

REPUBLIQUE ALGERIENNE DEMOCRATIQUE ET POPULAIRE
MINISTERE DE L'ENSEIGNEMENT SUPERIEUR ET DE LA RECHERCHE
SCIENTIFIQUE

UNIVERSITE MOHAMED BOUDIAF - M'SILA

FACULTE DE Technologie
DEPARTEMENT Electronique
N° :



FILIÈRE : Electronique
OPTION : Instrumentation

Mémoire présenté pour l'obtention
Du diplôme de Master Académique

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THÈME

**Development of a multi-output I-V tracer for the
characterization of photovoltaic modules**

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Année universitaire : 2021 /2022

Acknowledgement

First of all, we thank Almighty ALLAH, who has given us the courage strength and will to carry out this modest work

I thank DR Drif Mahmoud for the proposal of the theme and, I also like to express our strong thanks and gratitude to our Dr. A.

BENHAMADOUCHE for his encouragement, his attention, his patience and above all his very wise guidance which helped us to continue this study until the last minute.

We also express our thanks to the teachers of the Electronics department.

We would like to thank our parents because this work represents a small fruit of their suffering and which without them we cannot get through these long years of study and work.

Dedications

I dedicate this work
to my very dear parents for their encouragement and support throughout my
school life, may gods protect them.

to my brother and my sister

all my friends.

To my wonderful teacher

Dedications

I dedicate this modest work
to my dear parents who have supported me throughout my life studies.

To my brother and dear sisters.

For all the family and all my friends

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General Introduction

Energy production is a challenge of great importance in the coming years. Indeed, energy demand in the industrial world is constantly increasing. In addition, developing countries will need more and more energy to carry out their development. Today, a large part of the world's energy production is provided by fossil sources. Consumption of these sources leads to greenhouse gas emissions and thus increases pollution. The additional danger is that overconsumption of natural resources dangerously reduces its reserves for future generations.

Renewable energies are the perfect solution to reducing greenhouse gas emissions, they are around the world. Another objective of using renewable energies is to reduce the energy dependency against rival country. The most promoted renewable energy source over the last decade is photovoltaic energy.

Photovoltaic energy comes from the direct conversion of a portion of solar radiation into electrical energy. This energy conversion takes place through a cell known as a photovoltaic PV cell based on a physical phenomenon known as the photoelectric effect which produces an electric force when the surface the surface of this cell is exposed to light. The power generated is exploited through a set of cells are associated in PV panels, and a set of panels PV are connected in a PV array which give a valuable power to be utilized.

The performance of the system depends on the operating condition, the location of the system, and the configuration of the system and many other factors. Moreover, the presence of faults and failures may cause significant power losses. Therefore, to ensure the reliability, availability and safety of the PV installations, their health status should be monitored regularly to prevent from failures and contribute to an efficient condition-based maintenance policy.

One of the most important tools for the diagnostic of photovoltaic generator is to extract IV characteristic, this technique allows system operator to analyze PV system operation and performance. Furthermore, it permits to locate eventual defaults in the PV field.

In this work, we try to develop a multi-output I-V tracer for the characterization of photovoltaic modules in an outdoor field condition. This is done by the use of a PV tracer through a configuration matrix which is fixed to the PV panels.

For this purpose, our work is organized in three chapter.

In the first chapter, we present an overview of a photovoltaic system and the type of the system, the influence of temperature and illumination in the characterization of the cell and the design of a photovoltaic generator.

In the second chapter, we give a description of characterization and the diagnostic methods used for the detection of usual faults and defect. Then we present the impact of those defects on the PV module, and finally methods commonly used for the PV characterization.

In the last chapter, we present a simulation of a PV modules field characterization, where a characterizer is attached to each panel in ideal conditions. Then, we create scenarios to show the robustness of our proposed characterization method.

Finally, a conclusion is presented that highlight our contribution.

Chapter 1

General description of photovoltaic systems

1 Introduction

The sun is an almost inexhaustible source of energy which sends to the surface of the earth a radiation which each year represents approximately 8400 times the consumption energy this corresponds to an instantaneous power received of 1 kilowatt peak per square meter (kWp/m²) distributed over the entire spectrum, from ultraviolet to infrared, to harvest this energy we use the photovoltaic to achieve a conversion of the sunlight in to usable electricity

In this chapter we talk about generalities of photovoltaic systems, which include, amongst others, the basic element of a photovoltaic generator, materials used for solar cell production, and the electrical characteristics PV generators.

2 General information on photovoltaic systems

A photovoltaic, often known as a PV system or solar power system, is an electric power system that uses photovoltaics to generate usable solar electricity. This power is obtained by the use of a solar cell, which is a device that transforms P-V via the electrical characteristics of semiconductor materials.

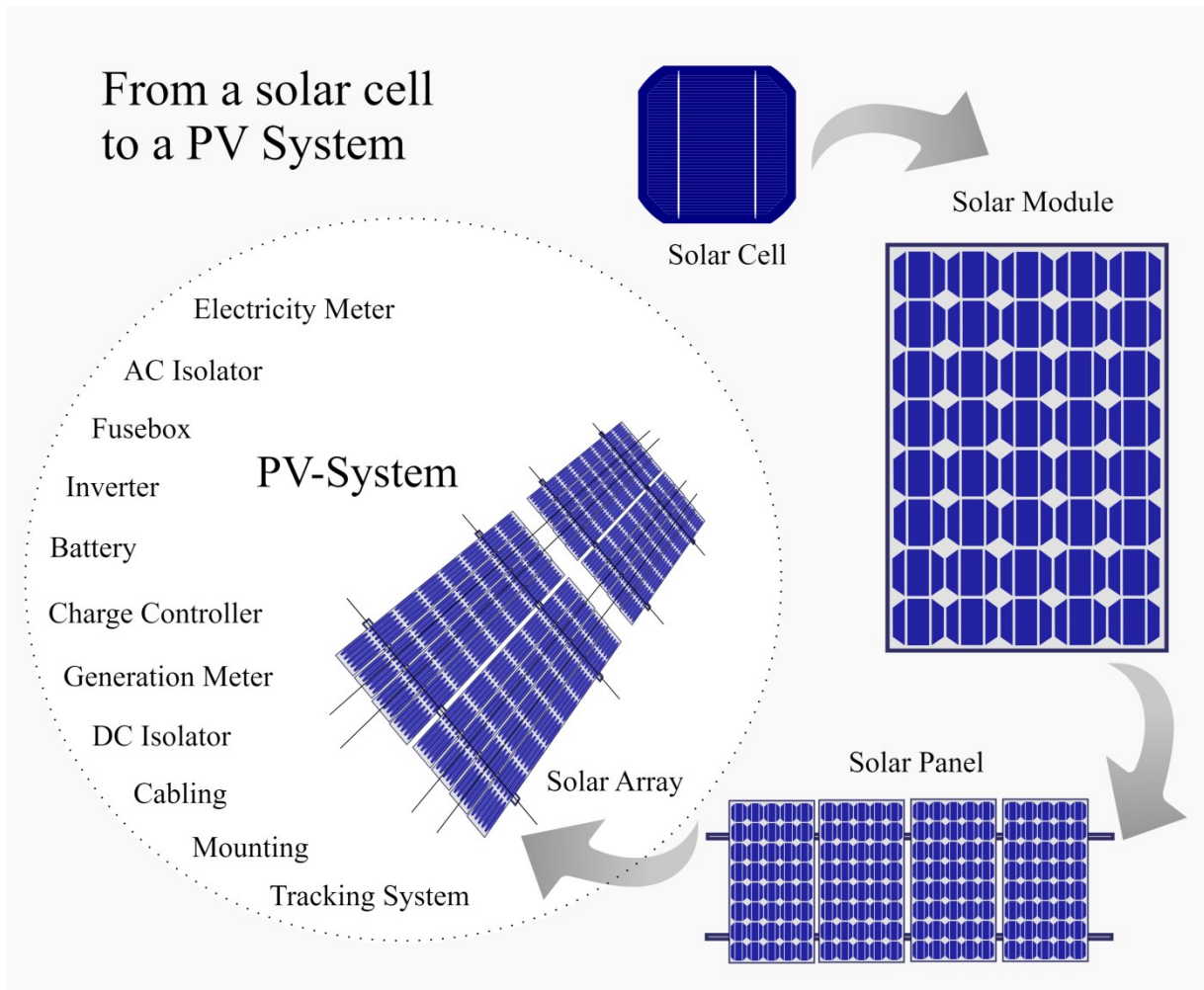


Figure 1. Typical elements of PV system

2.1 Photovoltaic systems

It consists of an arrangement of several components [1]

- **DC-DC converters** are used to convert the module output, which will have a variable voltage depending on the time of the day and the weather conditions, to a fixed voltage output that e. g. can be used to charge a battery or that is used as input for an inverter in a grid-connected system.
- **Inverters or DC-AC converters** are used in grid connected systems to convert the DC electricity originating from the PV modules into AC electricity that can be fed into the electricity grid.
- **Charger controller:** the charge controller can prevent battery over-charge and over-discharge automatically, Due to the cycle times of charge, discharge and the depth of

discharging is the main factor to determine the usage of battery life. Therefore, a charge controller is an essential equipment and it can also prevent over or under charging by monitoring the battery voltage.

- **Energy storage** is an important component of stand-alone systems since it ensures that the system can supply energy at night and during severe weather. Batteries are commonly utilized as energy storage equipment
- **Mounting structure:** it can be fix or mobile with a tracking device to help facing the sunlight all day.

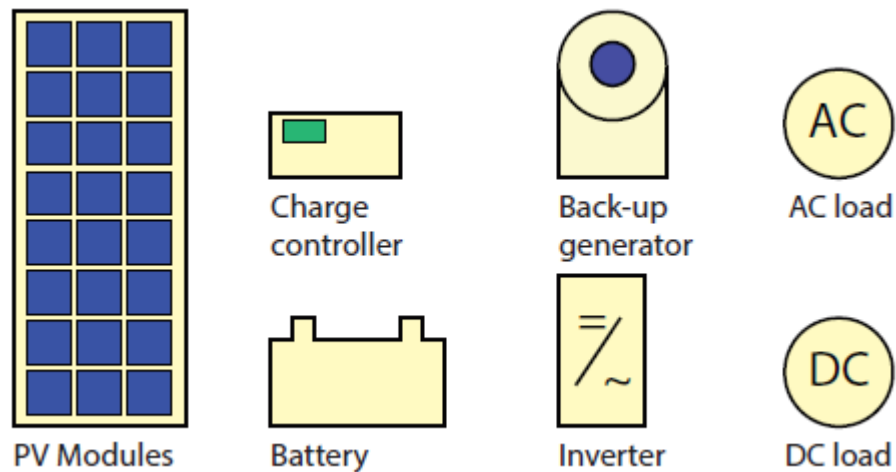


Figure 2. Different components of a PV system.

3 Type of photovoltaics systems

A photovoltaic system has several parts modules and a set of components that adapt the electricity produced. a set of specifications of the receivers (load, injection into the network).

These are three most common types of photovoltaic system

3.1 Hybrid system

A hybrid system is a combination of PV modules with another conventional energy source (diesel generator or wind turbine) use as backup generator, the hybrid system is often used in isolated regions. the different sources in a hybrid system can be connected in two configurations, DC bus architecture and AC bus architecture

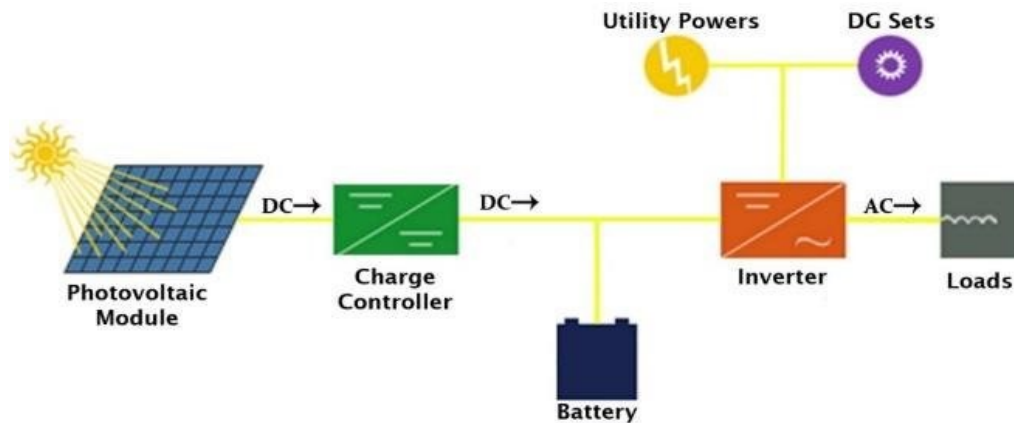


Figure 3. Hybrid photovoltaic system

3.2 Stand-alone system (off Grid)

The stand-alone system is used for ensuring an autonomous operation without an external energy source. It typically uses to store energy in a battery

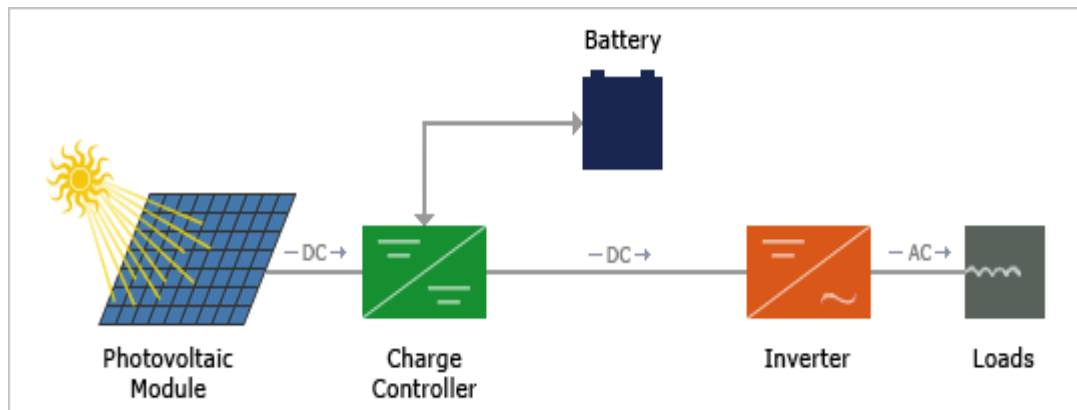


Figure 4. Standalone photovoltaic system

3.3 Grid connected system

The energy is produced closer to the places of consumption, Systems connected to a network reduce the need to increase the capacity of transmission lines and distribution. It produces its own electricity and channels its excess energy to the network, from which it obtains supplies as needed

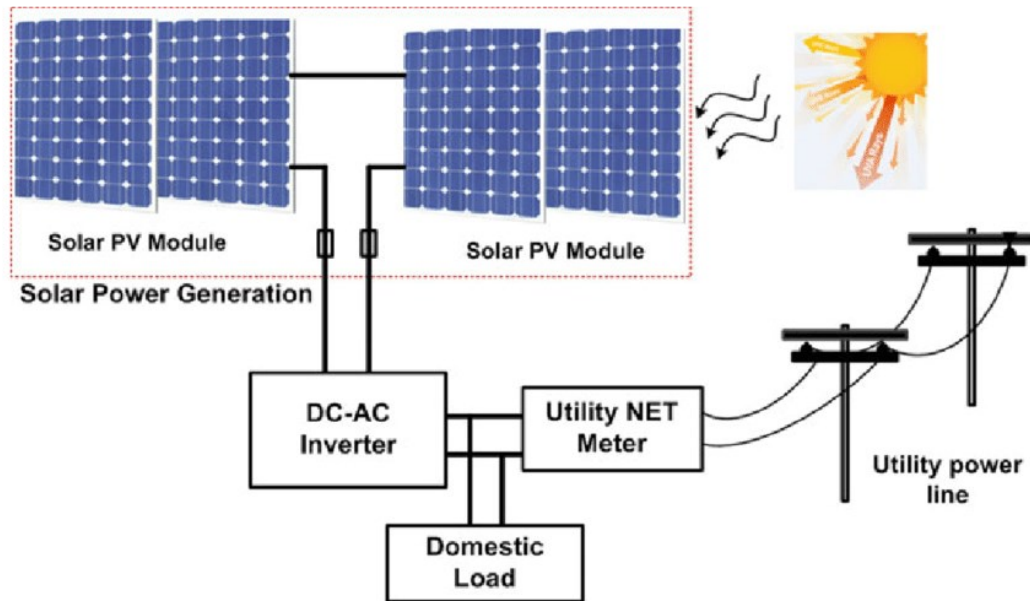


Figure 5. Grid connected photovoltaic system

4 Solar cells

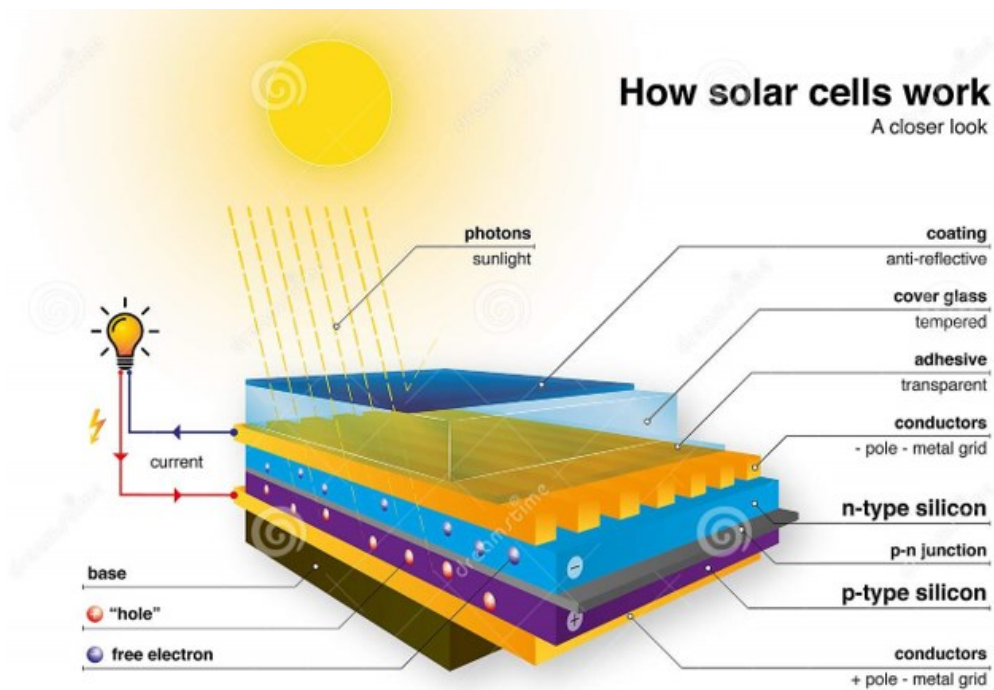


Figure 6. Solar cell structure

A PV cell is an electrical device, which uses photovoltaic effect to convert light energy directly into electricity, use the Norton equivalent circuit to represent its PV cells. The current and voltage relationship is given as:

$$I_{\text{cell}} = I_g - I_0 \left[e^{\left(\frac{v + I_{\text{cell}} R_{\text{sr}}}{nKT_c} \right)} - 1 \right] - \left(\frac{v + I_{\text{cell}} R_{\text{sr}}}{R_{\text{sh}}} \right) \quad (1)$$

Where :

- I_g : the photo current generated.
- I_0 : the saturation current.
- K : the Boltzmann constant.
- q : the electron charge.
- V : the output voltage.
- T_c : the cell temperature.
- R_{sh} , the shunt resistance and R_{sr} , the series resistance.

The material uses in solar panel have a big role in transforming light into electricity it's base of semiconductor materials that are capable of conducting or transporting electricity.

Most commercial photovoltaic cells are manufactured from silicon, the same material from which sand is made. In this case however the silicon is extremely pure.[2]

Solar cell is made of two types of semiconductors which are called P-type and N-type silicon. Because of adding atoms, the P-type silicon loses one electron. The N-type silicon is made by adding atoms so that it gets one more electron.

There are too many electrons in N-type layer, and in P-type layer, too many electron-holes. Near the junction of those two layers, the electron moves into the electron-hole from N-type layer, this creates a depletion zone so that the electrons fill the holes.

Because silicon is plentiful in nature, it is currently the most common semiconductor used to manufacture solar cells.

There are various varieties of photovoltaic cells, the most common of which are as follows [3]:

Table1 performance of different type of cell

Cell technology	Performance in laboratory	Performance in production
Silicon Amorphous (a-si)	13%	5-9%
Silicon polycrystalline (p-si)	19.8%	11 to 15%
Silicon monocrystalline(m-si)	24.7%	16 to 17%

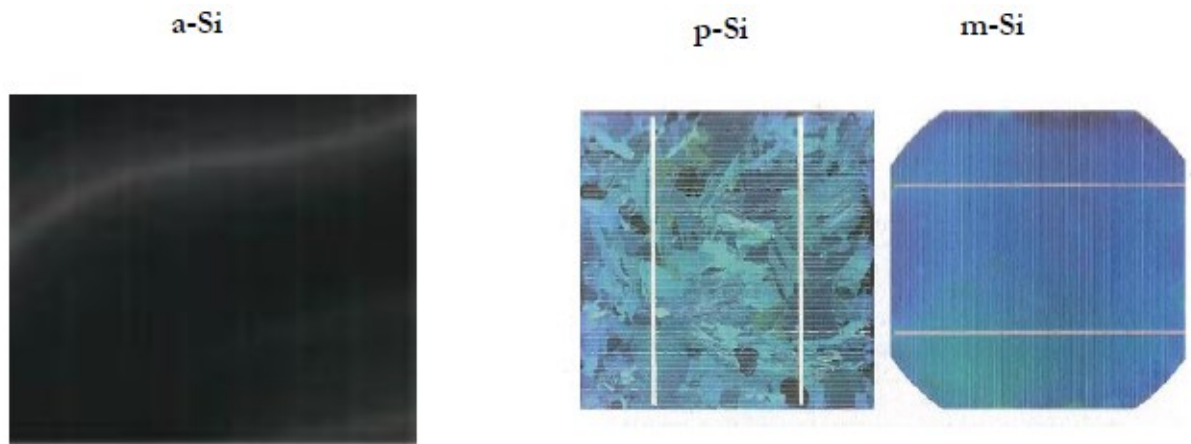


Figure7. Images of different types of photovoltaic cell

Because silicon is plentiful in nature, it is currently the most common semiconductor used to manufacture solar cells.

There are various varieties of photovoltaic cells, the most common of which are as follows:

4.1 Amorphous solar cell

Amorphous silicon units are made by depositing very thin layers of vaporized silicon in a vacuum onto a support of glass, plastic, or metal. can be found in small electronic device such as calculators or electric watch.

Advantage

- Doesn't need much light to operate,
- Cheap to manufacture

Disadvantage

- Low performance

4.2 Monocrystalline silicon (Single silicon)

Monocrystalline silicon solar panel efficiency is depended by its content, the more silicon the higher the efficiency, to make them, the silicon is purified, melted, and crystallized into ingots. The ingots are sliced into thin wafers to make individual cells, these cells produce more energy provided it is exposed to sunlight.

Advantage

- High performance

Disadvantage

- Very expensive

4.3 polycrystalline (multi silicon)

The Cells are made of polycrystalline silicon, the difference is that a lower cost silicon is used. the performance is not good as the monocrystalline however it is the most used type in photovoltaics

Advantage

- Not expensive as monocrystalline

Disadvantage

- Moderate performance

4.4 Organic (OSC)

Unlike silicon it's relatively new in solar panel material usage it uses organic polymers to absorb light and charge transport, to produce electricity from sunlight by the photovoltaic effect, it is cheap and lightweight.

5 Characteristics of a solar cell

Figure 7 shows the relation between I and V, also known as the IV curve; the red graph, also known as the Power curve, and it is the product of V and I, with the peak indicating P_{mpp} or maximum power.

Working solar cells have the following parameters, which is designate as open-circuit voltage (V_{oc}) and short-circuit current (I_{sc}), the theoretically attainable V_{oc} in modern and produced

cells is 0.6-0.65 V, but laboratory cells nowadays can reach a maximum value of 0.75-0.8 V. The short-circuit current is determined by the short-circuit current density J_{SC} and cell area. The best laboratory J_{SC} value is greater than 40 mA/cm².

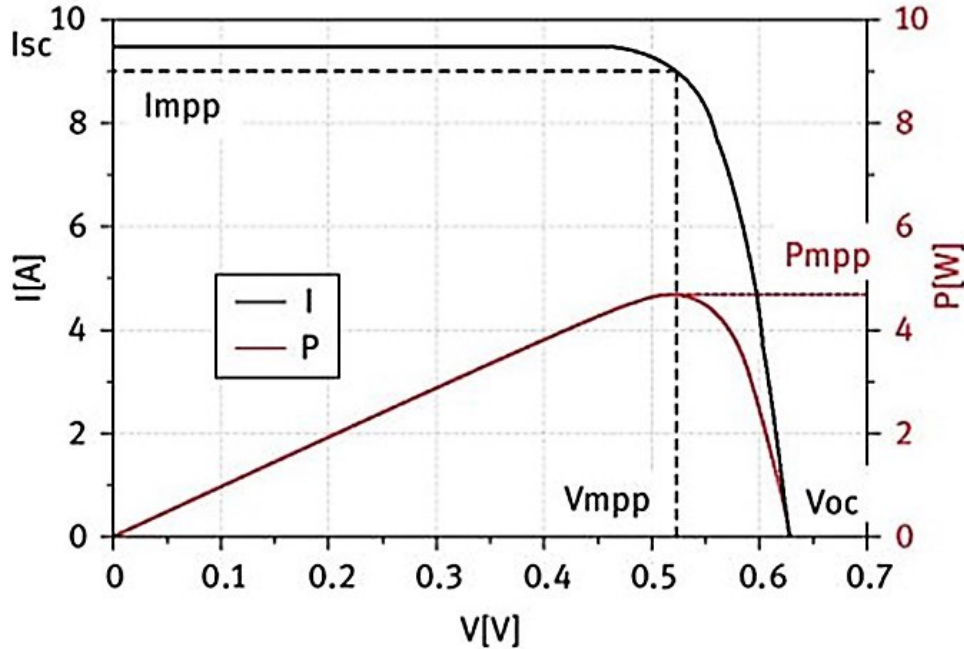


Figure 8. I-V/P-V cell characterization

Table 2 Parameters and factors calculated for PV cell

Isc [A]	Voc [V]	Impp [A]	Vmpp [V]	FF	Pmpp [W]	η [%]
9.50	0.627	9.00	0.522	0.79	4.70	19.30%

The fill factor (FF), as described by the following equation, is useful for analyzing the efficiency of solar cells. Common industrial solar cells have FF values in the 78–80 percent range, whereas high efficiency lab cells have FF values in the 81–83 percent range:

$$FF = \frac{V_{mpp} \cdot I_{mpp}}{V_{oc} \cdot I_{sc}} = \frac{P_{mpp}}{V_{oc} \cdot I_{sc}} \quad (2)$$

Where:

- V_{mpp} : maximum power point voltage (V),
- I_{mpp} : maximum power point current (A),

- V_{oc} : open-circuit voltage (V),
- I_{sc} : short-circuit current (A),
- P_{mpp} : maximum power (Watts).

A solar cell's efficiency η is defined as the ratio of supplied electric power (W) at the MPP to radiant flux on the complete cell area under a given irradiance, as shown in the following equation

$$\eta = \frac{P_{mpp}}{\Phi_e} = \frac{P_{mpp}}{E \cdot A_{cell}} \quad (3)$$

where:

- Φ_e : radiant flux (Watts),
- P_{mpp} : maximum power (Watts),
- A_{cell} : cell area (m^2),
- E : irradiance (W/m^2).

The conversion efficiencies of today's manufacturing cells vary from 13% to 16%, although module efficiencies are slightly lower. So far, the greatest laboratory efficiency of crystalline silicon attained is 24.7%, which is close to the theoretical limit of this type of solar cell [4]

5.1 I luminance Influences on I-V characteristics

According to the illumination and at ambient temperature, we note that the variations in the short-circuit current is proportional to incident solar flux, from where the strong influence of lighting on the current delivered by the PV module.

It results in increase of the power available in the cell's PV each time the illuminance increases. and at each value of the luminous flux corresponds to a maximum electrical power that a PV cell could provide.

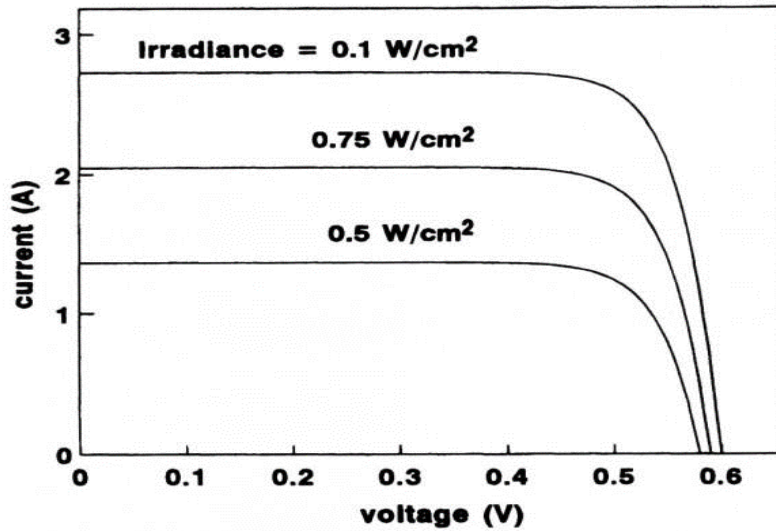


Figure 9. I-V characteristic function of illuminance

5.2 The Influences of temperature on characteristics I-V

The temperature is an essential parameter in the behavior of a PV cell, the constant illumination and various values of the temperature, the current short-circuit voltage I_{sc} varies little as a function of temperature, it causes a decrease in the open circuit voltage and is also reflected by a decrease in the maximum power available in the PV modules (figure9).

Hence the influence of temperature on the behavior of the PV module.

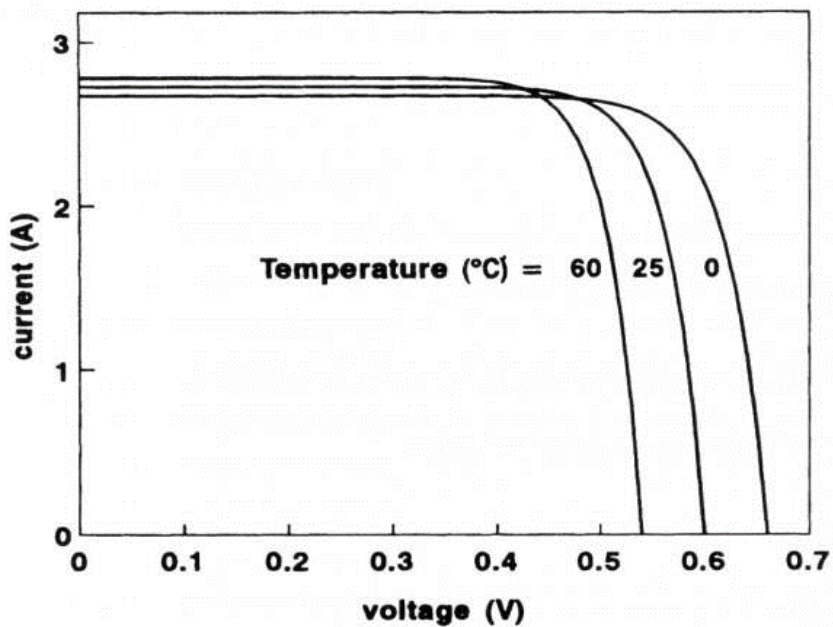


Figure 10. I-V characteristic function of temperature

6 Equivalent circuit of a solar cell

The representation of a PV cell with a model that use a diode, a series resistor R_s and a parallel resistor R_p these resistors are used to model the loss of voltage throughout the system so we can have a better understanding of the circuit [5]

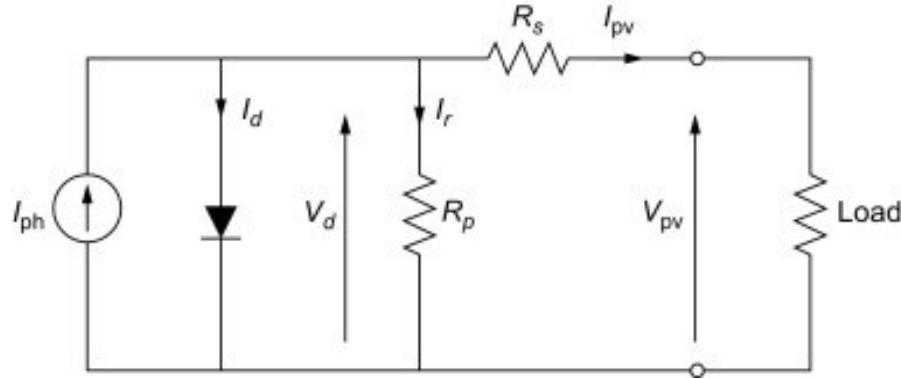


Figure 11 Single-diode electrical PV module equivalent circuit

$$I_{pv} = I_{ph} - I_d - I_p = I_{ph} - I_0 \left(e^{\frac{V_{pv} + R_s I_{pv}}{n_s V_t Q_d}} - 1 \right) - \frac{V_{pv} + R_s I_{pv}}{R_p} \quad (4)$$

Where:

- V_{PV} = PV module voltage (V)
- I_{PV} = PV module current (A)
- I_{ph} = light current (A)
- I_0 = diode reverse saturation current (A)
- Q_d = diode ideality factor
- n_s = number of cells in series
- R_s = series resistance (Ω)
- R_p = shunt resistance (Ω)
- $V_t = kT_c/q$ is the thermal voltage (V), k is Boltzmann's constant, T_c is the cell temperature, and q is the charge of an electron

7 Photovoltaic generators

7.1 Photovoltaic module

The photovoltaic modules consist of a generator of power to meet the needs of most home applications or industrial. an elementary cell of a few tens of square centimeters, delivers a

maximum of a few watts at a voltage below one volt (voltage of PN junction). to produce more power, multiple cells must be assembled to create a photovoltaic module or panel. Indeed, the PV modules are composed of a set of cells put in series or parallel, realizing the actual conversion of sunlight into electricity. the PV modules are associated in series and parallel to form a photovoltaic field with a power peak defined according to specific conditions of illumination, temperature.

7.2 cells in series association

In a series grouping, the cells are crossed by the same current and the resulting characteristic of the series arrangement is obtained by adding the voltages to current given, the figures (16) shows the resulting characteristic (I_{SCC}, V_{SCO}) obtained by associating in series (index s) N_s identical cells (I_{CC}, V_{CO}): The current generated by N_s PV cells in series being the same throughout the branch and limited by the lowest cell current This is why in production, all the cells are tested and sorted based on their performance[6]

$$I_{sc} = I_{cc} \text{ and } V_{oc} = N_s \times V_{oc} \quad (5)$$

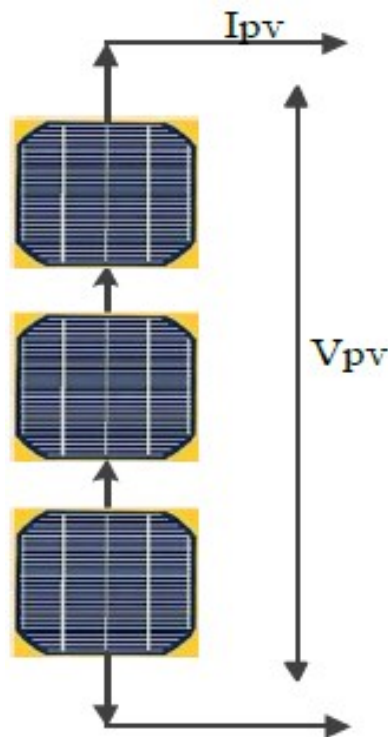


Figure 12. Diagram of 3 photovoltaic cells associated in series.

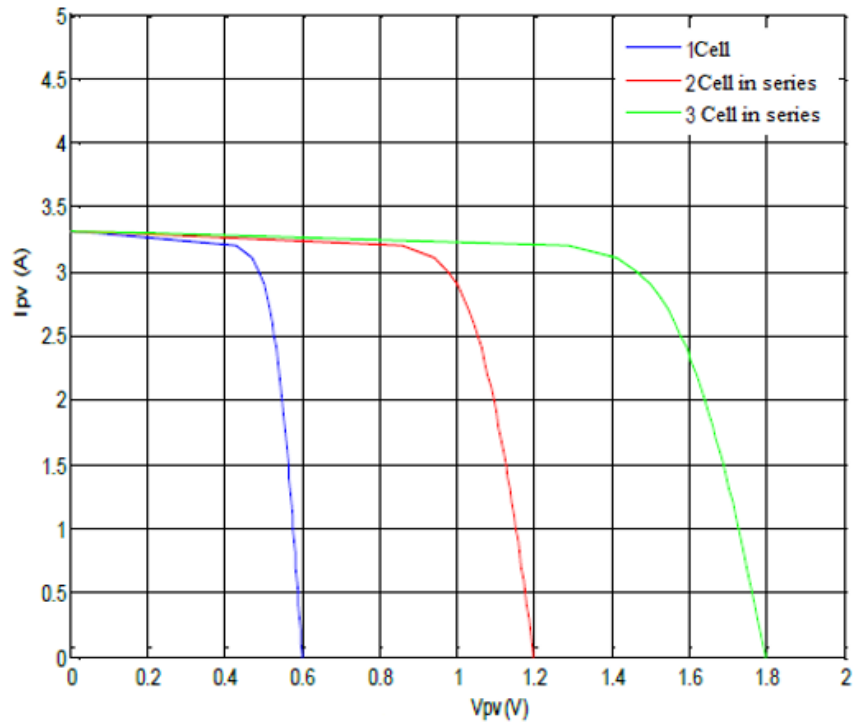


Figure 13. I-V characteristic of cells connected in series

7.3 Cells in parallel association

The properties of parallel grouping of cells are identical to those of serial grouping, thus in a group of cells connected in parallel, the cells are subjected to the same voltage and the resulting characteristic of the group is obtained by adding the currents at a given voltage. Figures (18) show the resulting characteristics (I_{pcc} , V_{pco}) obtained by associating in parallel (index p) N_p identical cells. [7]

$$I_{pcc} = N_p \times I_{cc} \quad \text{and} \quad V_{pco} = V_{co} \quad (6)$$

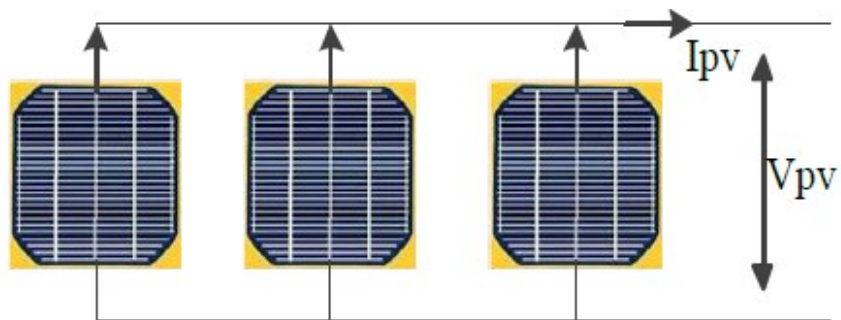


Figure 14. Diagram of cells connected in parallel

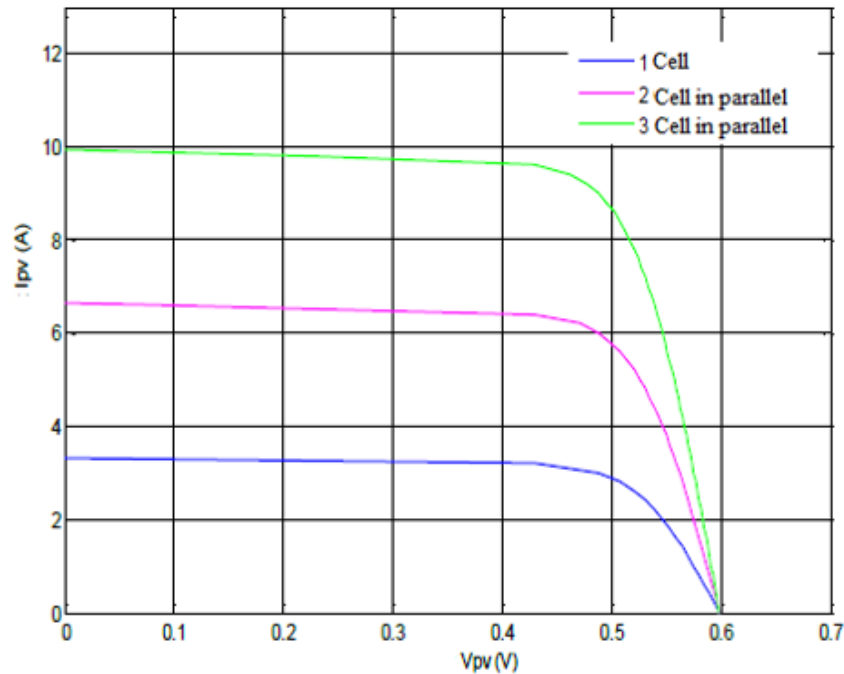


Figure 15. I-V characteristic of cells connected in parallel

7.4 Series and parallel association

This type of association is frequently used to generate a high voltage because the series association of solar cells produces a voltage equal to the sum of the individual voltages and a current equal to that of a single cell. The characteristic of a pair of solar modules that can be generalized across a sequence of N_s solar modules.

This type of arrangement increases the current. To obtain a few kW of electricity under a reasonable voltage, the modules must be connected in panels and mounted in rows of series and parallel panels to form what is called as a photovoltaic generator.[8]

8 Conclusion

We gained a general overview of the concept important for the study of a photovoltaic solar and explore the principle of conversion photovoltaics and the technologies used as well as the different types of cells.

The characteristics of a solar module clearly show that the maximum power generated strongly depends on the intensity of the solar radiation as well as the temperature, the solar module can only generate its maximum power for a certain operating voltage and current

Chapter 2

Characterization of photovoltaic generators

1 Introduction

The photovoltaic (PV) energy industry is under pressure to provide low-cost devices with guaranteed performance over a service life of several decades, successful commercial technology innovation and development programs depend on effective understanding and control of all issues contributing to performance, manufacturability, long-term reliability, and robustness.

To reach the effectiveness and the performance of photovoltaic system, auxiliary systems have to be included to the production equipment's, most of those systems perform diagnosis via electrical characterization.

In this chapter we present PV electrical characterization within production process or in real operating condition. The goal of using PV characterizer is to spot abnormalities in PV generators through performance evaluation monitoring and visual control. Moreover, in this chapter we study the diagnosis and the methods for detecting functional faults in PV modules.

2 Diagnosis

The installation of a solar panel is done in outdoor environment, exposed to harsh environmental conditions (sun beam, rain fall, dust...etc.) it reduces the performance of the PV system, the yearly power loss due to various issues is estimated to be around 18.9%. As a result, continuous monitoring, as well as fault diagnosis methods, are required to detect the causes affecting the PV system's performance [9].

Diagnosis is a procedure that consists of detecting and locating a defective component or element in a dynamic system. Its purpose is to find the cause of a failure, we will adopt the definition that has been adopted by the standardization bodies: Diagnosis is the identification of the probable cause of the failure(s) using logical reasoning based on a set of information from an inspection, control or test, this very short and concise definition summarizes the.

2.1 Diagnosis steps

The procedure for diagnosing failures and degradations likely to affect the various entities of an industrial process (figure 18) is based on the following steps [10].

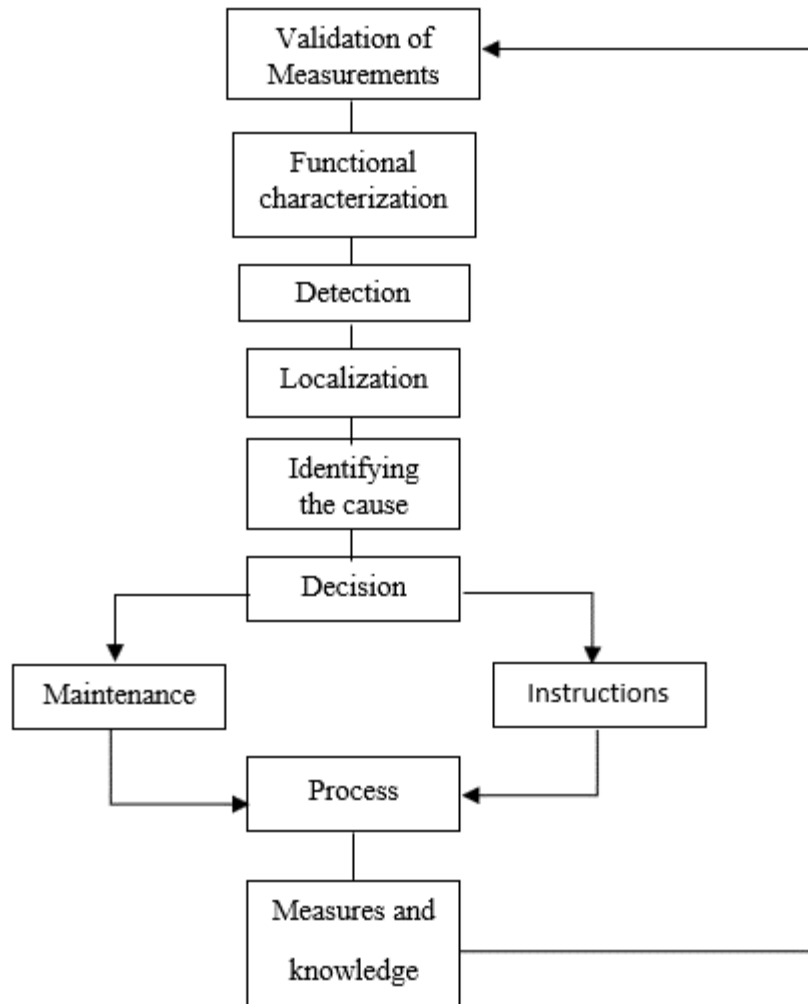


Figure 16. Stages of industrial diagnosis

2.2 Gathering data

This function should provide an understanding of the events. The following functions must be completed:

- Preprocessing and signal conditioning.
- The measuring signal is validated.

2.3 Detection

The initial step of diagnosis is detection, which entails making a binary decision: either the device is operating normally or a defect has occurred. The detection technique produces an alarm, indicating that the system's real performance no longer corresponds to the model of proper functioning.

2.4 Localization

This is the second step of diagnosis, which is initiated by a detection method and consisting of establishing the defective components more thoroughly: sensor, actuator, process, or control unit.

2.5 Identification

The identification of a defect is the process of calculating the magnitude and temporal development of a problem in order to better understand the system's behavior. This step of the diagnostic method is the final phase of fault detection.

2.6 Decision

It is critical to respond in such a manner that the required performance is maintained or that the degradations on the real system are limited after the faulty functioning of the system has been discovered. This selection allows you to pick from a number of options, including shutting down the system for repair or tolerating impaired performance. When possible, it may still include restructuring or rearranging the system.

3 Methods of diagnosis in a PV field

The state of the art of diagnostic methods is split into two categories: current industrialized procedures and methods reported in the literature.

3.1 Industrial diagnostic methods

In this category, there are two methods, the first is based on the analysis of current and voltage referred as electrical method, and second categories based on the analysis of values other than current and voltage which is called non electrical method.

3.1.1 Non electrical method

Is used to determine the source of the problem at the PV cell level. Cell cracking is the most common defect at this level. We can use the following as examples of methods: thermography testing, photoluminescence and electroluminescence imaging, mechanical bending tests.

The technology of infrared imaging (thermal camera) is frequently used in the PV module. This approach is based on the fact that all materials produce infrared radiation with a wavelength range that varies according to the material's temperature. [11]

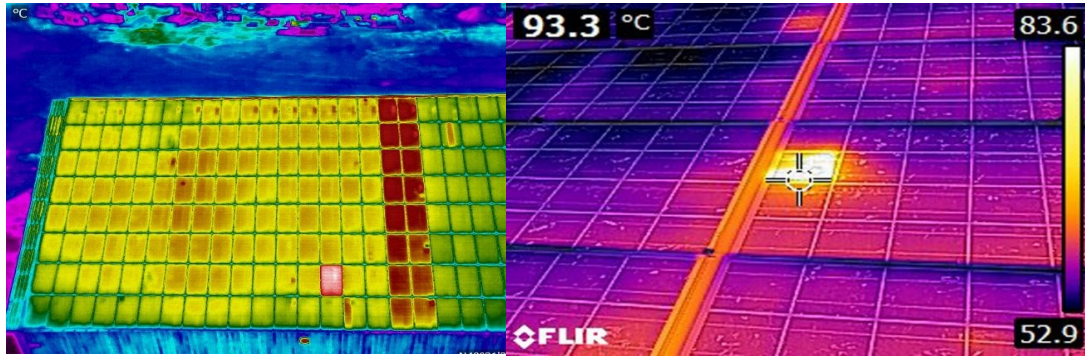


Figure 17. use of thermal camera for fault detection in a PV module

Some accomplishments in identifying problems with the thermal camera have been reported: leakage current in the cell, rise in the resistance of the connections between the cells, abnormal heating of the cells, bypass diode conduction.

This approach can also be used with junction box connections and anti-return diode capabilities.

3.1.2 Electric methods

The current PV monitoring systems are largely incorporated into the inverters, and the data measured is frequently the same from one system to another, the most often measured values are the following:

- The current delivered by the PV field
- The voltage across the PV field
- The insulation resistance between the positive and negative terminals of the PV field

Additional variables, such as the site's ambient temperature and the amount of sunlight, can be added to the electrical data, these data necessitate the use of a specialized sensor (temperature probe and reference cell). If these quantities are required, a particular automaton should be used to process them. This automaton is connected to the inverter and manages everything.

The AC measurements are more essential in terms of quantity since they are directly related to the energy that will be supplied. AC current it's common to note:

- AC voltage
- Frequency
- The network impedance seen by the inverter

With this parameter we can deduct the following

- DC instantaneous power
- Instantaneous AC power
- The energy produced over different periods on the DC and AC sides

The data is instantly calculated by the inverter's microcontroller or the connected PLC, often add

- The operating time of the inverter
- The date of commissioning
- CO2 not released into the atmosphere
- System failure alerts (mainly insulation faults)

3.2 Methods reported in scientific literature

To detect and locate defects in a PV system, a variety of diagnostic approaches have been offered, we present bellow some of those techniques.

3.2.1 Method of reflectometry

The reflectometry method is a diagnostic technique that involves transmitting a signal into the system or environment being investigated, in our case we inject the signal in a string of PV modules for fault detection (figure19 below)

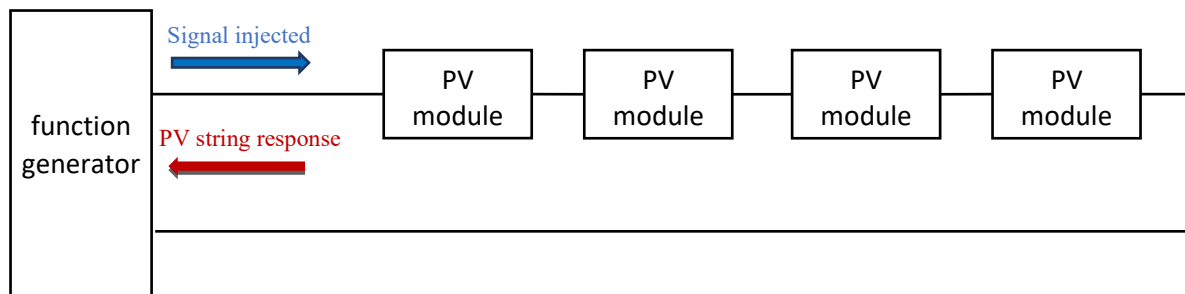


Figure 18. Principle of reflectometry to locate the fault in a PV string

A step or pulse signal is injected into the PV string, which is made up of a succession of modules linked together by wires. The experimental investigation verified the possibility of finding fault locations in the string of types open circuit short circuit and increased impedance [12][13].

3.2.2 Analysis of power and energy produced

Studies in the literature are based on the analysis of the power and energy produced by the PV field to detect and locate faults that have appeared, The current (measured) power or energy is compared to the expected one and when a significant deviation occurs, it is considered that there is a fault, for more in-depth analysis of the quantities measured, consists in generating additional attributes of the drop in power or energy produced such as: the duration, the amplitude, the frequency and the instants of the drop.

These same attributes are also predetermined for the different defects considered. During their comparison, the defect value of the attributes considered is closest to that deduced from the quantities measured is considered as the defect responsible for the drop.

Additional aspects of the energy loss have been addressed, the amount, length, and timing of the energy decline are examples of these characteristics.[14][15]

This approach allows four fault groups to be distinguished:

- Constant energy losses: degradation, dirt, defective module, defective string
- Variable energy losses: shading, high temperature, inverter overheating, MPPT error
- Total losses: defective inverter, failure of the control system
- Snow cover

3.2.3 Working Point Analysis

The analysis point is about comparison of the present maximum power point (current and voltage corresponding to maximum power) and the predicted maximum power point might offer further information on the status of the PV system.

The nature of the PV field's problems can be discovered by a relative comparison between the currents and voltages based on the combination of these two, the four problem families are as follows:[16]

- Faulty modules in a string
- Defective string
- Family of indistinguishable faults: shading, MPPT error, aging...
- False alarms

4 Faults Occurring in PV Panels

In solar panel, faults can be caused by system overload, hardware difficulties, connection failures, malfunctions, and other environmental impacts such as dust, water droplets, and partial shadowing situations are all examples of inadequate consumer maintenance, recent research into PV system failure has resulted in the development of novel approaches for detecting and locating the various kinds of defects that exist, the classification of faults that occur in PV panel arrays, and the possible faults that occur in the life cycle of a PV panel, these techniques have helped to increase the dependability and lifetime of PV systems[17].

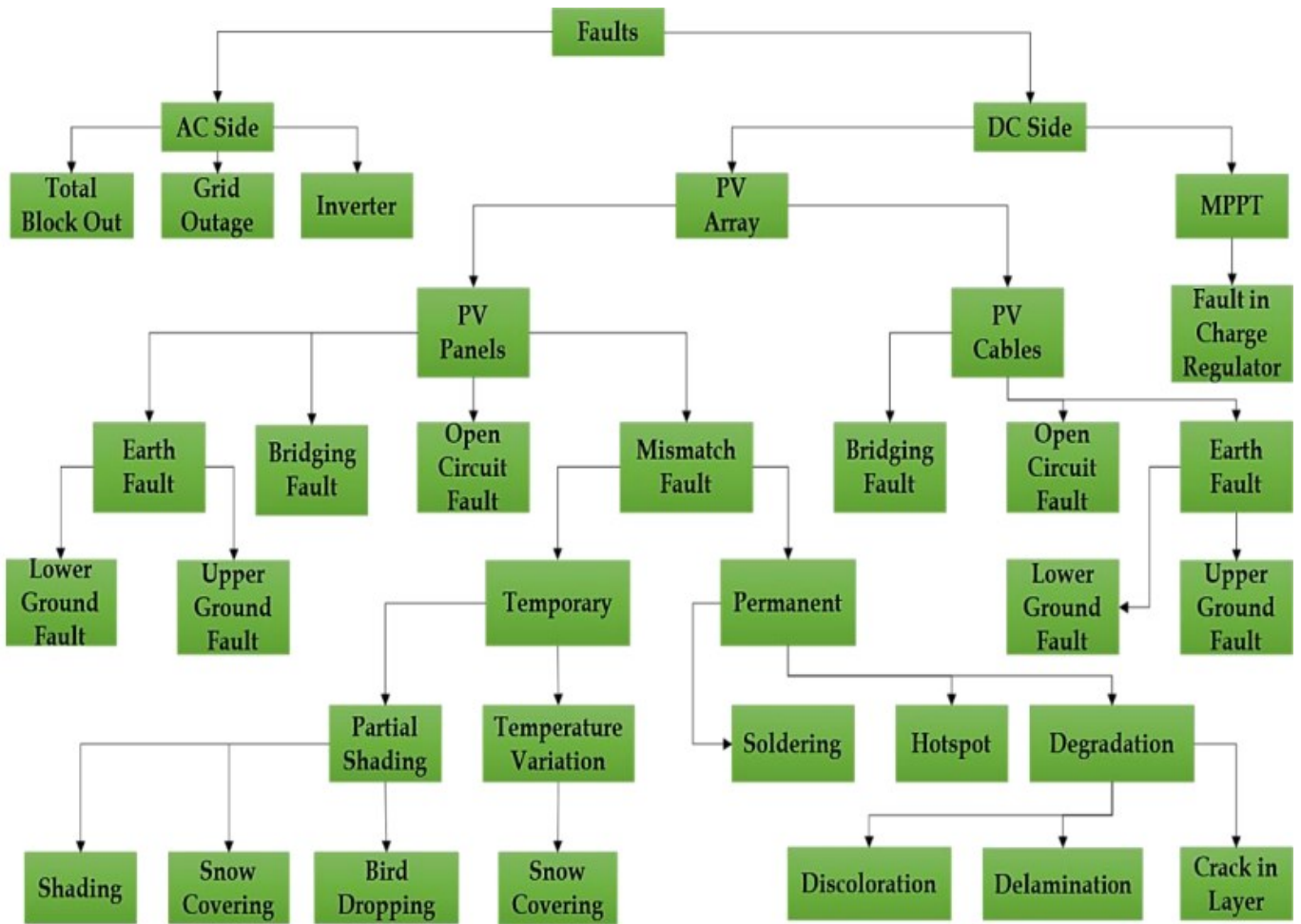


Figure 19. Classification of faults that occur in PV array panel

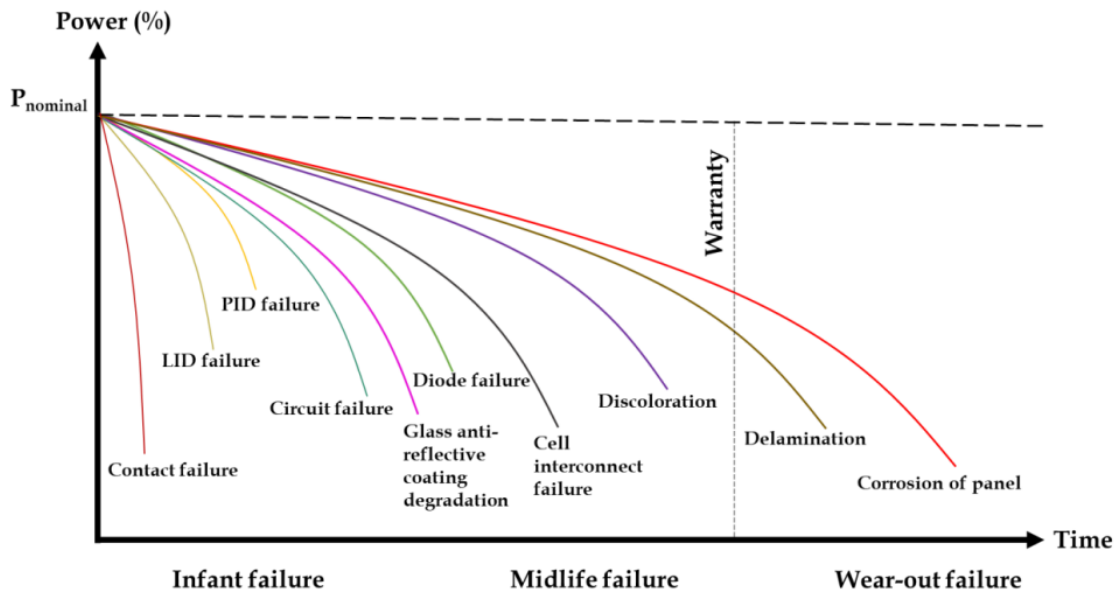


Figure 20. Possible faults that occur in the life cycle of PV panels

As an example, if the problem is discovered on the DC side of the PV system, a microscopic examination can be carried out to ascertain the reason, for microscopic examination, analytical methodologies have shown to be quite useful.[18]

When the fault location has been discovered, the modules are visually inspected for yellowing, cell fractures, corrosion in connector links, electrical short circuit defects, bypass diode failure, back-layer polyethylene fractures, bubble formation and matrix cracking in the encapsulate, oxidation and discoloration in intersection wires, encapsulate discoloration, and other flaws.[19]

4.1 Classification of PV generator faults

This section is about classification of fault, it's done by their location and appearance in a PV installation, in the table below, the first column illustrates the order of the components examined in the method, the second the type of the numerous flaws included in the phases, and the last column the name of each defect category for the modeling

Table 3: Classification of faults and anomalies of a PV field [3]

Component	Defects nature	Defect classification
Cells	<ul style="list-style-type: none"> -Torn or broken module -Cell overheating -Degradation of interconnections -Corrosion of connections between cells -Cell damage -Moisture penetration 	Mismatch and shading fault
Cell groups	<ul style="list-style-type: none"> -Destruction or absence of diodes -Shorted diode due to a faulty connection 	Bypass diode fault
Field	<ul style="list-style-type: none"> - Diode polarity reversal 	Faulty anti-return diode
Module	<ul style="list-style-type: none"> - Reversal of module polarity - Shorted modules - Shunted modules 	Module fault
Strings	<ul style="list-style-type: none"> - Module disconnected -Breaking or corrosion in contact - Electrical circuit breaker 	Connection fault

5 Definition of Characterization

The Is-Vs operating curve of a basic module is generated from the operating curve of an elementary cell by changing the scale on the two axes, as shown in figure (23).

These curves are used to calculate the performance of a solar module.

Knowing the shape of these characteristic curve over the widest possible range of illumination allows us to estimate both the maximum powers provided and the yields. correspondents.

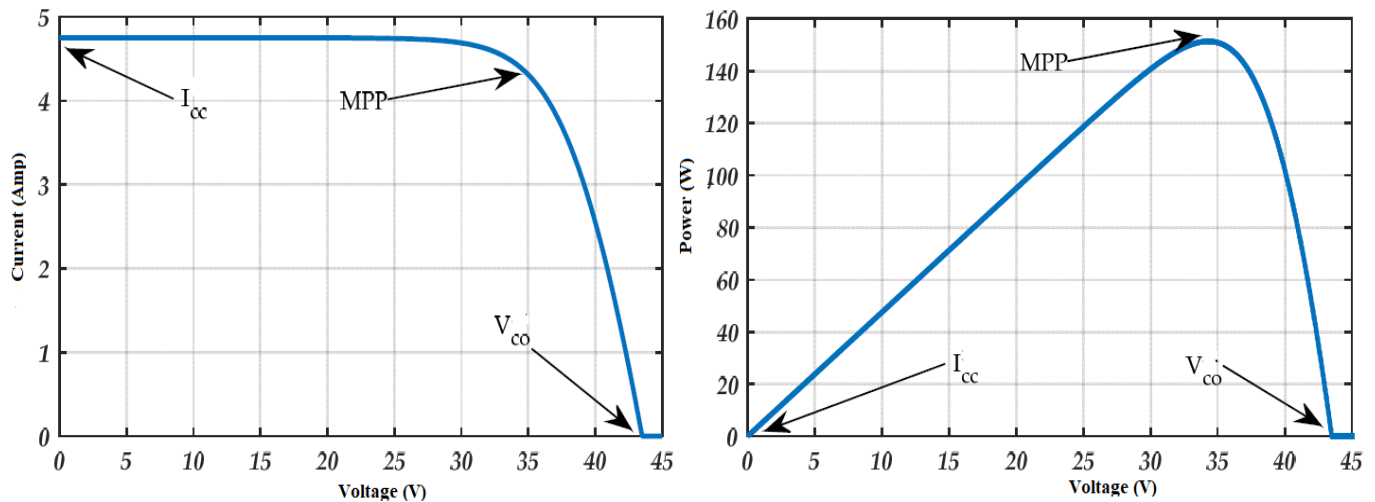


Figure 21 Electrical characteristics of a photovoltaic panel

5.1 Why the characterization

The goal is to provides information about PV modules such as

- Indicate the maximum rated power, maximum current, maximum voltage, and module efficiency.
- Simulation of IV curves in reference to light and temperatures
- Used as a method to analyze a PV module

6 Method of characterization

There are several methods for characterizing PV modules; the most common ones cover four different methods with varying degrees of complexity, fidelity, and cost.

The main methods of characterization electric of module PV are [20]:

- Variable resistance
- Capacitive load
- Electric charge
- Four quadrant loads

6.1.1 Variable resistance load

The use of a pure resistive load 'R' as indicated in Figure 24 is the simplest and most well-known approach in the characterization of PV modules, the resistance R is varied in stages, from zero to infinity with a regular or irregular step, in order to traverse the whole, I-V curve from the point of short circuit to the point of open circuit, recording the voltage and current in each step, due to the lack of resistors for higher power, this approach is only suitable to low-power GPVs, furthermore, the modification of the load resistance is done manually, which makes the process very slow, allowing the solar radiation and temperature conditions to be taken into account. During the measurement, it's possible that it'll alter, the voltage and current are measured using a pair of digital multimeters at each stage, and we use a set of resistors as a load in the plan test, the resistors are chosen so that the spread of the points is around the leg of the I-V curve, and two analog/digital converter channels from a computer board are used to measure each pair (I,V), with this approach, manual adjustment of the load resistor is avoided, and acquisition time is improved.

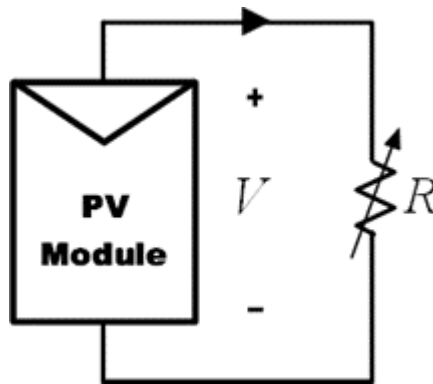


Figure 22 characterization using variable resistance

6.1.2 Capacitive load

This approach for measuring the I-V characteristic of a photovoltaic device is based on the employment of a capacitive load, i.e., the polarization of the device by a large capacitor,

initially discharged, the capacitor begins to charge as soon as the two switches S_2 and S_3 are opened, with an increasing voltage and a decreasing current which will be canceled at the end of the charge thus matching to the open-circuit situation ($V=V_{oc}$).

Instead of beginning the second charge with the short circuit current, we can begin with S_2 closed, charging the capacitor to a negative voltage and scanning the I-V curve from the second quadrant to obtain the short-circuit current I_{sc} . In addition, before performing a new test, the capacitor must be depleted through resistor R by closing switch S_3 . It's worth mentioning that the three switches must be reactivated in the correct order, the capacitor charging time is related to the value of C and the module's or GPV's open-circuit voltage, and inversely proportional to the short-circuit current.

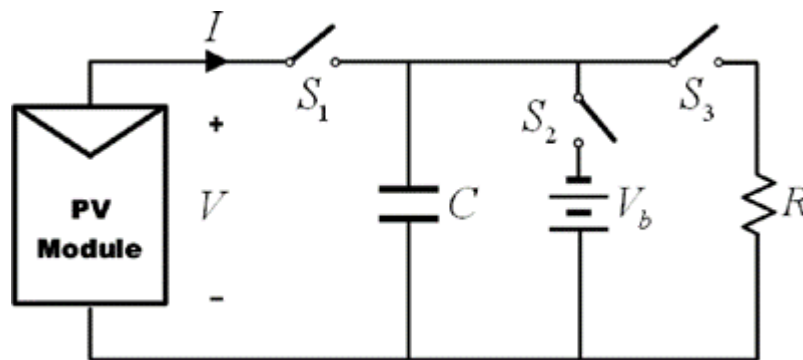


Figure 23 characterization using capacitive load

Based on this technique, two variants have been proposed which are reported in the literature

Variant 1: voltage and current are measured using an acquisition card piloted by computer

Variant 2: This is a portable capacitive load based on bipolar transistors insulated grids (IGBT) allowing the measure the characteristic from fields PV in real conditions of site, the figure switches are substituted by IGBTs and the capacitor is an association in parallel from abilities and resistances.

6.1.3 Electric charge load

A transistor (MOSFET) is used as the load in electric load approach, the resistance between the drain and source is varied by adjusting the gate-source voltage, and therefore the current supplied by the module is also varied, sweep of the I-V curve is achieved, and the MOSFET must function in one of its three operational regimes (cutoff, linear or triode and saturation), as

a result, this device will have to waste the majority of the energy supplied by the module, limiting its medium-power application.

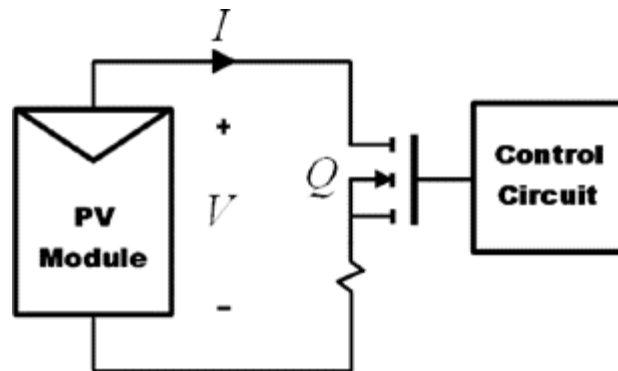


Figure 24 characterization using electric charge

6.1.4 Four quadrant Load

A four quadrant load functions as a bidirectional current source or generator and applies positive or negative voltage, allowing it to be used as an adjustable load, or a power supply capable of supplying and dissipating energy. The I-V curve that can create a load of four quadrants is shown in figure 26, and the functional diagram of the circuit that can be used to carry out a load of four quadrants is shown in figure 27.

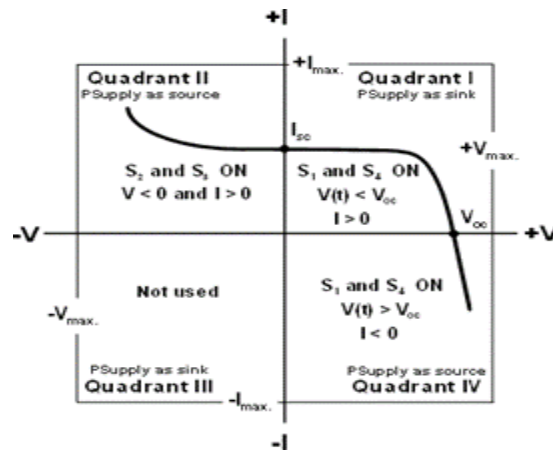


Figure 25 I-V Curve in Quadrants I-II-IV

The basic goal for a photovoltaic module is to get the I-V curve in the first quadrant, however, exploring the points in the 2nd and 4th quadrants could be a useful diagnostic tool for detecting mismatches in the operation of the PV module, such as shading, mismatch, hot-spot, and so on the basic operation of a four-quadrant load is based on a power supply where output

voltage is dependent on a reference signal, which can be modified by another external or programmed reference, in order to perform a sweep of different voltages.

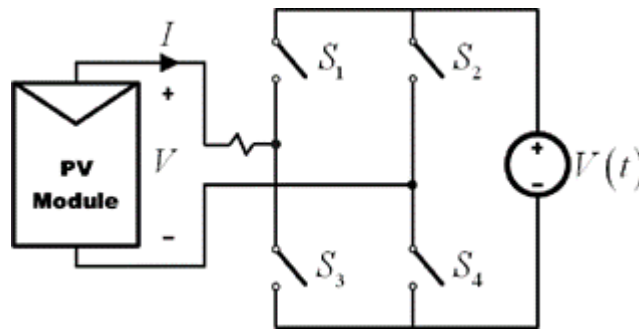


Figure 26 characterization using four quadrant loads

6.2 The advantages and disadvantages of different methods

Below is presented a synthesis of the advantage and disadvantages of the different techniques of characterization.

Variable resistance load

Advantage

- Very cheap and easy to replace.
- Easiest method.

Disadvantage

- Reliability and response are low need to program when using a programmable variable resistor.

Capacitive Load

Advantage

- They make excellent use of their properties while controlling changing voltage.

Disadvantage

- Relatively unreliable in circuits for each new measurement capacitor must be discharged.
- Difficult to control switches to sequence properly.

Electric Load

Advantage

- Reliable.
- MOSFET frequency very high (very fast).

Disadvantage

- high impedance and low capacitance.
- High voltages can destroy the MOSFET.

Four-quadrant load***Advantage***

- Direct display of the output is possible in this method.
- With this method second and third Quadrant curves can be obtained.

Disadvantage

- The cost is high.
- Due to the increased number of switches, it is more difficult to construct.
And it isn't suitable for huge PV installations.

6.3 Bibliographic review

In this part, a synthesis is developed for numerous bibliographies dealing with all of the techniques listed, with the introduction of micro electric, the forms of characterization of PV modules have significantly evolved the early forms deal with the resistive approach employing artificial light and regulated ambient temperature settings, the capacitive approach allowed for field characterization, while electric loading technologies allowed for extensive investigation.

The table below illustrates the major works identified on IV curve tracers for PV modules, with the following key characteristics: the data collection system, the acquisition time of the IV curve, and the system's interface software [3]

Table 4: Review of studies [3]

Method used	Data acquisition system	Graphic interface	Acquisition time
Capacitive	Oscilloscope	-	0.1s
Electrical charge	Oscilloscope	-	-
Electrical charge	PIC16F877	MATLAB	-
Four-quadrant power supply	Multimeters	Visual Basic	0.1s
Capacitive	Picolog1000 data acquisition card	LabVIEW	1s
Electrical charge	PIC16F876	Visual Basic	-
Electrical charge	Oscilloscope	-	-

Electrical charge	NI USB 6008 Data Acquisition Board	MATLAB	2s
Four-quadrant power supply	Multimeters	Borland Delphi	1s
Electrical charge	NI USB 6008 Data Acquisition Board	LabVIEW	-
Electrical charge	NI PCI-6228 Data Acquisition Board	LabVIEW	2s
Variable resistance	NI USB 6008 Data Acquisition Board	LabVIEW	-
Electrical charge	NI USB 6008 Data Acquisition Board	LabVIEW	6s

7 Conclusion

In this chapter, we presented a summary review on photovoltaic characterization and most methods used for photovoltaic system diagnostics. We presented also, the different electronic devices that permit to acquire practically the electrical characterization of a photovoltaic generator.

Chapter 3

Simulation and results

1 Introduction

The photovoltaic generator faces a number of problems, perhaps the well-known problem is shading, which greatly affects its production capacity and degrades its performance and efficiency. There is a large number of methods to detect and to localize defects in photovoltaic installations, we try in this work to elaborate a simple technique that allow in a competitive

Inthis chapter, we simulate a system of two panel characterization using capacitive load method to have a better understanding on the method, after that we move to a large-scale system we apply two different scenarios, ideal and shading we compare the result of each panel.

2 Capacity load method

IV curve tracer design with a capacitive load having low Equivalent Series Resistance (ESR). This is more efficient and gives better results for high power rated SPV module characterization. Low ESR helps to capture I_{sc} more accurately due to low resistance path offered by capacitive load during capture cycle. This method sweeps the curve automatically with minimum voltage and current ripple in the measured data points.[21]

The equation below gives the relation between curve tracer scan time (T_{scan}), electrical parameters (I_{sc} and V_{oc}) and the value of the capacitance (C). In this method.

$$C = \left(\frac{I_{sc}}{V_{sc}} \right) (T_{scan} \times 1) \quad (1)$$

To discharge the capacitor, any resistive element (R) which acts as an energy sink can be used in the IVCT circuit. The capacitor discharges to 63% of its full-scale voltage after a one-time period ($1 \times R \times C$) by observing the transient behavior of a fully charged electrolytic capacitor. To completely discharge the capacitor, it must be connected to discharge circuitry more than 5 time periods ($5 \times R \times C$). Therefore, after T_{scan} , to assure safety and to start a new measurement cycle without error, the capacitive load must be discharged first. [22]

$$T_{zero} > 5 \times C \times R \quad (2)$$

And for the resistor R we use the equation above to calculate we put $T_{zero}=T_{scan}$.

When we simulate a PV field SP with 16 panel 4 in series and 4 in parallel, to know which capacity to use, the equation (1) show use how to calculate C, the sweeping of one panel is done in 0.2s, the value of the capacity change by the output: individual panels characterization, field characterization

- Individual panels

The output of the panels is $I_{sc}=6.21A$ and $V_{oc}=90.5V$ using equation (1) and (2). After numerical application we get:

$$C = 34 \times 10^{-4}F$$

$$R = 3\Omega$$

- Field characterization

When we simulate a PV field SP with 16 panels at the same time the I_{sc} and V_{oc} change because the Current and Voltage is higher than individual panels, the new values are $I_{sc}=24A$ and $V=360V$ using equation (1) and (2). After numerical application we get:

$$C = 133 \times 10^{-4}F$$

$$R = 0.3\Omega$$

3 Simulation IV tracer with two panel

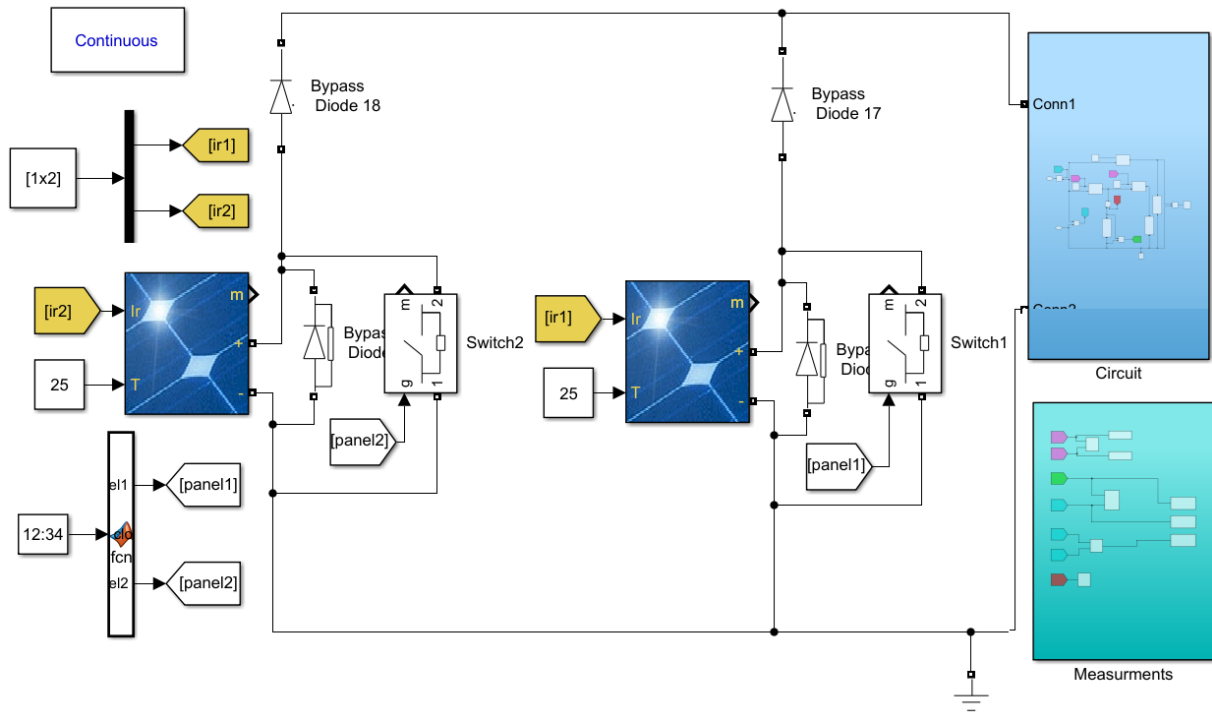


Figure 27 two panel simulation

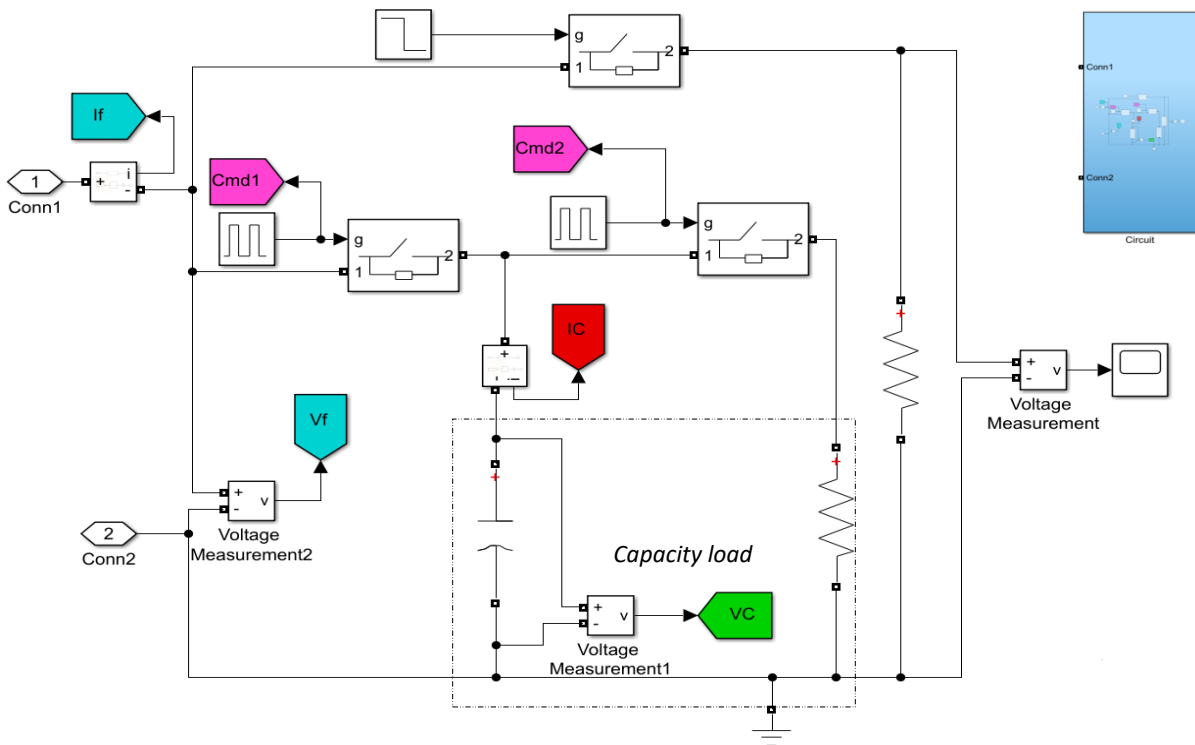


Figure 28 circuit block

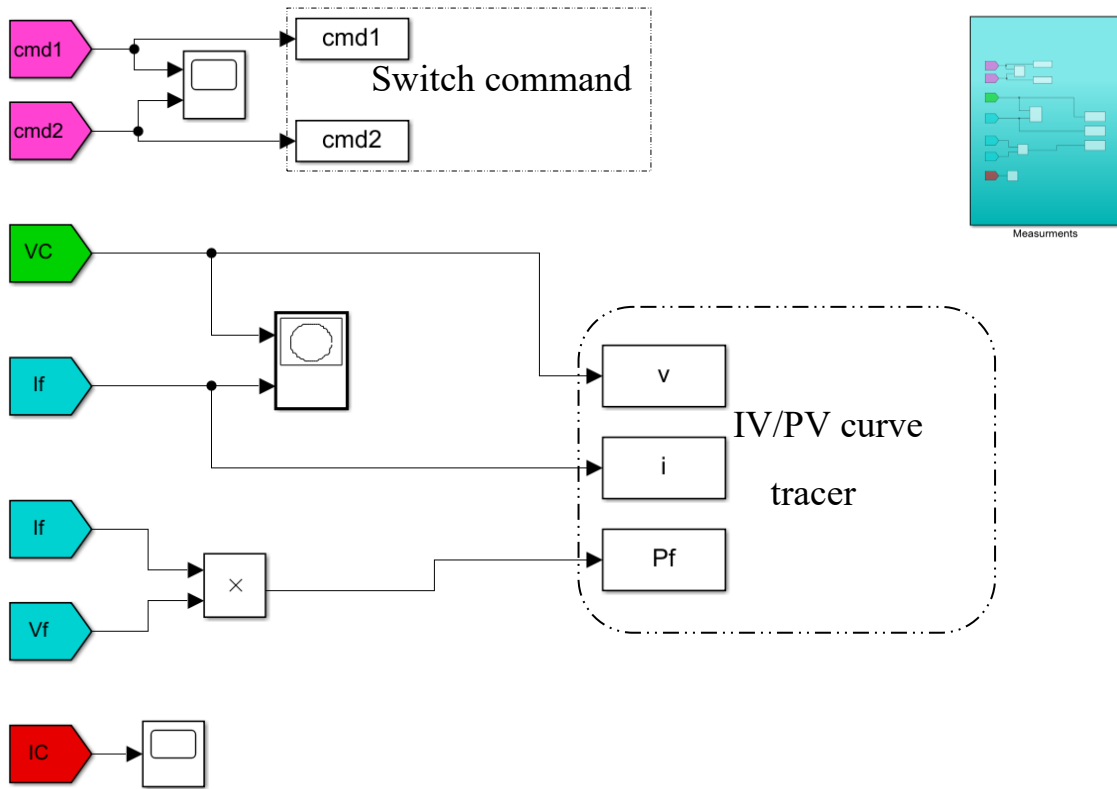


Figure 29. Measurement block

In this part of our work, we trace the IV curve of two panels, we apply a command function to the panel switches to isolate on another for extracting the curve the specific panel, for charging and discharging of the capacitor, the switches are controlled by generator pulse (figure 29)

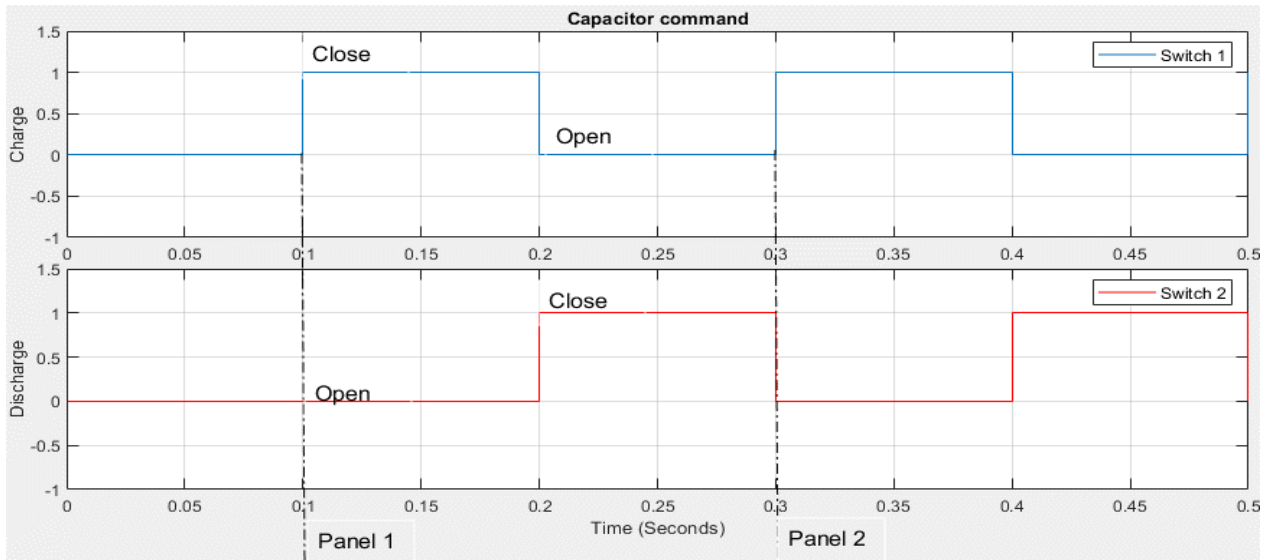


Figure 30. Switch capacity command

As we apply this command, we can observe the voltage and the current of each panel separately the result are.

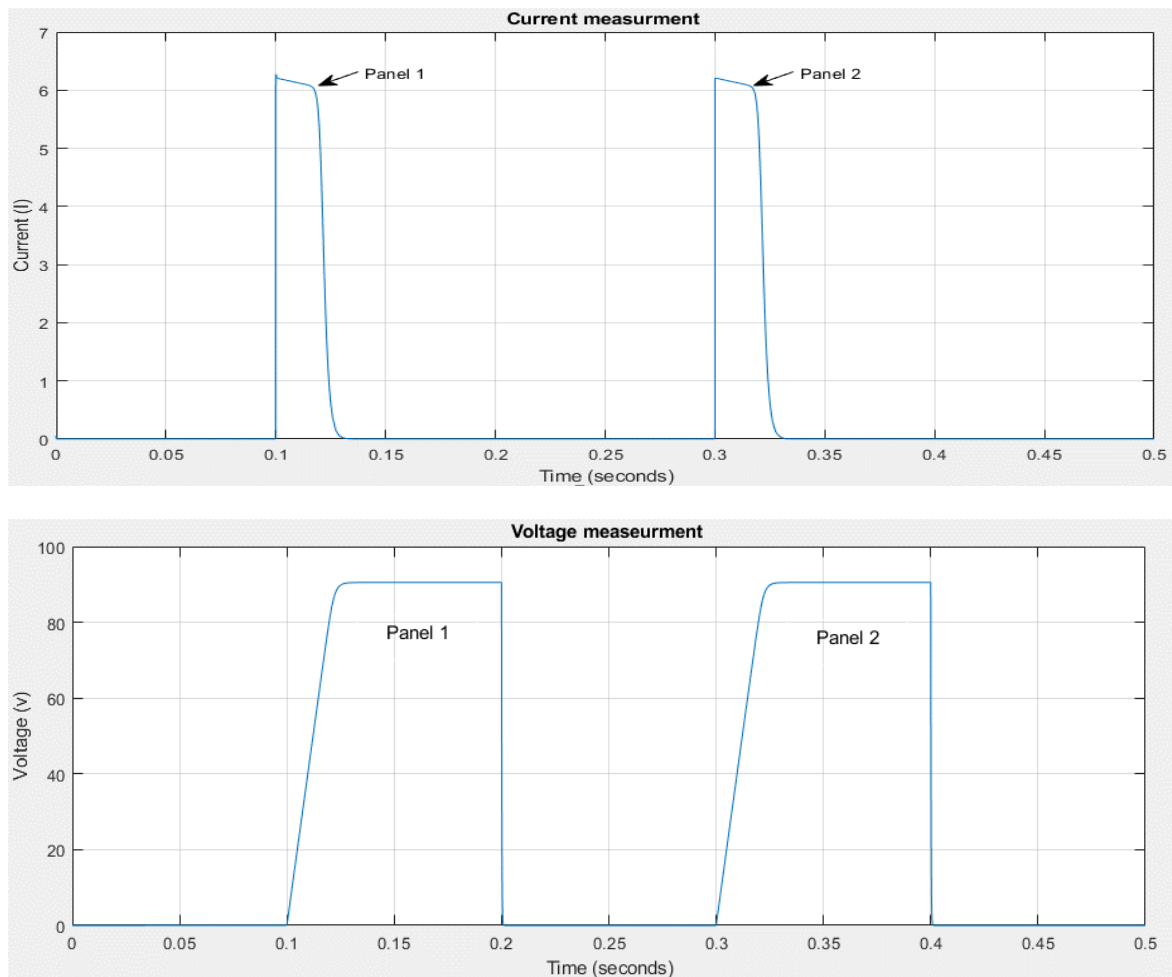


Figure 31. Panels measurement

Theoretically, we know that the panels used have an output of 90.5V and 6.21A, from the figure above we see the same result in current and voltage, in conclusion by applying this technique we can have the IV/PV curve panel.

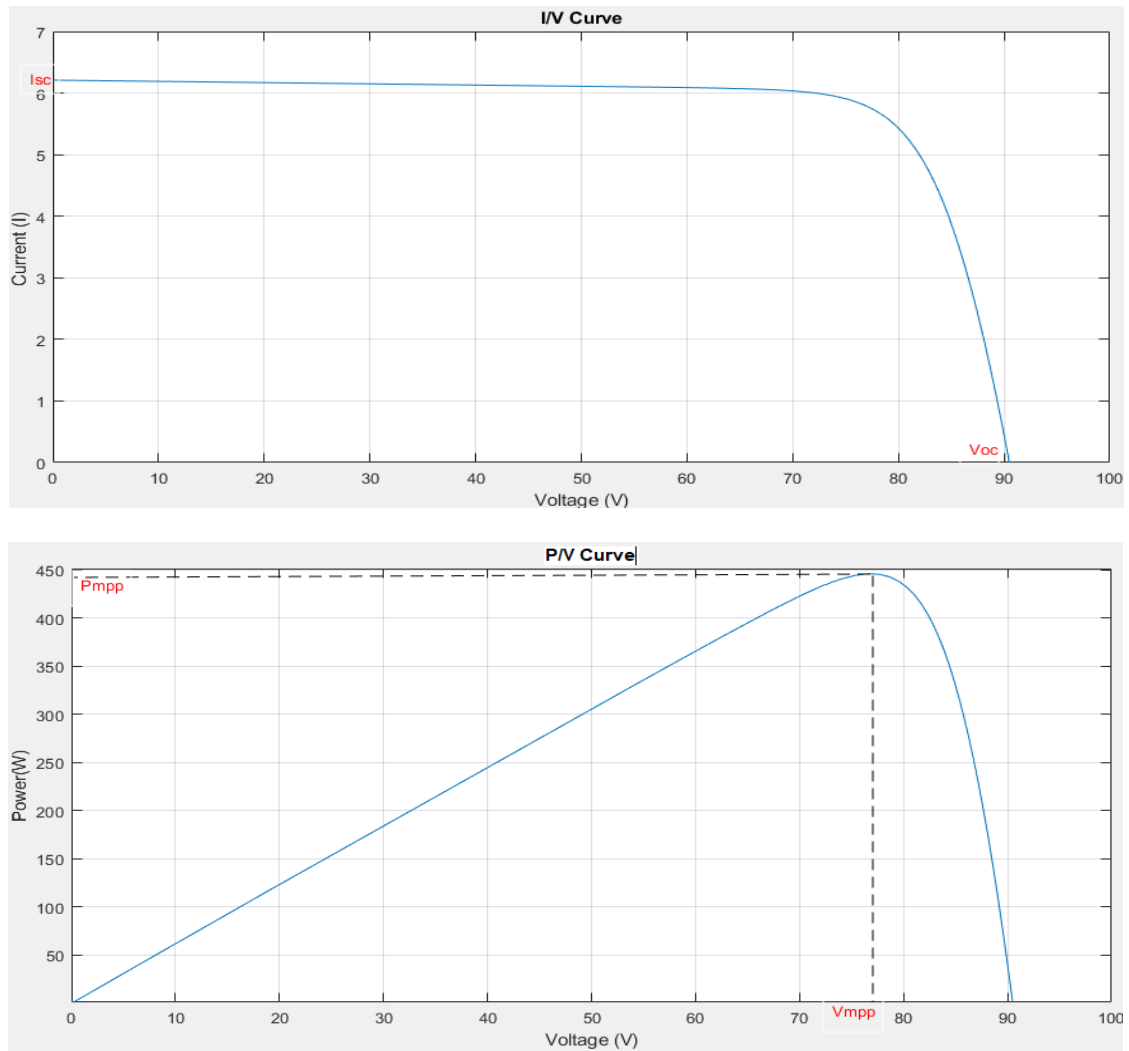


Figure 32. I/V P/V curve simulation result

From this simulation we gained idea on how to operate the command for the capacity by using this method we can simulate 16 panel for diagnostic purposes.

4 Field diagnostic simulation

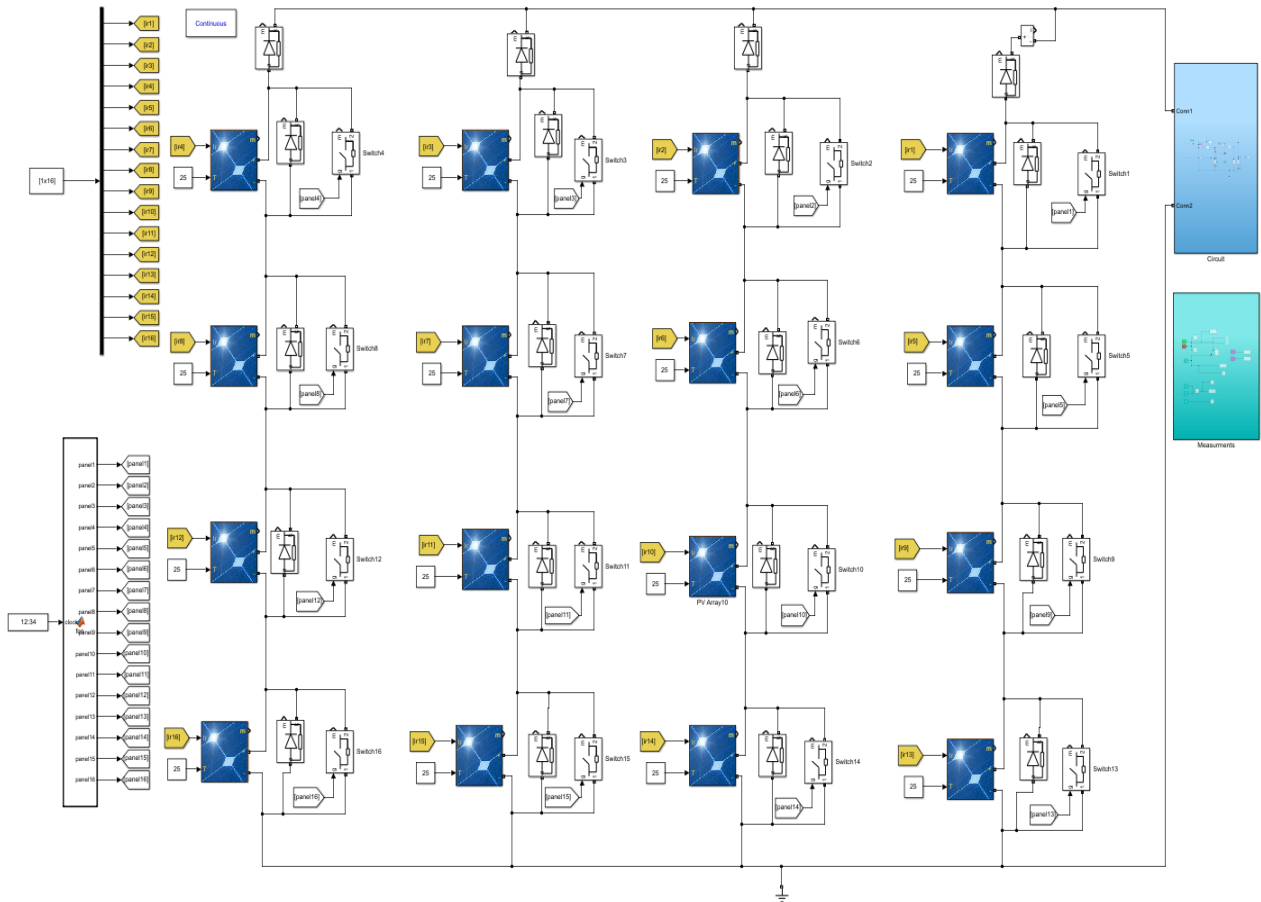


Figure 33. Field simulation model

In the capacity command, the opening and the closing times are changed because the charging/discharging time varies according to the value of the capacity used.

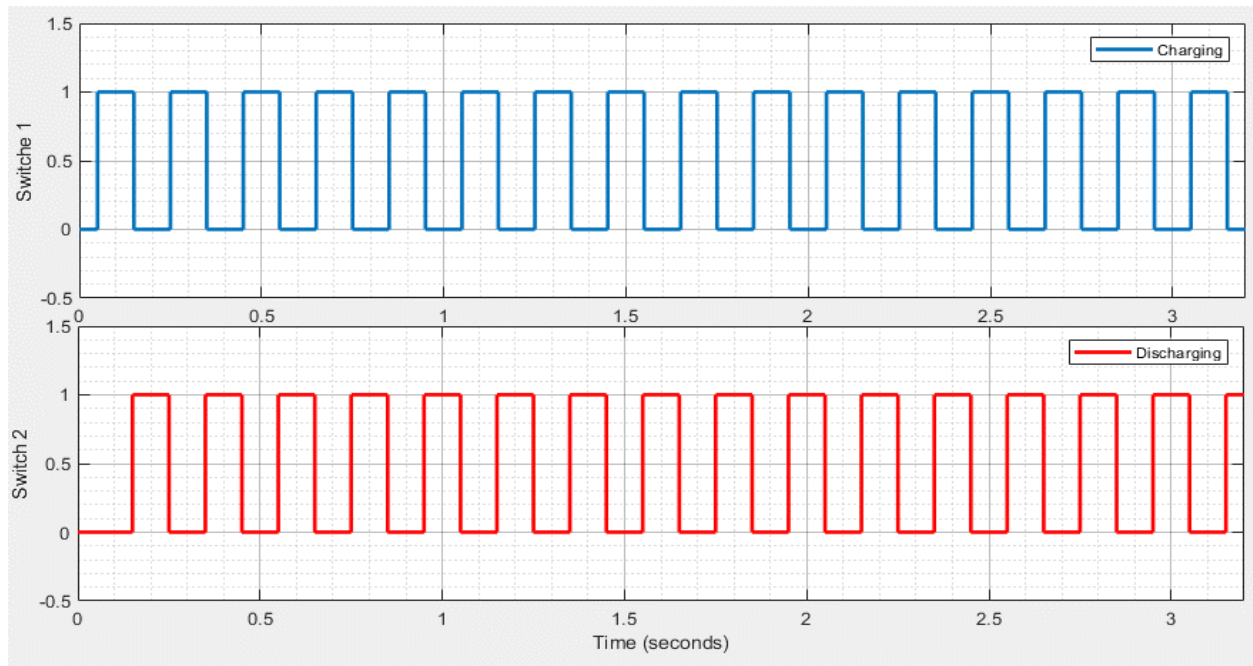


Figure 34. Capacity charge and discharge command

4.1 Scenarios

The PV array performance is mostly influenced by different shading conditions and patterns. We apply scenarios and compare the result. By applying patterns (scenarios), the IV-PV curves show us there is a fault in the field, we extract current and voltage of each panel to show us the panels effecting the field.

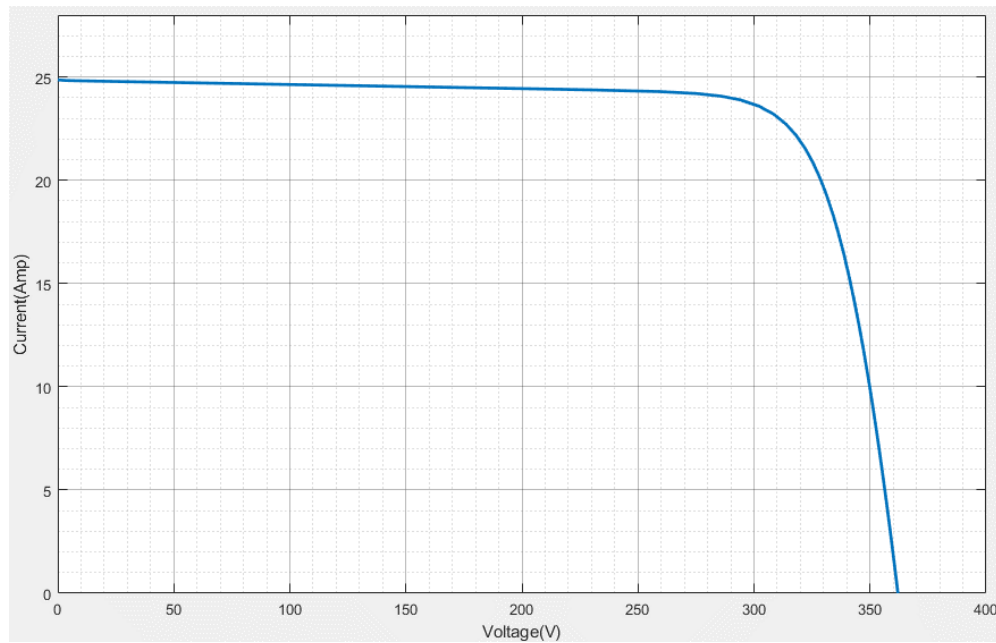
4.1.2 ideal scenario

It is reference I-V and P-V characteristics for the PV generator, therefore we run the simulation in these parameters: $I_r=1000 \text{ W/m}^2$ and $T=25 \text{ C}^\circ$.

Table 4. Ideal scenarios (reference)

1000w/m ² PV4	1000w/m ² PV3	1000w/m ² PV2	1000w/m ² PV1
1000w/m ² PV8	1000w/m ² PV7	1000w/m ² PV6	1000w/m ² PV5
1000w/m ² PV12	1000w/m ² PV11	1000w/m ² PV10	1000w/m ² PV9
1000w/m ² PV16	1000w/m ² PV15	1000w/m ² PV14	1000w/m ² PV13

We use these tables above to have a spatial representation of each scenario, which help to visualize the irradiance covering. After executing the simulation, we got.



Figur35. field characteristics ideal scenario

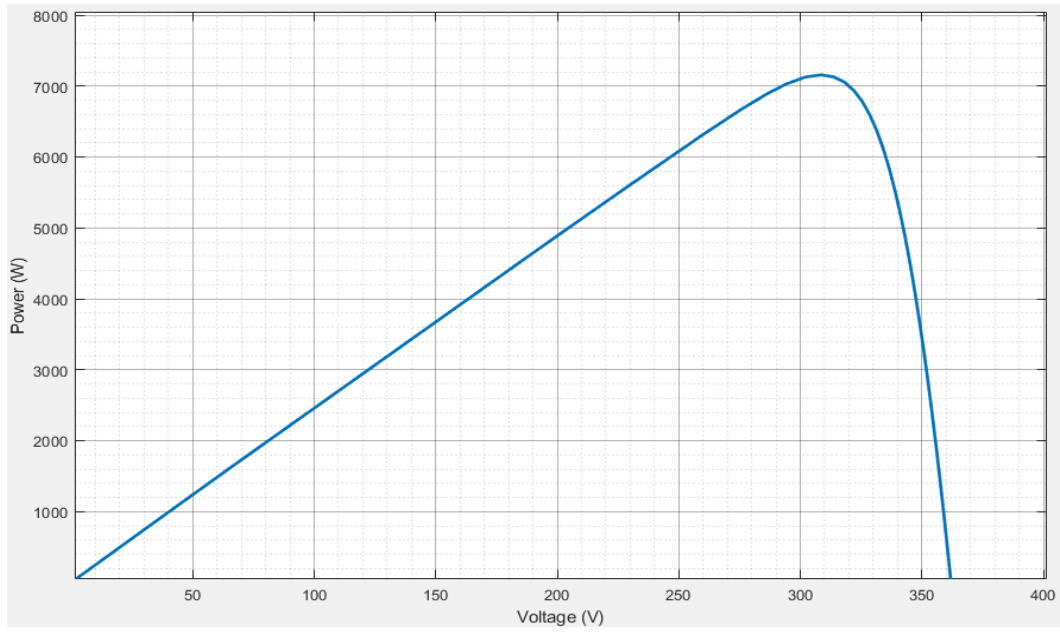


Figure 36. Power measurement ideal scenario

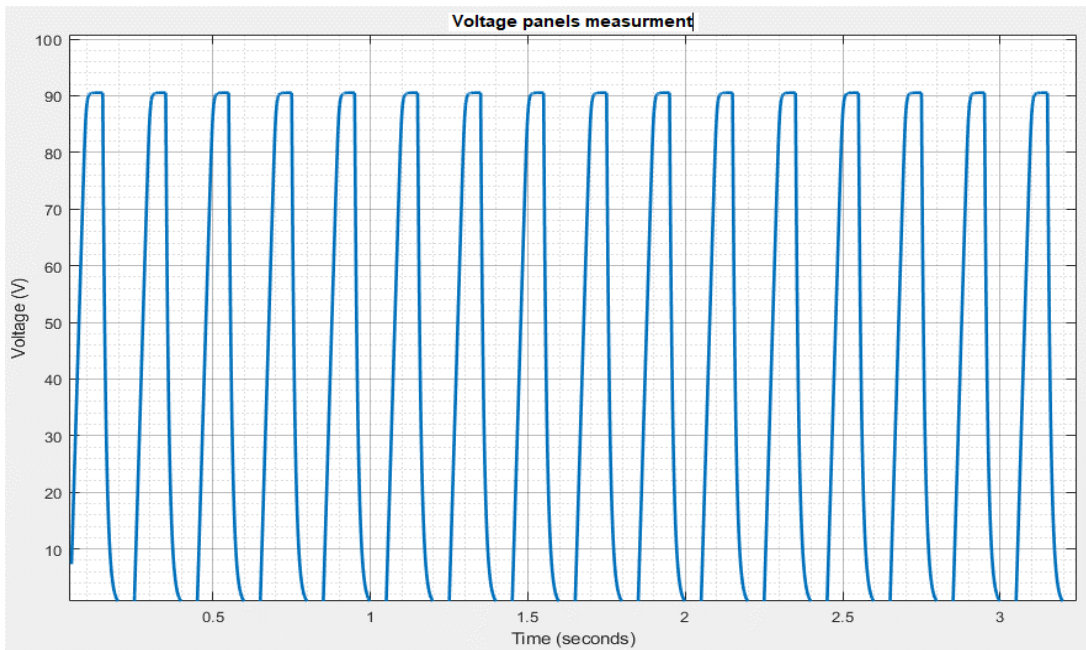


Figure 37. Voltage measurement

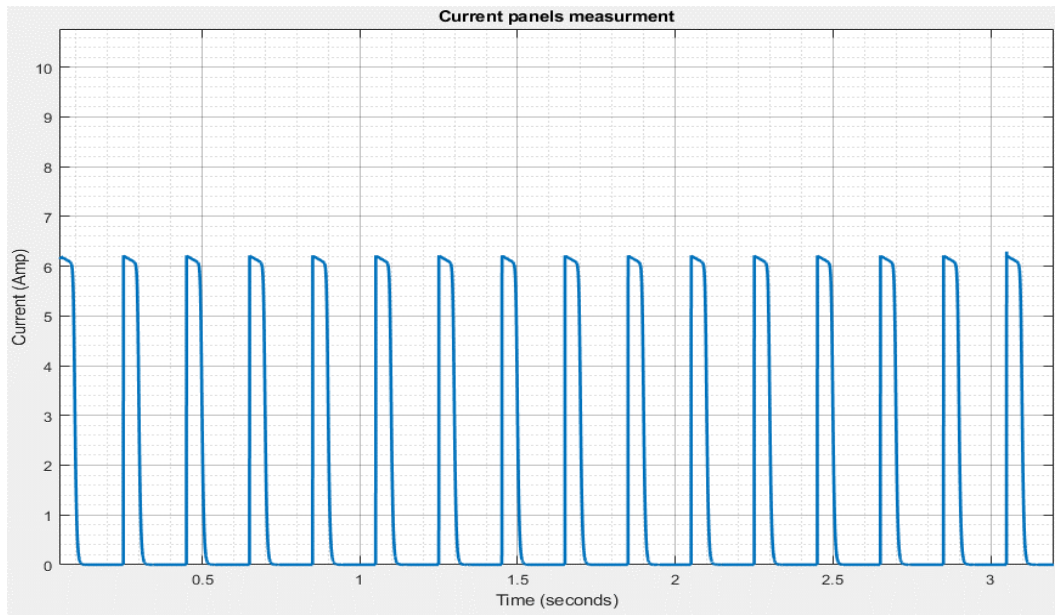


Figure 38. Current measurement

4.1.3 Left side shading scenario

Table 5 left side shading scenario

650w/m ² PV4	650w/m ² PV3	1000w/m ² PV2	1000w/m ² PV1
850w/m ² PV8	450w/m ² PV7	1000w/m ² PV6	1000w/m ² PV5
450w/m ² PV12	650w/m ² PV11	1000w/m ² PV10	1000w/m ² PV9
450w/m ² PV16	650w/m ² PV15	1000w/m ² PV14	1000w/m ² PV13

In this pattern the left side of the field is under shading

- PV8 is shaded at 850w/m²
- PV3 PV4 PV11 PV15 are shaded at 650w/m²
- PV7 PV12 PV16 are shaded at 450w/m²,
- The rest of the modules are exposed to 1000w/m²

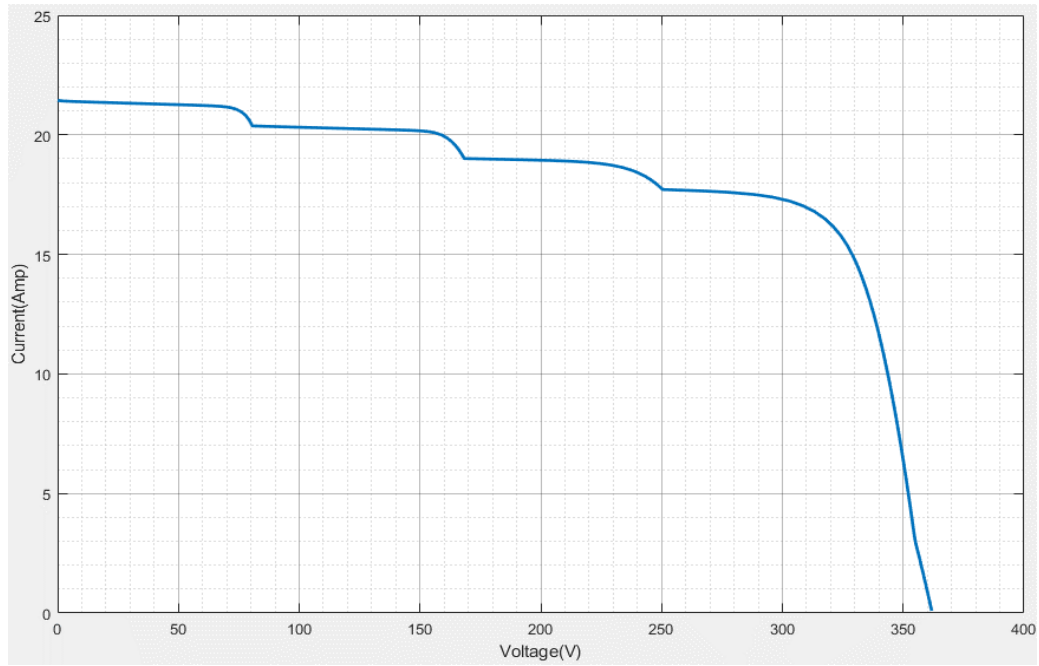


Figure 39. IV curve field left side shading scenario

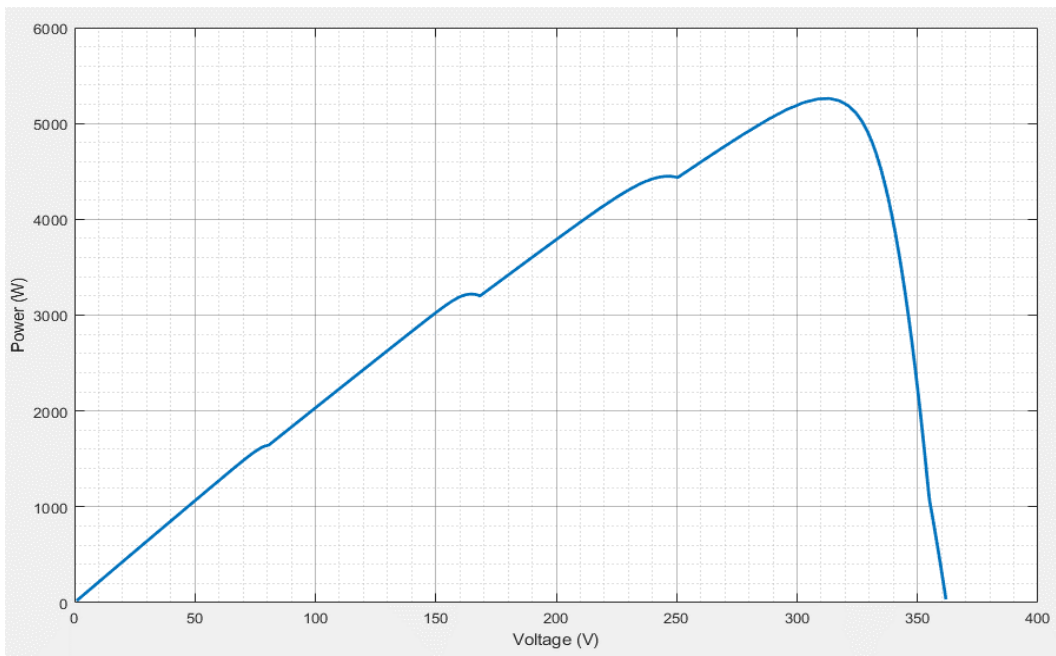


Figure 40. PV curve field left side shading scenario

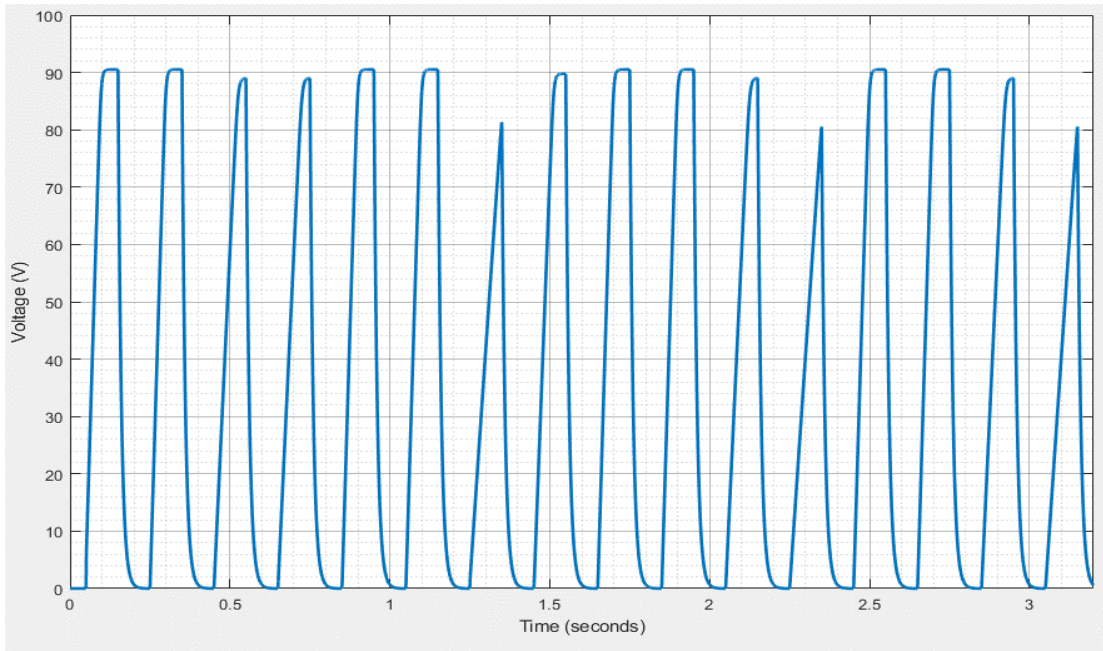


Figure 41. Voltage measurement left side shading scenario

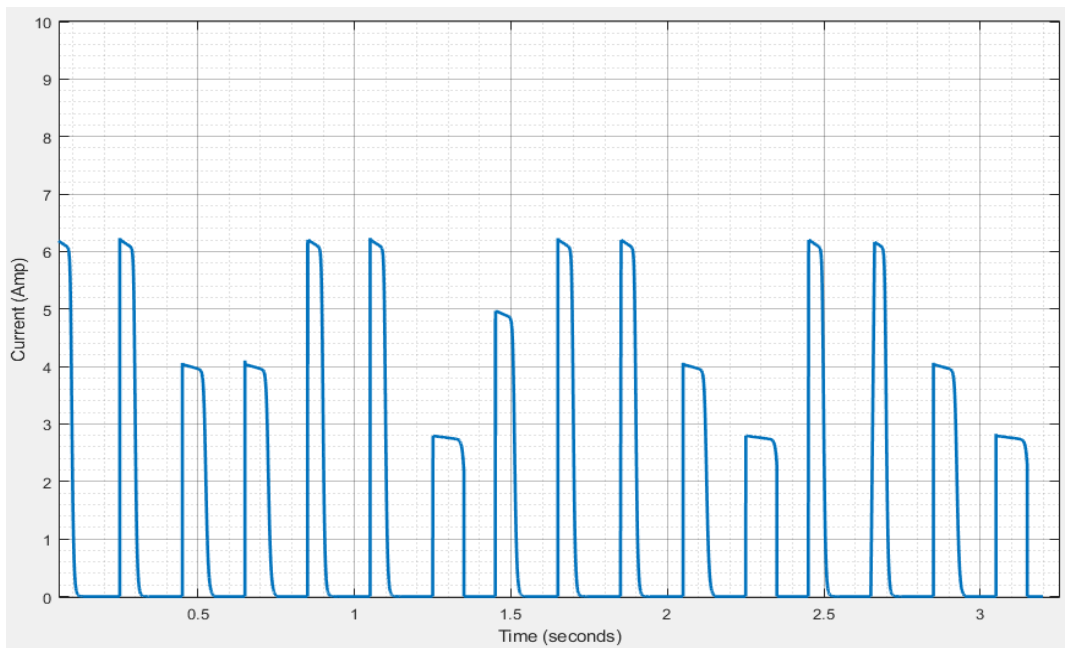


Figure 42. Current measurement left side shading scenario

4.1.4 Right side shading scenario

Table 6. right side shading scenario

1000w/m ² PV4	1000w/m ² PV3	650w/m ² PV2	650w/m ² PV1
1000w/m ² PV8	1000w/m ² PV7	650w/m ² PV6	450w/m ² PV5
1000w/m ² PV12	1000w/m ² PV11	450w/m ² PV10	850w/m ² PV9
1000w/m ² PV16	1000w/m ² PV15	650w/m ² PV14	850w/m ² PV13

The right side of the field is under shading pattern

- PV1 PV2 PV6 PV14 are shaded at 650w/m²
- PV5 PV 10 are shaded at 452w/m²
- PV9 PV 13 are shaded at 850w/m²
- The rest are shaded at 1000w/m²

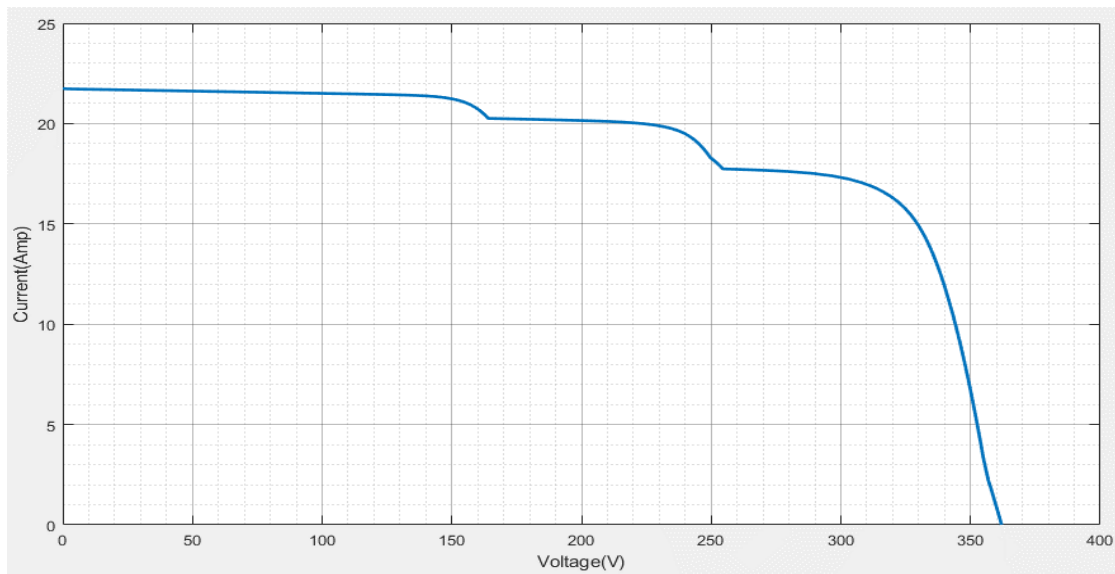


Figure 43. field iv measurement Right side shading scenario

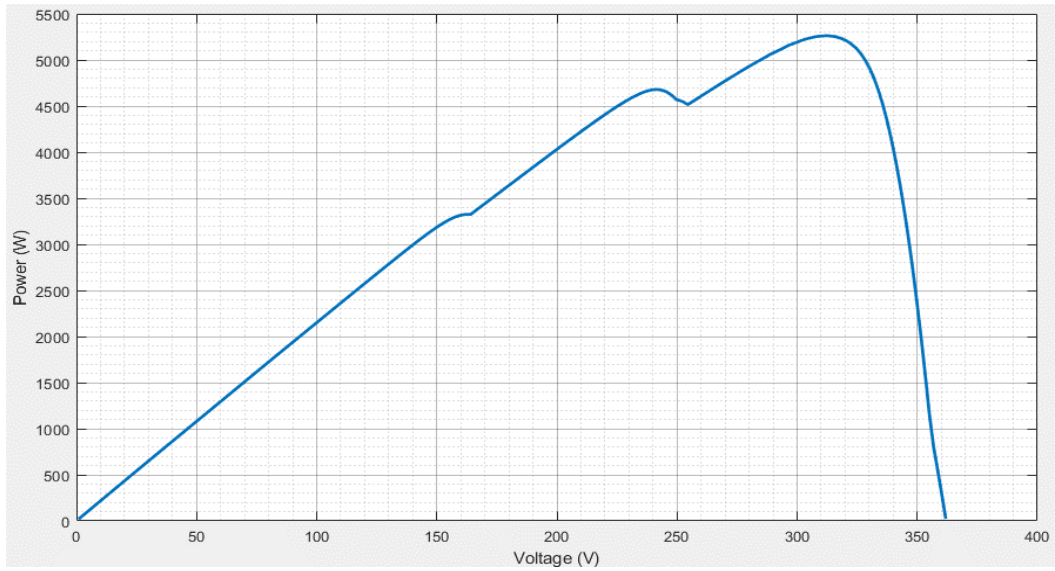


Figure 44. field PV Right side shading scenario

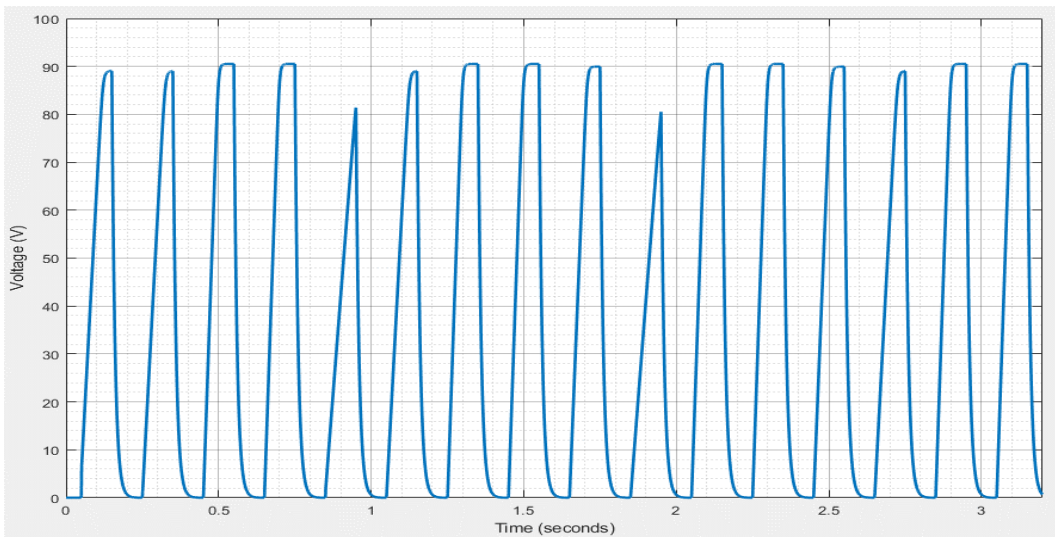


Figure 45. Voltage measurement Right side shading scenario

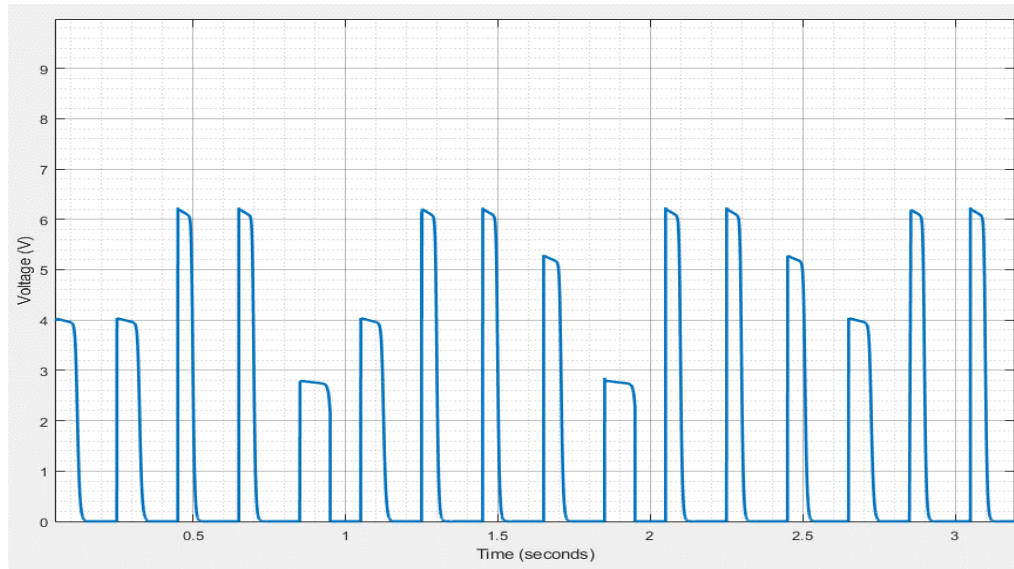


Figure 46. Current measurement Right side shading scenario

From the figure above we can extract each panel characterization, and we can get

4.1.5 Middle shading scenario

Table 7. field middle shading scenario

450w/m ² PV4	650w/m ² PV3	850w/m ² PV2	1000w/m ² PV1
650w/m ² PV8	650w/m ² PV7	650w/m ² PV6	850w/m ² PV5
850w/m ² PV12	650w/m ² PV11	650w/m ² PV10	650w/m ² PV9
1000w/m ² PV16	1000w/m ² PV15	1000w/m ² PV14	1000w/m ² PV13

In this pattern the middle field is under shading

- PV2 PV5 PV12 are shaded at 850w/m²
- PV3PV6PV7PV8 PV9 PV10 PV11 are shaded at 650w/m²
- PV4 is shaded at 450w/m²
- The rest are exposed to 1000w/m²

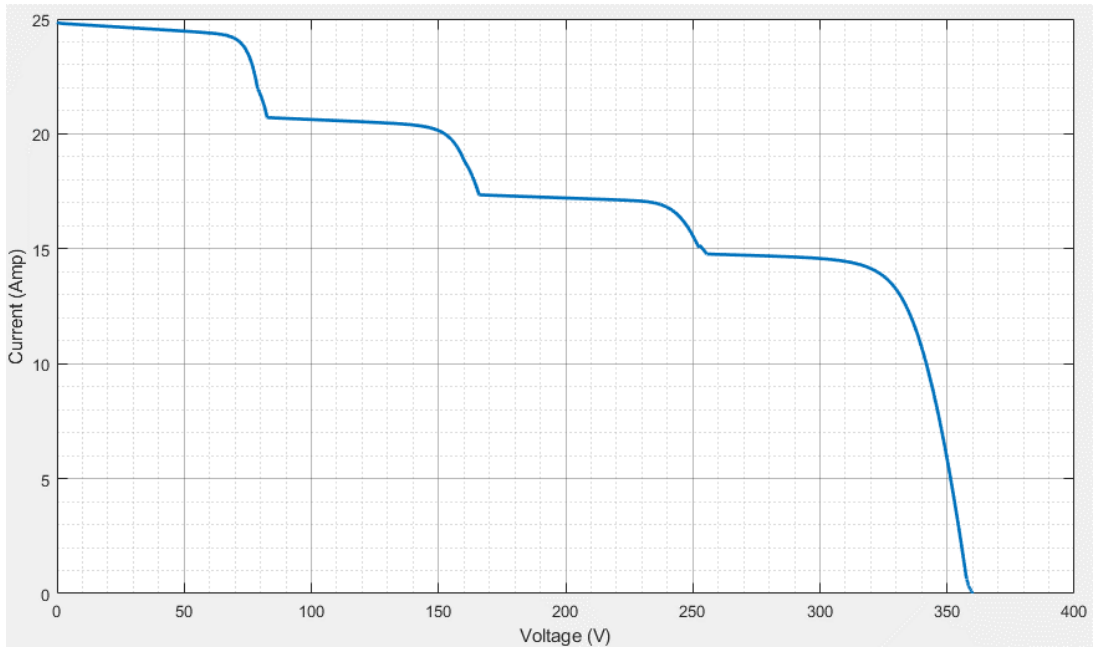


Figure 47. IV curve field middle shading scenario

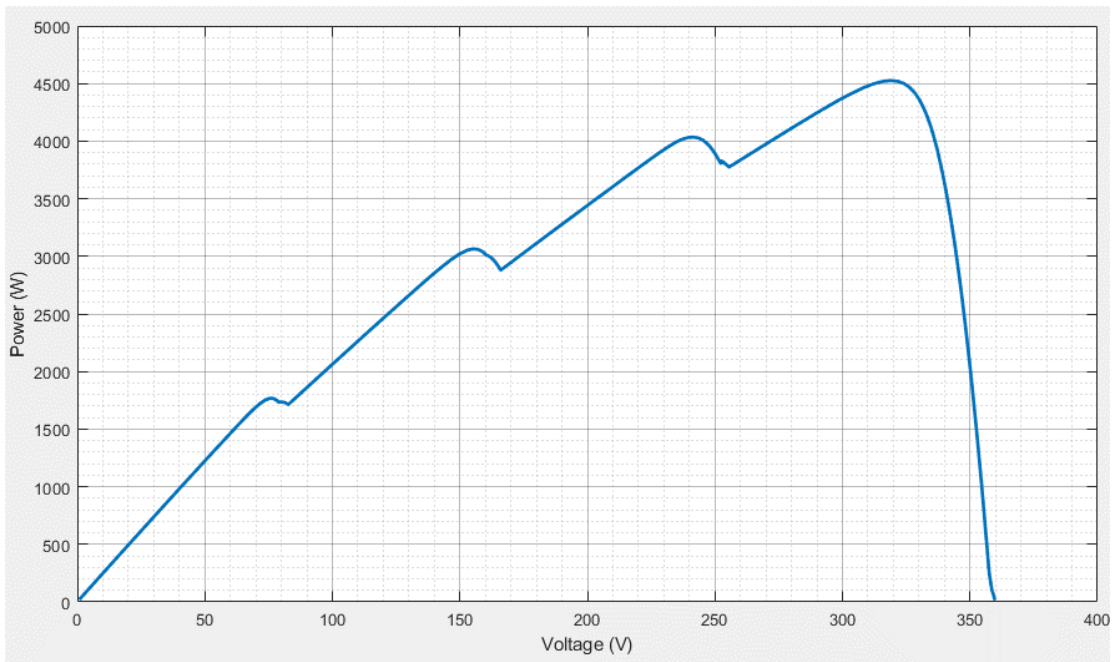


Figure 48. PV curve field middle shading scenario

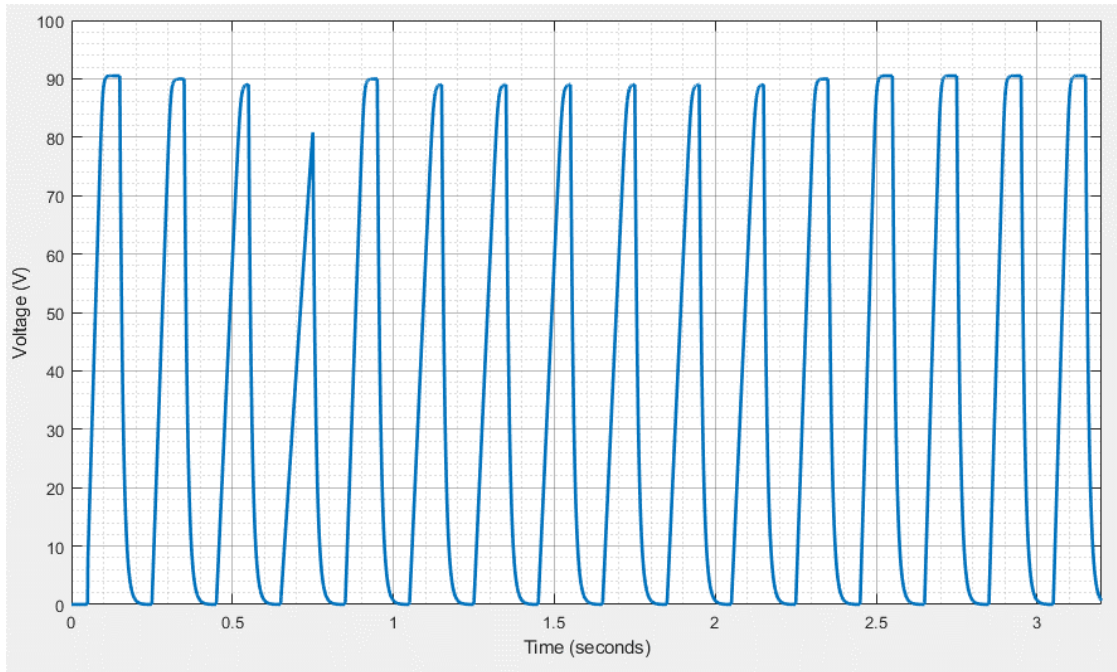


Figure 49. Voltage panels field measurement middle field shading

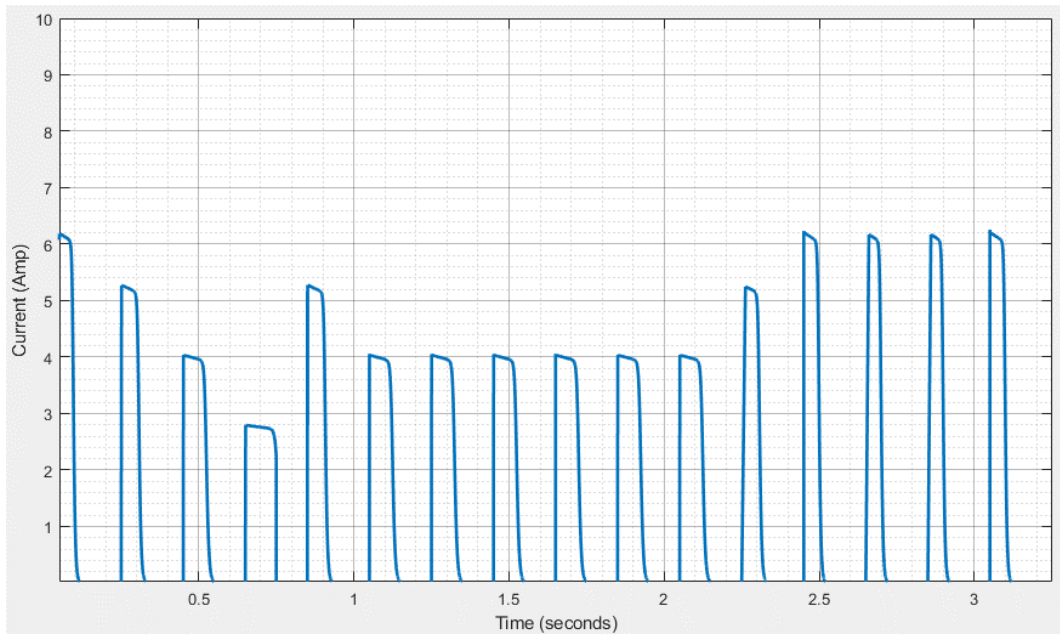


Figure 50. Current panels field measurement middle field shading

From the figure above we can extract each panel characterization, we get

5 Conclusion

In this chapter, we present the simulation and results for the proposed method to get individual characteristic of PV panel connected in a large PV field. First, we presented a two-panel model that enabled us to establish a switching control function for charging and discharging the capacitor of the characterizer.

Then a largest model with different scenario models is used to verify the functional behavior of the proposed method. We have confirmed that the presented method is also efficient for a large PV field.

General Conclusion

The world's constant demand for electric power and the overuse of fossil fuel extraction have led to the search for new methods of electric energy production. Among these processes, photovoltaic solar energy is prominent. Renewable, clean, available and free energy. This also explains its considerable growth in the world.

In this work, we present a new solution for fault detection and diagnostic, it's about PV field characterization, in this solution a switch matrix is used to plot the characteristic of all PV panels individually without disconnecting them from the PV generator.

First, we gave general information on photovoltaics on solar radiation and temperature, the operating principle of a PV cell and their characterization. Following by a studied of different faults that can occur in PV panels and how to detect them using diagnostic methods.

Finally, we simulate a field of 16 panels with an RC load in ideal conditions and shading with each panel; an ideal switch is used to isolate them in the field and other switches in the load to charge and discharge the capacitor to extract the characterization of each panel in different conditions.

A command function is conceived to open and close the needed switches in a specific order and time throw the simulation process. This is done to extract the characteristic of each solar panel.

Keywords: Photovoltaic Field, Photovoltaic Characterization, Capacitive IV tracer, Multi-output IV Tracer

Abstract

In this thesis, we presented a multi-output characterizer using a capacitive load. This technique allows us to individually characterize PV panels connected together in a large PV field. This is carried out under different radiation conditions, to test the effectiveness of this method we applied several shading scenarios on the simulated field, and we observed the behavior of the panels and the observable changes on the characteristic of each PV module.

Résumé

Dans ce mémoire nous avons présenté un caractériser multi sortie en utilisant une charge capacitive. Cette technique nous permet de caractériser individuellement des panneaux connectés ensemble dans un champ de panneaux solaire. Ceci est réalisé dans différents conditions de rayonnement, pour tester l'efficacité de cette méthode nous avons appliqué plusieurs scénarios d'ombrage sur le champ simulé, et nous avons observé les comportements des panneaux et les changements observables sur la caractéristique de chaque module PV.

ملخص

في هذه الرسالة ، قدمنا أداة خصائص متعددة المخرجات باستخدام حمولة سعويه. تسمح لنا بتمييز الألواح الفردية في حقل الألواح الشمسية في ظروف إشعاع مختلفة، ونطبق سيناريوهات التظليل في هذا الحقل ونلاحظ سلوك الألواح وتأثير التظليل في أداء مجال الألواح الشمسية