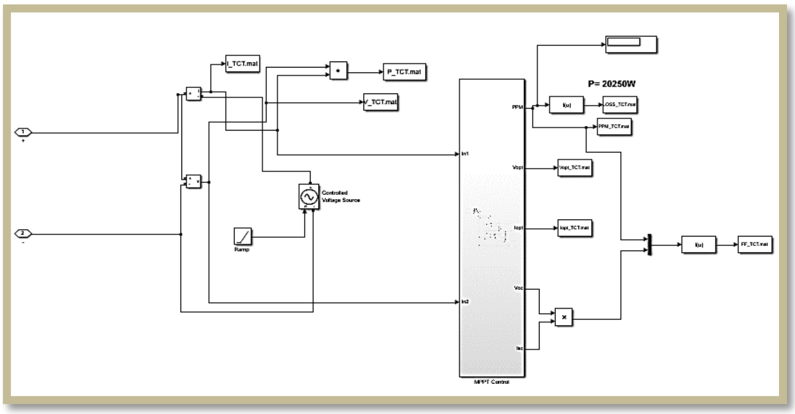
➢ Block diagrams of simulation



(a)



(b)



(c)

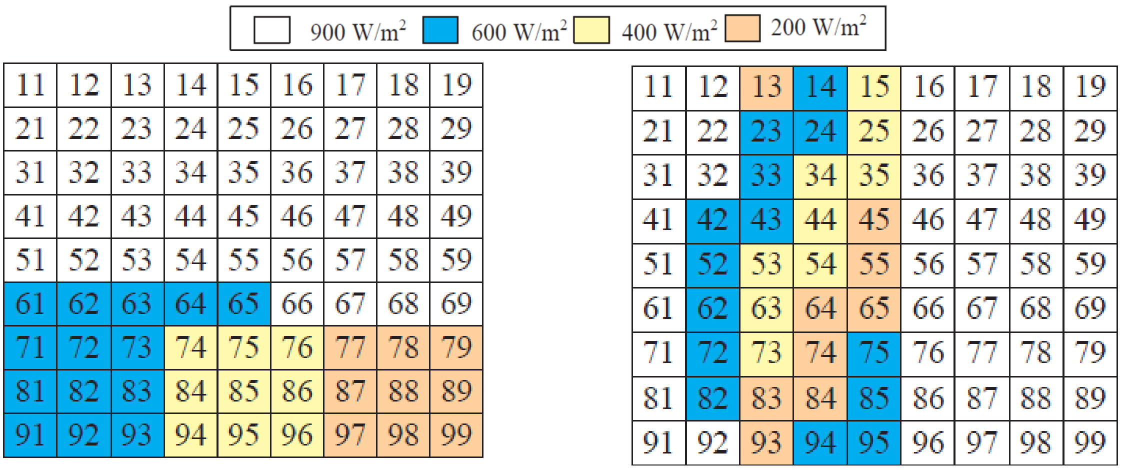
Figure III.5 Blocks diagram of the simulation, (a): overall layout of simulink,(b):CS configuration simulink block and (c) TCT configuration simulink block

III.4. Simulation results and discussion:

To examine the performance of competence square technique, four different shade patterns are analyzed in this section. Further the results are compared with different interconnections schemes such as TCT and CS methods in terms of array row current. For simulation, the one diod model explained in Section 2 is built in MATLAB/SIMULINK platform is used. The performance of each inter connections are examined with respect to characteristics curve. In addition, performance parameters such as fill factor, mismatch loss, power loss and the power enhancement array also analyzed to justify the current proposition. As partial shading causes multiple peaks in PV characteristics curve, the overall assessment of reconfiguration methods is arrived by computing the number of local and global peak occurrences. Further, percentage power enhancement with the application of CS method is also calculated and the results are compared with TCT and CS schemes.

Pattern 1: short & wide (SW) case :

For the first shade pattern case, the figure III.5 shows a short wide shade applied in array of (9×9) panels connected initially in configuration TCT. Figure III.5 (a) indicated a first five rows receive uniform irradiation of 900 W/m² and the remaining rows receive irradiation profile of 200 W/m², 400 W/m2 and 600 W/m² respectively. The figure III.5 (b) shown the final rearrangement of PV panels following the CS method steps.



(a) (b)

Figure.III.6. Simulation of pattern1(a): TCT connected (9×9) PV array with SW shade pattern and (b): CS based shade dispersion.

The figure III.6 indicates the I-V and P-V characteristics curves for the initial configuration (TCT) and the compared method CS under short and wide shade. Therefore, the global MPP resulted by TCT and CS method are 10680 W and 13910 W respectively. The proposed method CS has clearly a higher power production than TCT arrangement with appreciable power difference of 3230W. Moreover, the proposed CS technique produces a smoother P-V curve with the negligible number of LMPPs as compared to initial configuration TCT.

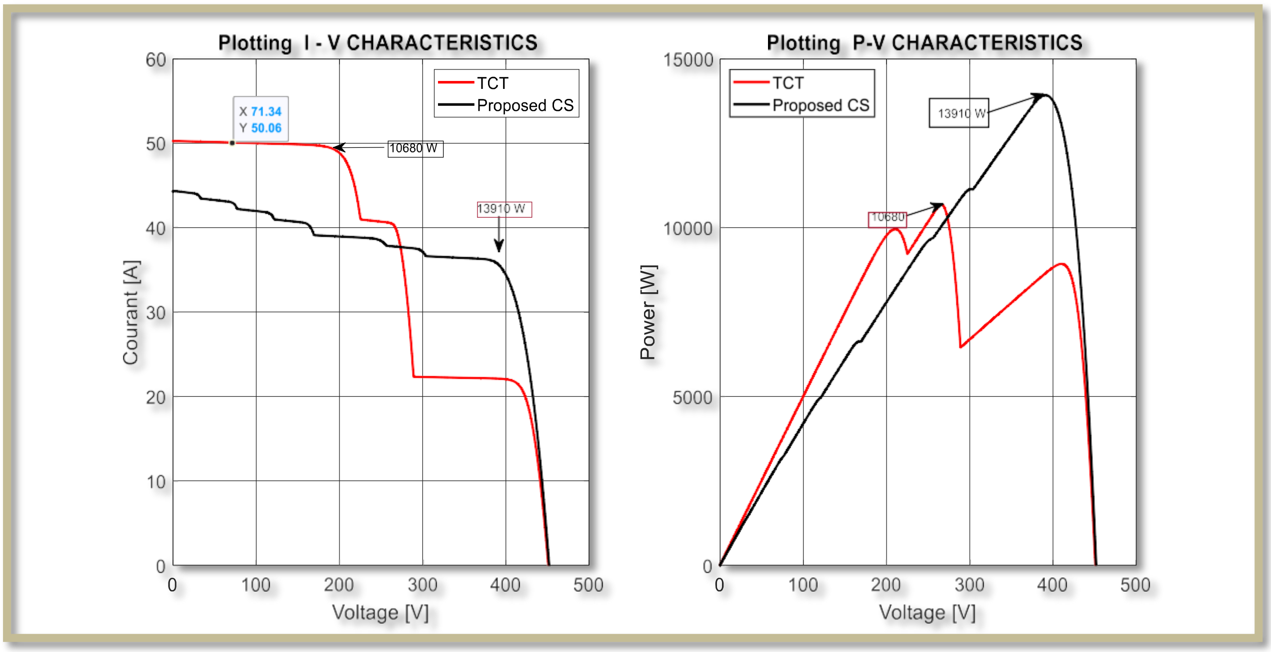
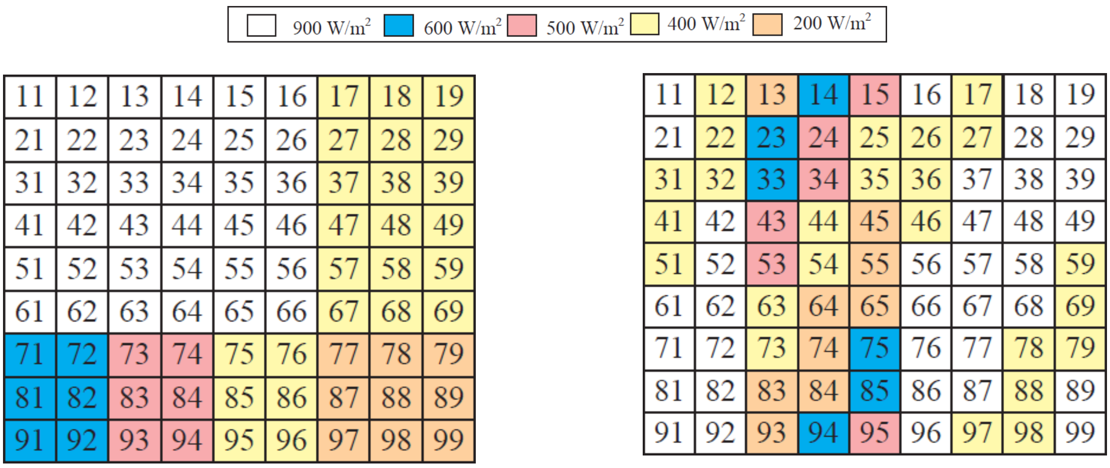


Figure.III.7. Characteristics curve for TCT, CS method under short wide pattern.

➢ **Pattern 2: long & wide (LW) case :**

In the case of long and wide shade pattern, the rows 6, 7, 8 and 9 are shaded with irradiation of 600 W/m², 500 W/m², 400 W/m² and 200 W/m². Furthermore, the shadows levels of 200W/m² and 400 W/m² are applied for the totally column of 7, 8 & 9. The figure III.7(a) and III.7(b) shows the PV array arrangement using the TCT and proposed CS method respectively.



(a) (b)

Figure.III.8. Simulation of pattern2, (a) TCT connected (9×9) PV array with LW shade (b) CS based shade dispersion.

Figure III.8 indicate the I-V and P-V characteristics curves of the case of LW shade for the initial configuration TCT and proposed method CS respectively. The maximal output power obtained using the above methods are 9741W and 12390W respectively. The proposed method CS has clearly a higher power production than TCT arrangement with appreciable power difference of 2649W. Moreover, the proposed CS technique produces a smoother P-V curve with the negligible number of LMPPs as compared to initial configuration TCT.

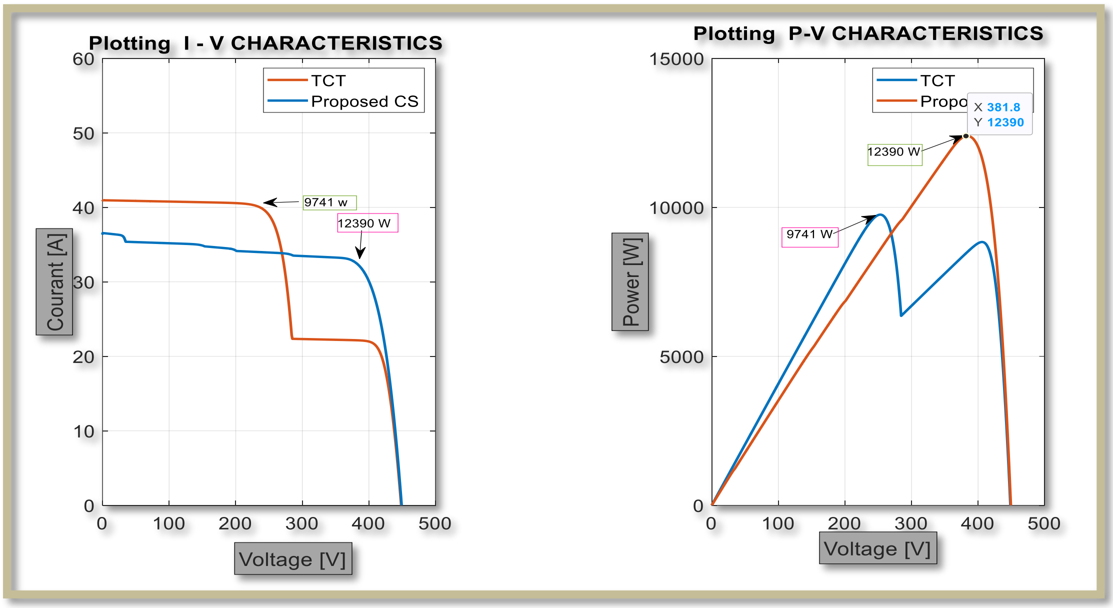
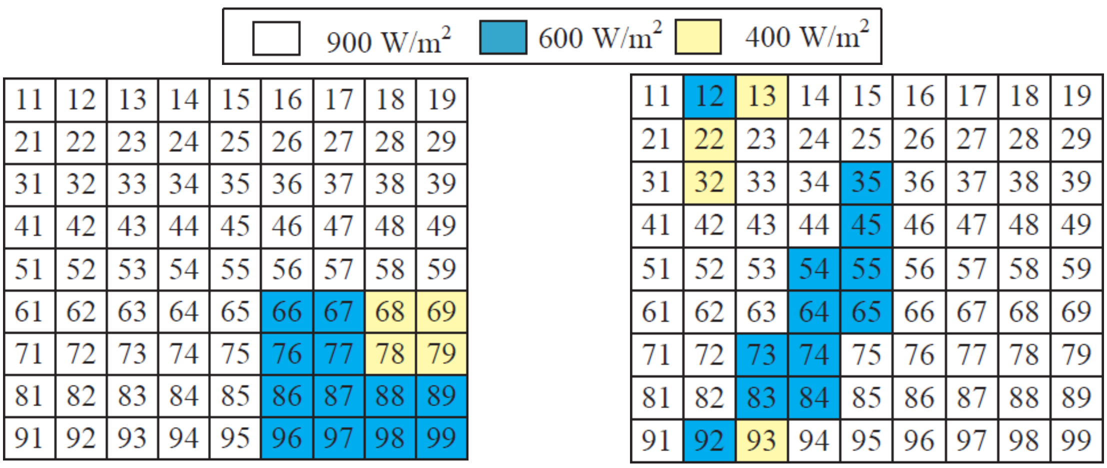


Figure.III.9. Characteristics curve for TCT, CS method under long and wide pattern.

➢ **Pattern 3: short & narrow (SN) case**

The figure III.9 duplicate a (9×9)PV array under short and narrow shade pattern, however, the modules make the PV array are experiences only two different irradiation levels such as 600 W/m² & 400 W/m².



(a) (b)

Figure III.10. Simulation of pattern3, (a) TCT connected (9×9) PV array with SN shade (b) CS based shade dispersion.

In order to shows the I-V and P-V characteristics curves, the figure III.10 represent the behavior of the compared methods under SN shade. Therefore, is clearly observed that the proposed CS method has a great MPP (16710W) compared to initial configuration TCT(15490W). In regard to the P-V curve of both methods, the proposed CS method has a very negligible LMPP.

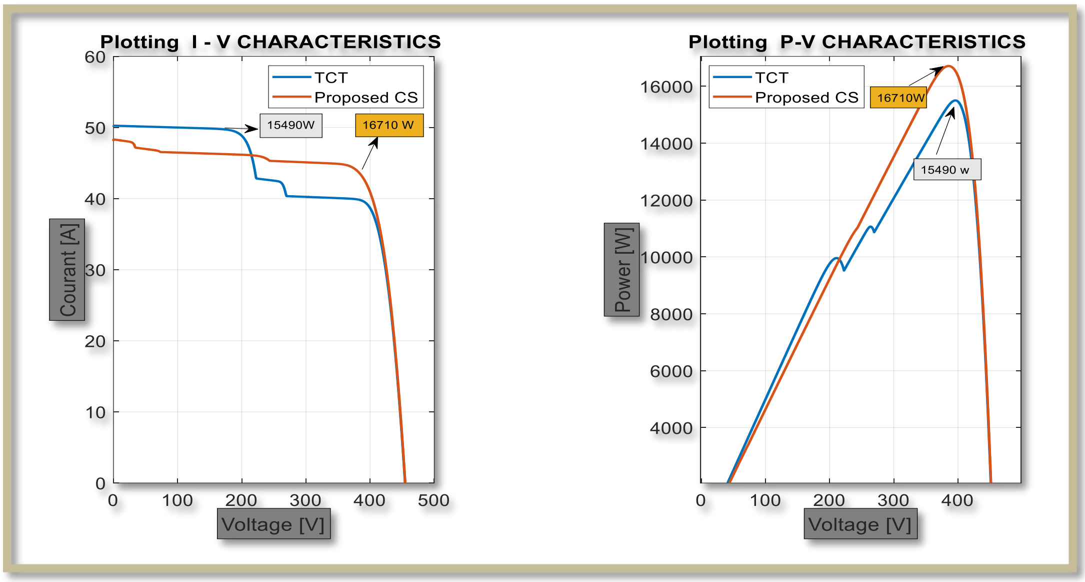


Figure.III.11. Characteristics curve for TCT, CS method under SN pattern.

- **Pattern 4: long & narrow (LN) case:**

In the figure III.11, we present another case of PSC applied on (9×9) PV array, this shade is named Long Narrow (LN) shade. Therefore, the three shading levels are 700 W/m², 400 W/m2 and 300 W/m².

900 W/m² 700 W/m² 400 W/m² 300 W/m²

11	12	13	14	15	16	17	18	19
21	22	23	24	25	26	27	28	29
31	32	33	34	35	36	37	38	39
41	42	43	44	45	46	47	48	49
51	52	53	54	55	56	57	58	59
61	62	63	64	65	66	67	68	69
71	72	73	74	75	76	77	78	79
81	82	83	84	85	86	87	88	89
91	92	93	94	95	96	97	98	99

(a)

11	12	13	14	15	16	17	18	19
21	22	23	24	25	26	27	28	29
31	32	33	34	35	36	37	38	39
41	42	43	44	45	46	47	48	49
51	52	53	54	55	56	57	58	59
61	62	63	64	65	66	67	68	69
71	72	73	74	75	76	77	78	79
81	82	83	84	85	86	87	88	89
91	92	93	94	95	96	97	98	99

(b)

Figure III.12. Simulation of pattern4, (a) TCT connected (9×9) PV array with LN shade (b) CS based shade dispersion.

The I-V and P-V characteristics curves are shown in the figure III.12, the last one illustrate the superiority of the proposed CS method compared to the initial configuration TCT with an enhancement of 1220W. Therefore, the obtained values of GPPM of the compared method are (15490W) TCT and (16710W) proposed CS. Moreover, the proposed method CS has a smoothly P-V cure.

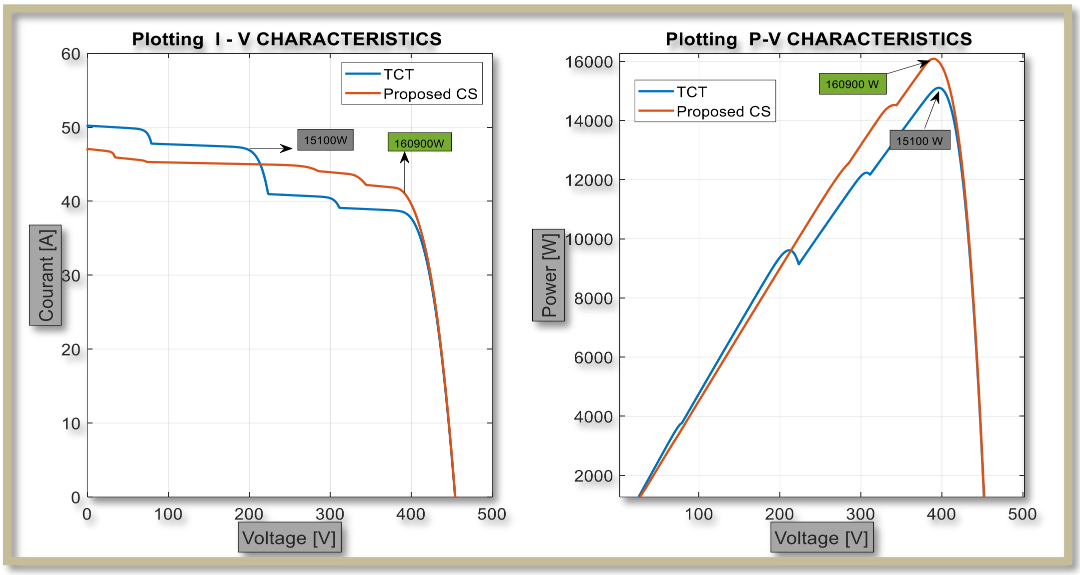


Figure.III.13. Characteristics curve for TCT, CS method under LN pattern.

III.5 Conclusion:

This chapter presented a Competence Square (CS) shaded dispersing technique for PV array. The efficacy of the proposed method for a (9× 9) PV array has been discussed through simulation under different PSC. Indeed, the Short and Wide (SW), Long and Wide (LW), Short Narrow (SN) and Long Narrow (LN) shade patterns are investigated. The obtained results shown that the CS method has a power enhancement up to 30.2% compared to initial configuration TCT. Furthermore, the proposed CS method has a very negligible local MPP (LMPP).

GENERAL CONCLUSION

The PV Power generation is the best source of renewable energy due to advantages such as free fuel cost, cleanness, little maintenance, and causing no noise due to absence of moving parts. However, the partial shading is one of the PV array power generation problems.

In our work, we proposed an innovative Competence Square (CS) technique for physical rearrangement of PV panels interconnected initially in a TCT configuration. We started with a general review of PV-systems, their components, and their different types with utility, as well as, the principles of operation and characteristics of PV cells, advantage and disvantage. Then, we have recalled all of the PV architectures, a brief explanation of MPPT control, different types of algorithms, and principal working. In addition, the effects of shadowing were discussed, as well as the phenomena of bypass diodes and its application in PV array.

The proposed method has been applied in a (9× 9) PV array under partial shading conditions (PSC) in order to increase the output power generation. Therefore, the performance analysis of the proposed method CS was verified by comparing the Global Maximum Power Point (GMPP), value and P-V characteristics curve.

Several test results show the ability of the CS technique to efficiently disperse the shadow over the whole PV array. Four different shading patterns are investigated and the results are exhaustively compared with the conventional TCT configuration and Counting Square (CS) techniques. Based on the obtained results, it was observed that the reconfiguration of the proposed competence sequence (CS) method enhances the maximum power output of the PV array, minimizes the mismatch losses and offer a smooth P-V characteristics by minimizing the occurrence of multiple power peaks. In addition, physical relocation methods are proven to be efficient and economical in achieving better shade dispersion since, it neither demands complex switching arrangements or high end controllers for reconfiguration.

As perspectives, the practical implementation of the proposed technique can be considered under various unfavorable operating conditions of the PV generator. In addition, a way can be found to minimize the number of current sensors in order to reduce the cost of the PV system.

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