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THEME

Extremum seeking control for maximum power point tracking of PV systems

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ملخص

تستخدم الأنظمة الكهروضوئية على نطاق واسع في الوقت الحاضر كمصدر بديل لتوليد الكهرباء. وهي تتألف من الألواح الشمسية، البطاريات، المحولات، العاكسات وأقصى نقطة تعقب للطاقة (MPPT) و وحدة تحكم للشحن الشمسي. (MPPT) هي عناصر التثبيت التي تعطي الطاقة القصوى. كما أنها حجج تسويقية رئيسية للأعمال التجارية. تعمل هيئة تنظيم (MPPT) على تحسين تشغيل نظام كهربائي مستقل. لذلك، هذه طريقة تستعمل لزيادة توفير الطاقة. حيث يقوم منظم (MPPT) بمسح الجهد الكهربائي الذي تنتجه اللوحة الكهروضوئية عدة مرات في اليوم والغرض منه هو العثور على أقصى نقطة إخراج من التيار الذي توفره اللوحة. ثم تتأكد من استخدام دائم لهذه القوة وبالكامل. باختصار، تستمد وحدة تحكم الشحن (MPPT) أقصى قدر من الطاقة من اللوحة بجعل التثبيت ذكيا. ويقترح عدة طرق للوصول إلى هذه النقطة القصوى مثل حالات اضطراب ومراقبة وتسلق التل والذكاء الاصطناعي وغيرها. ومع ذلك، فإنها تعاني دائما من عيوب خاصة في حالة الأيام الملبدة بالغيوم. وبالتالي، نقترح في هذا العمل نظام السعي لأقصى تحكم (ESC) من أجل تتبع أقصى قدر من الطاقة المولدة من الأنظمة الكهروضوئية. ESC هو نوع من التحكم التكيفي الذي يمكن أن يدفع ويحافظ على مدخلات ومخرجات النظام الخاضع للرقابة إلى أقصى الحدود الخاصة بهم. وستعطى محاكاة كاملة في Matlab لنظام الكهروضوئية الذي يتحكم فيه (ESC) بالتفصيل وسيتم مناقشة نتائج المحاكاة.

كلمات مفتاحية: الأنظمة الكهروضوئية، أقصى نقطة تعقب للطاقة(MPPT) ، نظام السعي لأقصى تحكم (ESC)، Matlab.

Abstract

Photovoltaic systems are used widely nowadays as alternative source for generating electricity. They are composed of Solar panels, battery, converters, inverters and maximum power point tracker MPPT solar charge controller. MPPT are the elements of an installation that give real energy freedom. They are also major marketing arguments for a business today. The MPPT regulator optimizes the operation of an autonomous electrical system. So, this is a way to increase energy savings. The MPPT regulator scans the electrical voltage produced by the photovoltaic panel several times a day. Its purpose is to find the maximum output point of the current supplied by the panel. Then make sure to always use this full power. In short, the MPPT charge controller derives maximum power from the panel. It makes an installation intelligent. Several methods are proposed to reach this maximum power point such as perturb and observe, hill climbing, artificial intelligence and others. However, they always suffer from drawbacks especially in the case of cloudy days. Hence, we propose in this work an extremum seeking control (ESC) in order to track the maximum power generated from a photovoltaic system. ESC is a kind of adaptive control which can drive and maintain the input and output of the controlled object to their respective extrema. A full simulation in Matlab of a PV system controlled by ESC will be given in detailed and simulation results will be discussed.

Keywords: Extremum seeking control (ESC), Matlab, Maximum power point tracker (MPPT), Photovoltaic systems.

Résumé

Les systèmes Photovoltaïques sont utilisés largement maintenant comme une source alternative pour la production de l'électricité. Ils sont composés par : les panneaux solaires, les batteries, les convertisseurs, les onduleurs, et le un contrôleur de charge solaire avec un traqueur de point de puissance maximale (MPPT). MPPT sont les éléments de l'installation qui donne une vraie liberté énergétique. Aussi, Aujourd'hui ils sont des principaux arguments marketing pour une entreprise. Le régulateur MPPT optimise le fonctionnement d'un système électrique autonome, c'est donc un moyen d'augmenter les économies d'énergie. le régulateur MPPT scanne la tension électrique produite par le panneau photovoltaïque plusieurs fois par jour. Son but est de trouver le point de sortie maximum du courant fourni par le panneau Alors toujours assurez-vous d'utiliser cette pleine puissance. En bref le contrôleur de charge MPPT tire la puissance maximale du panneau cela rend une installation intelligente. Plusieurs méthodes sont proposées pour atteindre ce point de puissance maximale point tel que perturber et observer, escalade, intelligence artificielle et autres. Mais toujours ils souffrent d'inconvénients surtout en cas de jours nuageux. C'est pourquoi nous proposons dans ce travail un contrôleur chercher d'extremum (ESC) afin de suivre la puissance maximale générée à partir d'un système photovoltaïque. Le contrôleur chercher d'extremum est un sort de contrôle adaptatif qui peut piloter et maintenir l'entrée et la sortie de l'objet contrôlé à leurs extrême respectifs. Une simulation complète en Matlab d'un système PV contrôlé par ESC sera détaillé et les résultats de la simulation seront discutés.

Mots clés: Contrôleur chercher d'extremum (ESC), Matlab, Systèmes Photovoltaïques (PV) , Traqueur de Point de Puissance Maximale (MPPT).

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BAOUCHI Slimane

HAMAMA Aicha

It is great pleasure to dedicate this modest work to:

My mother **Fatma ben choula** who is the dearest person in m'y life.

To m'y beloved, m'y father **Hamama Lazhari**, may God have mercy on him.

To m'y dear brothers, sisters, and everyone holds a place in m'y family and to everyone named "**Hamama**"

Also I dedicate this work to anyone participated in m'y success.

Hamama Aicha

I dedicate this modest work

To my dearest Mother, who was always at my side

To my father and my brothers and sisters,

To all my friends who I shared the best moment of my life,

And to all those who have helped me near or far.

Slimane BAOUCHI

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List of Abbreviation

T: Temperature (K)

Tc: Cell Temperature (K)

E: Energy (j)

G: Solar irradiation (w/m^2)

ρ: Density (kg/m^3)

σ : Stefan-Boltzmann Constant

α: Altitude Angle

z: Azimuth Angle

Φ: Zenith Angle

Isc: Short Circuit Current (A/K).

P: Power (W)

V: Voltage(v)

Vc: Voltage Across diode (V)

Vin: Input Voltage

Vout: Output Voltage

V_{MPP}: MPP Voltage

V_{OC}: Open-Circuit Voltage

V_{PV}: PV Voltage

I_0: Saturation Current (A)

I: Current(A)

I ref: Reference Currant

I-V: Current-Voltage

P-V: Power-Voltage

R: Resistance (Ω)

Rs: Series Resistance (Ω)

Rp: Shunt Resistance (Ω)

MeV: Mega electron-Volt

CdTe: Cadmium Telluride (solar cell)

CdS: Cadmium Sulfide (solar cell)

a-Si: Amorphous silicon (solar cell)

c-si: Crystalline silicon

0.7 R: Convective Zone

ε: The emissivity of the surface

η: Diode ideal factor

e: electron charge (1.602×10– 19C)

k: Boltzmann constant

List of acronyms

PV: Photovoltaic

MPPT: Maximum Power Point Tracker

MPP: Maximum Power Point

GHG: Green House Gases

DSSC: Dye Sensitized Solar Cells

CIGS: Copper Indium Gallium Selenide (solar cell)

DC: Direct Current

AC: Alternative Current

PWM: Pulse-Width Modulation

LPSP: Loss of Power Supply Probability.

P&O: Perturbation and Observation

INC: Incremental Conductance

ANN: Artificial Neural Networks

HC: Hill-Climbing

CV: Constant-Voltage

MOSFET: the SiC Metal-Oxide-Field-Effect Transistor

DSP: Digital Signal Processing

General Introduction

General Introduction

Currently, the production of domestic and industrial energy is based, to a large extent part, on a limited resource: oil. The sources of oil are becoming more and more scarce, while the world's energy demands are continually rising. It is estimated that world reserves will be exhausted by 2030 if consumption is not radically modified, and at most around 2100 if efforts are made on the production and consumption. Since this form of energy covers a large part of the production energy, it is necessary to find another solution to take over, the imposed constraint is to use an economical and low-polluting energy source because the environmental protection has become an important point [1].

The search for alternative energy resources has therefore become a crucial issue of These days. Much scientific research has been carried out, not only in the field nuclear energy production, but also in the energy sources sector unlimited, such as wind power generation and solar energy transformation [2]. In the latter case, the design, optimization and implementation of the photovoltaics systems are topical issues since they surely lead to better harnessing solar energy. For a photovoltaic installation, the 50% variation of the lighting or the load induces a degradation of the power supplied by the PV generator around 50%; in addition, the PV generator no longer operates in optimum conditions [3]. Moreover, these electricity-generating photovoltaic systems can be operated in different places: electrification of isolated sites, installation in buildings or direct connection to the electricity network, ... However, a main problem of PV systems is the output power. Generally, the output generated power by PV systems is not always reached. Hence, a control method in order to track the maximum power is needed. Hence, it is necessary to analyse and test these tracking methods called MPPT in order to get the highest possible output power delivered by the PV system.

In this context, our work consists of designing, modelling and building a small power PV system operating in continuous mode under optimal conditions. Regardless of weather conditions and load variation. we will present the results concerning the design and modelling, in the Matlab/Simulink environment, of a PV system whose operation is regulated by an MPPT control. More specifically, we are designing a photovoltaic system (PV generator, DC-DC energy converter and connected load), adapted by extremum seeking MPPT control, this control is characterized by its simplicity of realization and its low cost compared to other MPPT methods. In addition, it could operate at high switching frequencies.

To this end, our dissertation is organized as follows;

In the first chapter, overall background about renewable energy presenting some basic definitions and useful general information about solar radiation in particular coordinate systems, as well as a general description of photovoltaic panels including their mathematical modelling.

The second chapter gives general description of photovoltaic systems including a full review of the existing maximum peak power tracking control methods.

The third chapter, is devoted to the simulation results of implementation of the proposed maximum seeking control algorithm in order to maximise the output power,

At the end this work, a general conclusion is then given as well as some recommendations for the present work and the future development.

Chapter I

Fundamental of PV systems

I.1 Introduction

As the earth natural resources are decreasing day by day, to meet the increase in the power demand, the power sector is looking at alternate energy resources. Due to usage of renewable energy sources, the carbon content in the atmosphere can be reduced by which global warming problem can be overcome. Out of various renewable sources, solar PV system is leading nowadays due to its simple structure. In this chapter, we will present the various structure of PV panel system as well as its principal working.

I..2 Solar energy

Solar energy from the Sun gives life to human beings and all living organism on planet Earth. The existence of an atmosphere with greenhouse gases (GHG) between the Sun and the Earth is responsible for the survival of human beings in the terrestrial region. The Sun is responsible for all renewable energy sources on Earth, which meet the needs of human being. Solar radiation is treated as an electromagnetic wave with wavelength between 0.30 and 3 μm as well as photons in a visible wave length [1].

I.2.1 Sun

The source of solar energy is the Sun, which is the largest member of the solar system with other members revolving around it. The Sun, having a diameter of 1.39×10^9 m, is at an average distance of 1.5×10^{11} m from the Earth. It is a sphere of intensely hot gaseous matter. The Sun rotates on its axis approximately once every 4 weeks.

It is known that 90 % of the Sun’s energy is generated in a spherical region having a radius 0.23 times the Sun’s radius. The average density (ρ) and the temperature (T) in this region are 10^5 3 kg/m^3 and approximately $(8\text{-}40) \times 10^6$ K, respectively. Energy generated in the region is due to several fusion reactions. In fusion, two hydrogen molecules (i.e., four protons) combine to form one helium nucleus at approximately 10^7 K. The mass of the helium nucleus is less than that of four protons. The mass, having been lost in the reaction, is converted into energy by the relation given by Einstein, i.e., $E = mc^2$. The fusion reaction is given by

$$H_2 + H_2 = He + 25\ \text{MeV} \qquad \text{Eq. (I.1)}$$

The produced energy ($E=mc^2$) is transferred to the outer surface of the Sun by convection. The temperature and the density drop, respectively, to approximately 1.3×10^5 k from the centre to 0.7 R. Therefore, in the region beyond 0.7 R, convection dominates the heat transfer; hence, the region from 0.7 R to R is termed the "convective zone." The outer layer of the convective zone is known as the "photosphere."

The periphery of the photosphere has low density. Above the photosphere there is a layer of cooler gases called the "reversing layer." Outside the reversing layer, there is a layer referred to as the "chromosphere." The Sun has an effective black-body temperature of 5777 K (~6000K).

Solar energy is radiated into space, which is calculated using the following formula:

$$E = \varepsilon \, \sigma \, T_s^4 \qquad \text{Eq. (I.2)}$$

ε and σ are, respectively, the emissivity of the surface and the Stefan-Boltzmann constant.

Solar energy from the Sun can be classified as a heat (electromagnetic waves) and light (photons), respectively. Basically, the Sun is responsible to produce directly most of the renewable energy sources (Fig. I.1). It is also responsible for providing indirect sustenance for non-renewable sources such as fossil fuels. Fossil fuels are actually solar energy stored millions and millions of years ago [1].

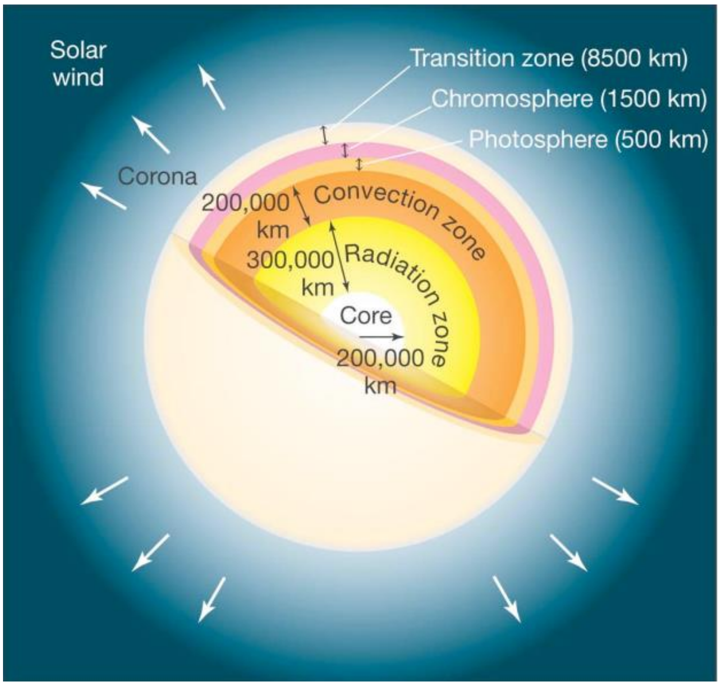

Fig. I.1 The structure of the Sun [2].

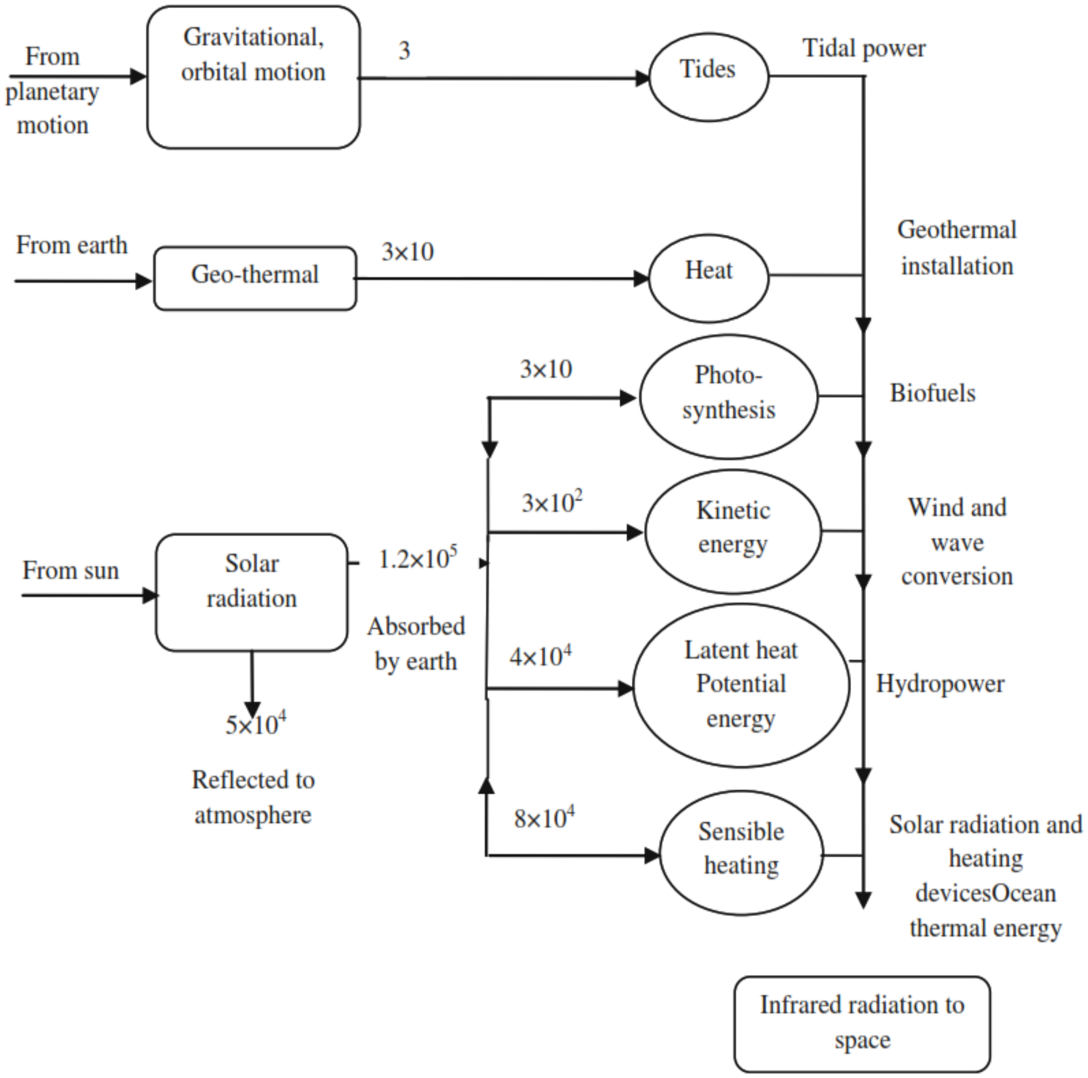

Fig. I.2 Continuous flow of natural energy as renewable energy on the Earth. Units, terawatts (1012W) [1].

I.2.2 Solar geometrics

When designing any type of system that relies on solar radiation, it is important to take into consideration the seasonal and hourly changes in position of the sun. This has a direct influence on the incident angle of sunlight.

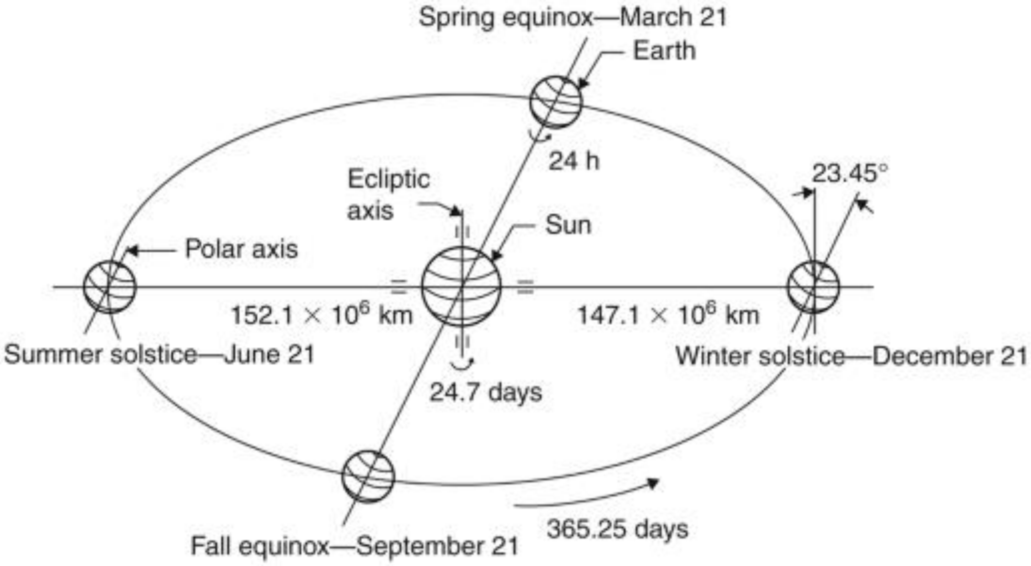

Fig. I.3 Annual motion of the earth about the sun.

- **Solar Zenith Angle**

The solar zenith angle is the angle between the sun's rays and the vertical direction

$$\cos \theta o = \sin\varphi \sin \delta + \cos\varphi \cos \delta \cos h \qquad \text{Eq (I.3)}$$

δ is the solar declination angle

- **Solar Azimuth Angle**

The solar azimuth angle z is the angle of the sun's rays measured in the horizontal plane from south

The solar azimuth angle (φ_o) is calculated as:

$$\sin \phi_0 = \frac{\sin (h-\lambda)}{sin\beta_0} \qquad \text{Eq (I.4)}$$

Where: $$\cos\beta o = \cos(\varphi) \cos (\lambda - \lambda s) \qquad \text{Eq (I.5)}$$

- **Solar Declination Angle**

It is the angle between the sun – earth centre line and the projection of this line on the equatorial plane.

δ is the solar declination angle and varies from -23.45 deg to +23.45 deg through the year and can be approximated as:

$$\delta = -23.45 COS\left(\frac{2\pi J}{365} + \frac{20\pi}{365}\right) \qquad \text{Eq (I.6)}$$

Where J is the day of the year.

- **Solar Hour Angle**

The hour angle h, of a point on the earth's surface is defined as the angle through which the earth would turn to bring the meridian of the point directly under the sun [2].

The hour angle (h) is defined as the longitude of the sun, which is calculated as:

$$h = -\frac{t-12}{12} \qquad \text{Eq (I.7)}$$

where t is the fractional GMT time (e.g., for hh:mm:ss then t = hh + mm/60. + ss/3600.)

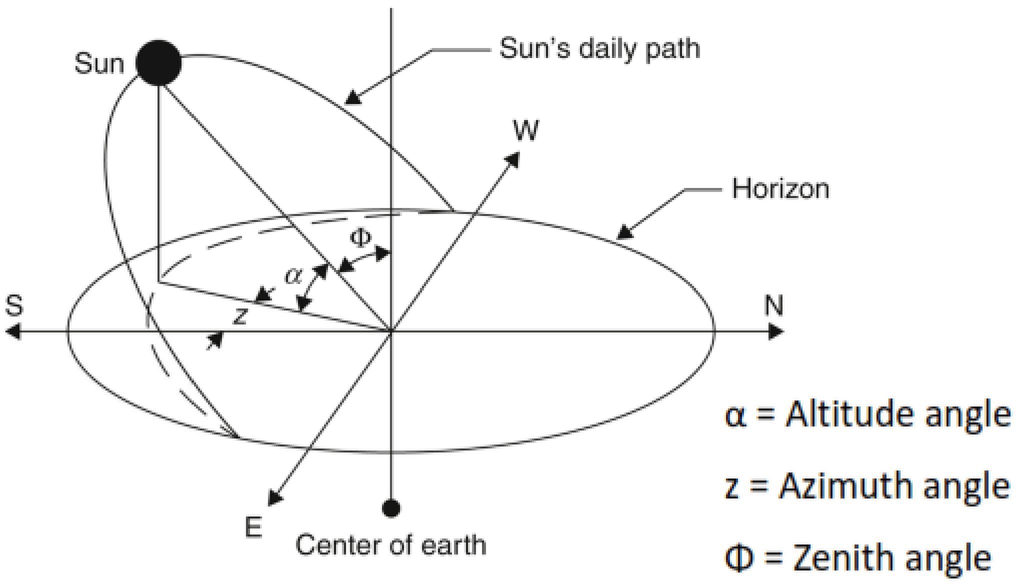

Fig. I.4 Position of the sun in the sky [2].

I.2.3 Extra-terrestrial solar radiation

The region between the Sun and atmosphere is known as the "extra-terrestrial region." its identified as the area between the atmosphere and the Earth.

Half of the Earth is lit by short wavelength sunlight at a time. The Earth constantly spins around its axis. The inclined axis (at approximately 23.5°) of the Earth causes variable lengths of day and night. Solar radiation coming from the Sun is reflected back to space from the Earth (approximately 4 %) and its atmosphere (26 %). The amount of radiation reflected back to space is known as "albedo." The amount of albedo depends on type of soil, plantation cover over the Earth's surface, and cloud distribution [1].

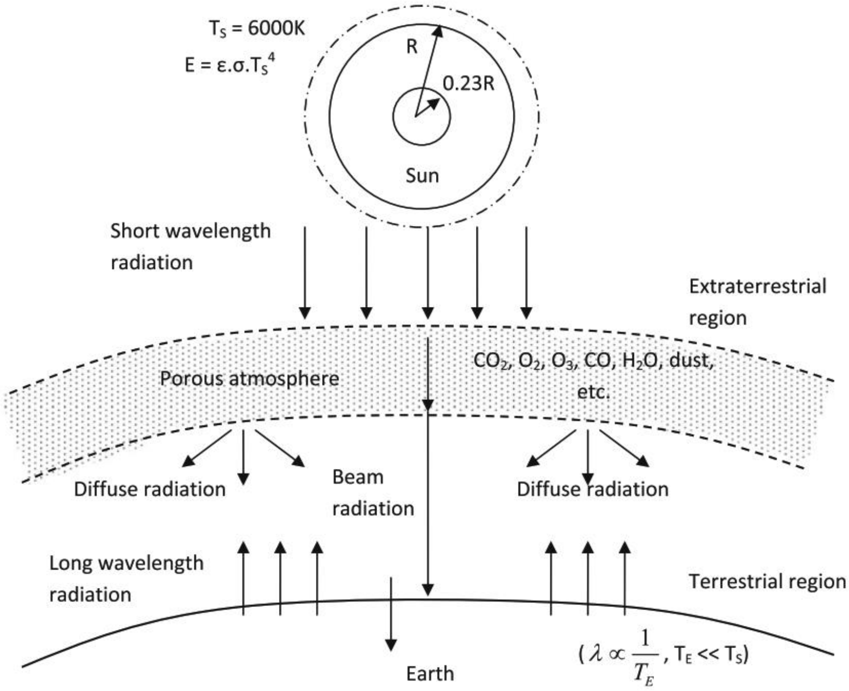

Fig. I.5 View of the atmosphere between the Sun and the Earth [1].

I.2.4 Solar radiation at ground level

The different extinction processes provoke that not all radiation that reaches the Earth atmosphere reaches the ground. Actually, only about 52% hits the Earth's surface. Additionally, scattering provokes that a part of the radiation, that reaches the ground level, Atmospheric absorption is also a process of radiation extinction which reduces the available solar radiation at the Earth's surface considerably [3].

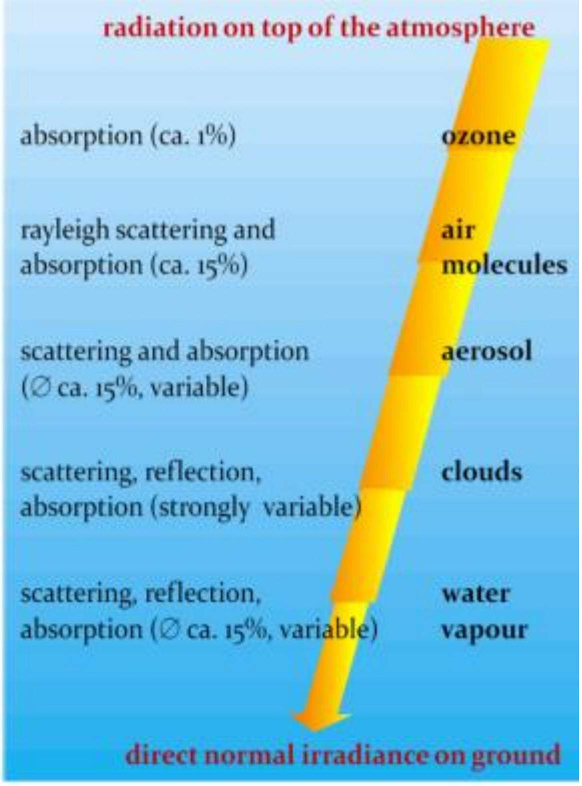

Fig. I.6 Radiation reduction through atmospheric extinction processes [3].

Solar radiations while passing through the Earth's atmosphere are subjected to the mechanisms of atmospheric absorption and scattering (diffusion) or reflection.

I.2.4.1 Absorption

As solar radiation passes through the atmosphere, gasses, dust and aerosols absorb the incident photons. Specific gasses, notably ozone (O_3), carbon dioxide (CO_2), and water vapor (H_2O), have very high absorption of photons that have energies close to the bond energies of these atmospheric gases [4].

I.2.4.2 Reflection

Reflected radiation. It depends on the ground reflectivity. As we know, it varies considerably being much higher at fresh snow than at a green meadow [4].

I.2.4.3 Diffusion

Atmospheric scattering can be either due to the molecules of atmospheric gases or due to smoke, haze, and fumes. One of the mechanisms for light scattering in the atmosphere is known as Rayleigh scattering, which is caused by molecules in the atmosphere. Rayleigh scattering is particularly effective for short wavelength light (that is, blue light). Beside Rayleigh scattering, aerosols and dust particles contribute to the scattering of incident light known as Mie scattering [5].

I.2.5 Solar measurements

I.2.5.1 pyranometer-pyrheliometer

Determination of solar irradiance on tilted surfaces typically starts from measurements in the horizontal plane. Solar radiation is commonly measured by two main classes of instruments: pyrheliometers and pyranometers. A pyrheliometer measures solar radiation coming directly from the Sun and a small portion of the sky around the Sun at normal incidence. In this device sunlight typically enters through a window to a thermopile (a device that converts heat to electricity). The electrical signal that is generated can be recorded and converted into W/m^2. The window of the pyrheliometer acts as a filter that only lets through sunlight in the 0.3-3 µm range.

The pyranometer measures total hemispherical (diffuse plus beam) solar radiation, usually on the horizontal plane. This means that the device must give an unbiased response to radiation from all directions. It consists of a thermopile sensor that is horizontally oriented and a glass dome that limits the wavelength range, as in the pyrheliometer. The glass dome preserves the 180◦ view and shields the thermopile from air convection. Schematic illustrations of a pyranometer and a pyrheliometer are shown in Fig. I.7 [6].

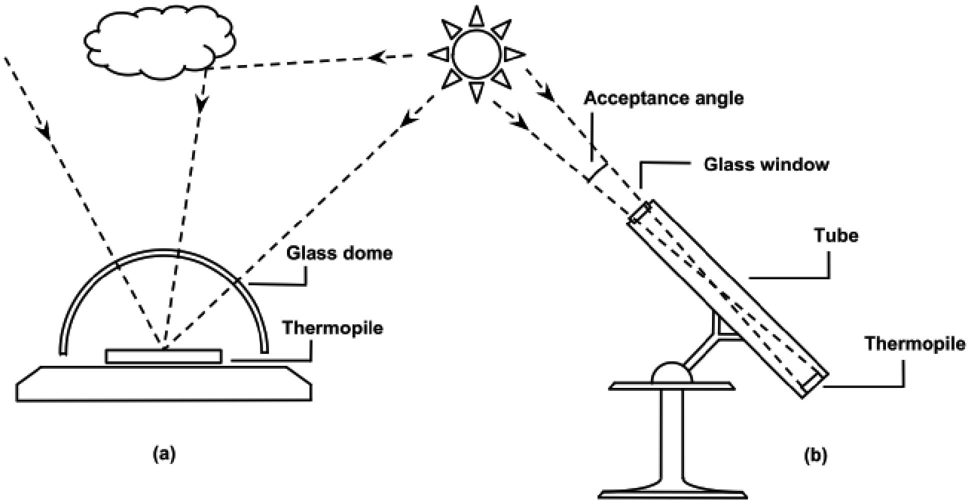

Fig. I.7 (a) Schematic illustration of a pyranometer, and (b) a pyrheliometer [6].

I.2.5.2 Sunshine Recorder

Sunshine recorders are used to indicate the amount of sunshine at a given location. The results are used to provide information on the climate of an area and some of the fields, they are divided into two groups. In the first group the time of the occurrence of the event is provided by the Sun itself and in the second a clock-type device is used to provide the time scale. The older type of recorder required the interpretation of the results by an observer and these may have differed from one person to another. Today, with the use of electronics and computers, it is possible to record the sunshine duration that does not rely on an observer's interpretation. At the same time the newer recorders can also measure the global and diffuse radiation.

A sunshine recorder consists of a glass sphere mounted in a section of a spherical brass bowl with grooves for holding the recorder cards. The sphere burns a trace on the card when exposed to the Sun, the length of the trace being a direct measure of the duration of bright sunshine. There are sets of grooves for taking three sets of cards: long curved for summer, short curved for winter and straight cards at equinoxes [5].

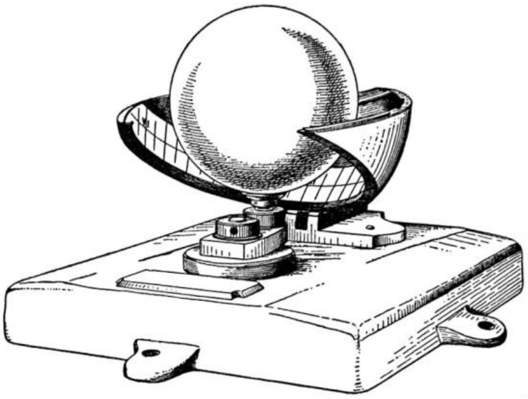

Fig. I.8 Sunshine recorder.

I.2.6 Sunshine duration

Solar time is recognized when the Sun reaches its highest point (when it just crosses the meridian), at noon. The next day, when the Sun again crosses the meridian, it is again noon. The time that elapses between successive noon's is important. Sometimes it is more and sometimes less than 24 hours of clock time. In the middle months of the year, the day length is close to 24 hours, but around 15 September the days are only some 23 hours, 59 minutes and 40 seconds long. Around Christmas the days are 24 hours and 20 seconds long. Clock time recognized each day is exactly 24 hours long, which is not actually true. But it is obviously much more convenient to have a clock time which takes exactly 24 hours for each day because mechanical clocks and watches (and more recently electronics) can be made to measure these exactly equal time intervals. Obviously, these small differences in the lengths of days produce larger differences between solar and clock time. These differences reach a peak of just over 14 minutes in mid-February, when solar time is slower relative to clock time. It reaches just over 16 minutes at the beginning of November when solar time is fast relative to clock time. There are also two minor peaks: first in mid-May, when solar time is nearly 4 minutes fast, and second in late July, when solar time is just over 6 minutes slow. These minor peaks contribute towards the fortunate effect in the northern hemisphere. The differences are relatively small during most of the months when there is a reasonable amount of sunshine [5].

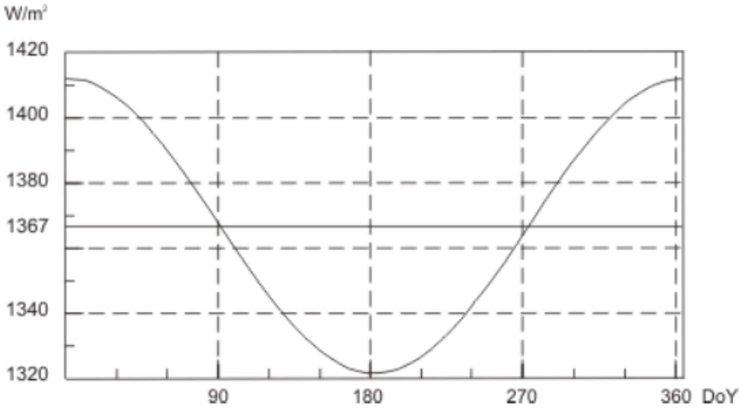

Fig. I.9 Annual variation of the extra-terrestrial irradiance at normal incidence due to the varying Sun-Earth distance [1].

I.3 Solar panels

I.3.1 History

Solar energy and utilizing solar power from the sun has been something people have used for thousands of years, from cavemen using solar power to start fires, to today, where there are planes, cars, homes, and businesses powered with solar energy.

The photovoltaic effect, which is the voltage that comes when a material is exposed to light, was discovered in 1839 by Edmond Becquerel, who was only 19 years old at the time, but made a definite impact in the solar energy of today.

In 1873 photoconductivity was discovered in selenium by Willoughby Smith, an English engineer, and a few years later Professor William Grylls Adams, with his student, Richard Evans Day, built upon Smith’s discovery and observed the electricity that is created when a material was exposed to light through an electric current.

The first photovoltaic cell design was created in 1883 by Charles Fritts, an American inventor, who created the cell design using selenium wafers.

Solar energy today is being used for everything from reducing electrical costs for residential homes to helping those in agricultural and other business entities. Using this natural source of power both saves the environment, unlike other energy sources, and also allows people to use this never-ending source of power for the rest of their lives [7].

I.3.2 Technology

Solar cells are usually divided into three main categories called generations up to recent years. The first generation contains solar cells that are relatively expensive to produce, and have a low efficiency. The second generation contains types of solar cells that have an even lower efficiency, but are much cheaper to produce, such that the cost per watt is lower than in first generation cells. The term third generation is used about cells that are very efficient. Most technologies in this generation are not yet commercial, but there is a lot of research going on in this area. The goal is to make third generation solar cells cheap to produce.

Efficiency of the 1st generation solar cells lab-based efficiency was 24.7% and module based 22.7%. 2nd generation solar cells lab-based efficiency 18.4% and module based 13.4%. 3rd generation solar cells have very high efficiency >30% [8].

I.3.3 Generation of PV panels

I.3.3.1 First generation

Solar cells include a. Single Crystal Solar Cells b. Multi Crystal Solar Cells. This are the oldest and the mostly commonly used technology type due to high efficiencies. 1st generation solar cells are produced on wafers. Each wafer can supply 2-3 watt-power. To increase power, solar modules, which consist of many cells, are used. As seen in the list, generally there are two types of first-generation solar cells. They differ by their crystallization levels. If the whole wafer is only one crystal, it is called single crystal solar cell. If wafer consist of crystal grains, it is called multi-crystal solar cell. Anyone can see the boundaries between grains on the solar cell. Although efficiency of mono crystal solar cells is higher than multi-crystal solar cells, production of multi-crystal wafer is easier and cheaper. so, they are competitive with mono-crystals [8].

I.3.3.2 Second generation

Solar cells focused on a. a-Si thin film solar cells b. mc-Si solar cells c. CdTe solar cells d. CIS and CIGS solar cells. Their efficiencies are less than 1st generation, their costs are also less than 1st generation. In addition, they have an advantage in visual aesthetic. Since there are no fingers in front of the thin film solar cells for metallization, they are much more applicable on windows, cars, building integrations etc. These thin films can also be grown on flexible substrates. As an advantage of thin film solar cells, they can be growth on large areas up to 6 m^2. However, wafer based solar cell can be only produced on wafer dimensions. The second-generation solar cells include amorphous Si (a-Si) based thin films solar cells, Cadmium

Telluride/Cadmium Sulfide (CdTe/CdS) solar cells and Copper Indium Gallium Selenide (CIGS) solar cells.

I.3.3.3 Third generation

Solar cells considered a. Nanocrystal based solar cells b. Polymer based solar cells c. Dye sensitized solar cells d. concentrated solar cells. These are the novel technologies which are promising but not commercially proven yet. Most developed 3rd generation solar cell types are dye sensitized and concentrated solar cell. Dye sensitized solar cells (DSSC) are based on dye molecules between electrodes. Electron hole pairs occur in dye molecules and transported through TiO_2 nanoparticles. Although their efficiency is very low, their cost is also very low. Their production is easy with respect to other technologies. Dye sensitized solar cells can have variable colours [8].

I.3.4 Structure of a solar cell

A typical solar cell is a multi-layered unit consisting as shown in Fig. I.10 of:

- **Cover**: a clear glass or plastic layer that provides outer protection from the elements. Transparent Adhesive - holds the glass to the rest of the solar cell;
- **Anti-reflective Coating**: this substance is designed to prevent the light that strikes the cell from bouncing off so that the maximum energy is absorbed into the cell;
- **Front Contact**: transmits the electric current;
- **Back Contact**: transmits the electric current;
- **N-Type Semiconductor Layer**: is often formed from Silicon and a small amount of Phosphorus. Phosphorus gives the layer an excess of electrons and therefore has a negative character. The n-layer is not a charged layer, it has an equal number of protons and electrons, but some of the electrons are not held tightly to the atoms and are free to move;
- **P-Type Semiconductor Layer**: is formed from Silicon and Boron and gives the layer a positive character because it has a tendency to attract electrons. The p-layer is not a charged layer and it has an equal number of protons and electrons;
- **P-N Junction**- when the two layers are placed together, the free electrons from the n-layer are attracted to the p-layer. At the moment of contact between the two wafers, free electrons from the n-layer flow into the p-layer for a split second, then form a barrier to prevent more electrons from moving from one layer to the other. This contact point and barrier are called the p-n junction [9].

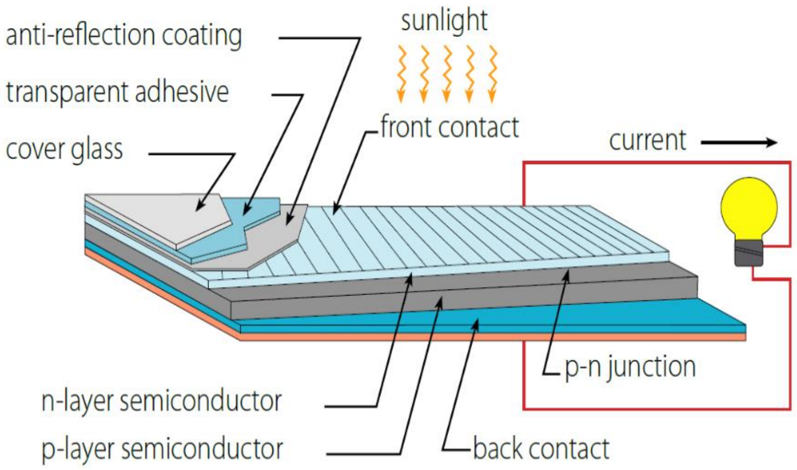

Fig. I.10 Structure of solar cells.

I.3.5 Mathematical modelling of PV cells

The solar cell terminal current can be expressed as $I = I_{ph} - I_d - I_{sh}$. As shown in Fig.I.11

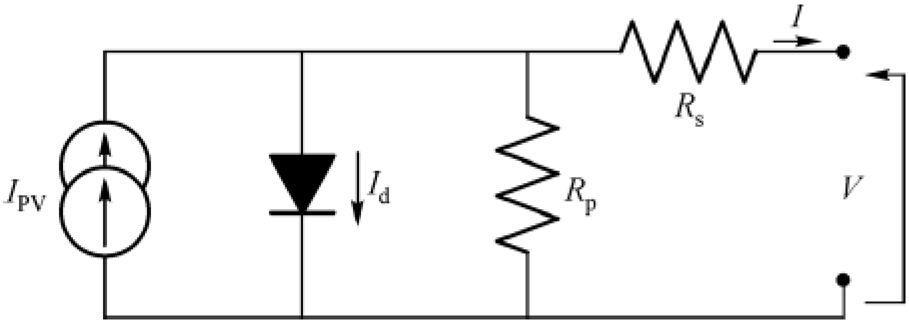

Fig. I.11 Equivalent circuit model of PV cell [10].

The photo-generated current I_{ph} depends on both irradiation and temperature. It is measured at some reference conditions such as reference temperature $T_{c,ref}$, reference radiation Gref and reference photo current $I_{ph,ref}$ and related as Eq (I.8):

$$Iph = \frac{G}{Gref}[Iph,ref + Isc(Tc - Tc,ref)] \qquad \text{Eq. (I.8)}$$

where G is the actual solar irradiation (W/m^2); T_c, the actual operating temperature of cell (K); and I_{sc}, the manufactured supplied temperature coefficient of the short circuit current (A/K). The diode current is given by the Shockley equation

$$Id = Io[exp\left(\frac{e(Vc)}{\eta KTc}\right) - 1] \qquad \text{Eq. (I.9)}$$

where V_c is the voltage across diode (V); I_0, the reverse saturation current (A); η, the diode ideal factor; R_s the series resistance (Ω); e, the electron charge1.602×10^{-19}C; and K, the Boltzmann constant,1.38×10^{-23} J/K. The reverse saturation current I_0 is given by Eq. (I.10).

$$Io = Io,ref\left(\frac{\mathrm{Tc}}{\mathrm{Tc,ref}}\right)^3 \exp\left[\left(\frac{eEg}{\eta \mathrm{K}}\right)\left(\frac{1}{Tc,ref}-\frac{1}{\mathrm{Tc}}\right)\right] \qquad \text{Eq. (I.10)}$$

The shunt current I_{sh} is given by

$$Ish = \frac{\mathrm{V+IRs}}{\mathrm{Rp}} \qquad \text{Eq. (I.11)}$$

Total equation

$$I = I_{ph} - I_0\left(e^{\frac{e(Vc)}{\eta KTc}} - \ 1\right) - \frac{(V+IR_S)}{R_p} \qquad \text{Eq.(I.12)}$$

where R_p is the shunt resistance (Ω) [10].

I.3.6 Effects of solar radiation and temperature on Solar panel

The PV module power can be computed using:

$$P=IV \qquad \text{Eq. (I.13)}$$

The power-voltage (P-V) and the current-voltage (I-V) characteristic curves of the PV array are nonlinear, as depicted in Figure below presents the PV panel characteristic curves under weather conditions.

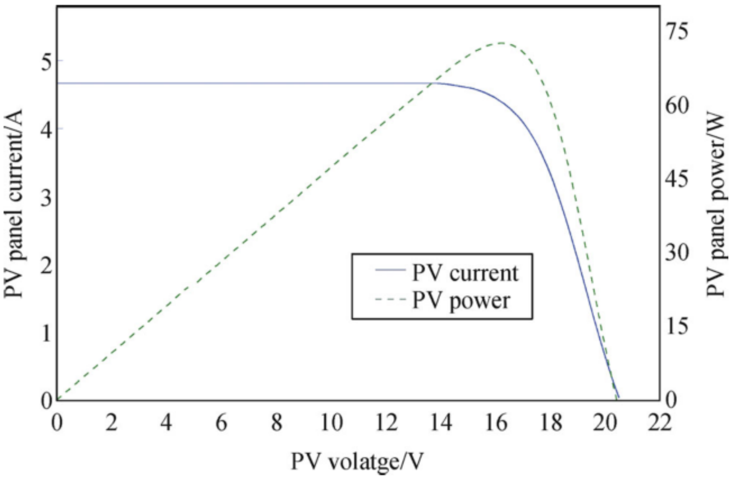

Fig. I.12 The P-Vand the I-V characteristic of PV array.

In high temperatures, the PV module's power output is reduced. The temperature of a PV module also effects its efficiency. In general, a crystalline silicon PV module's efficiency will be reduced about 0.5 percent for every degree °C increase in temperature. PV modules are usually rated at module temperatures of 25°C (77°F) and seem to run about 20°C Over the air temperature. This means that on a hot day of 40°C(100°F), the module will operate at 120°F, or 50°C, and so will have its power reduced by about 12.5% [11].

The following graphs represent the characteristic's P(V) and I(V)

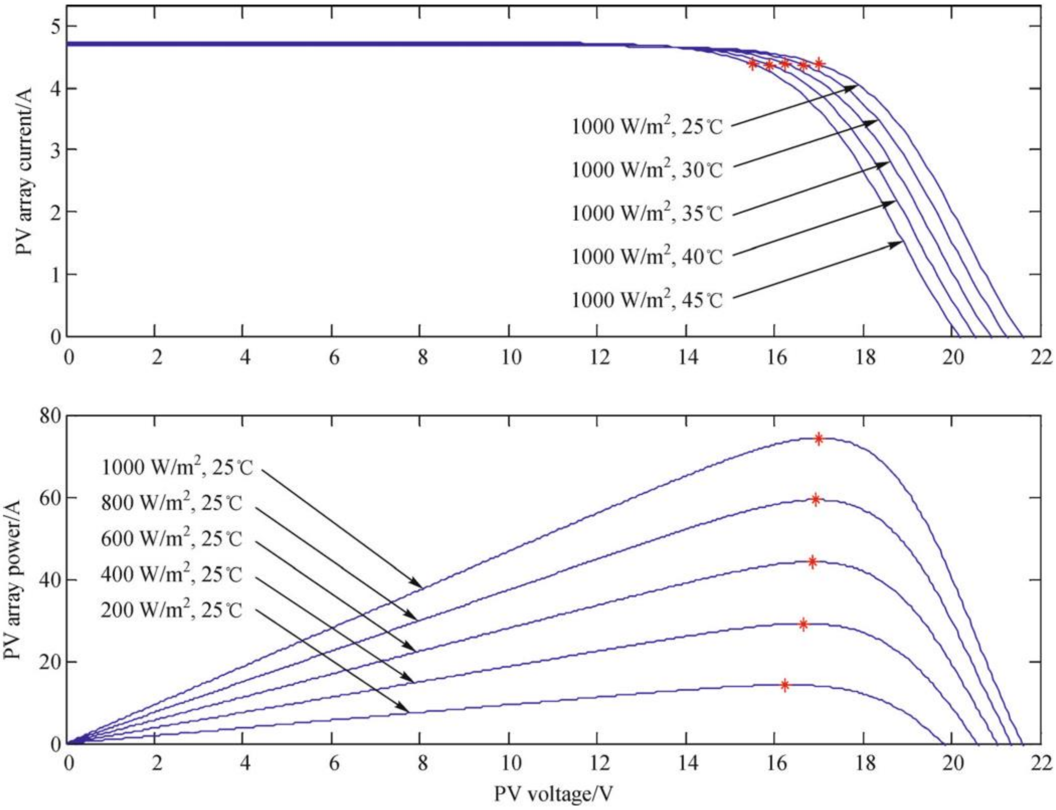

Fig. I.13 Effects of ambient temperature and irradiation variations on I-V and P-V.

I.4 Conclusion

This chapter deals with the principal definitions and notions of the PV panels. They are devices used to convert the light into electricity taking the advantage of the continuous and renewable solar radiation. The next chapter will explain in details the use of this PV panels in what we called PV systems. A full study of these systems will be discussed.

Chapter II

MPPT for PV systems

II.1 Introduction

A photovoltaic (PV) system is composed of one or more solar panels combined with an inverter and other electrical and mechanical hardware that use energy from the Sun to generate electricity. PV systems can vary greatly in size from small rooftop or portable systems to massive utility-scale generation plants. In this chapter, we will present the different types of photovoltaic cells as well as their components. Moreover, the maximum power point tracking (MPPT) is discussed. The goal of the (MPPT) is to match the resistance of load to the optimal resistance of PV module. The MPPT uses a DC–DC converter between the PV module and load to acts as an interface to operate at the maximum power point (MPP) by changing the duty cycle of the converter as requested by the MPPT tracker. Hence, we will give a full review of different existing MPPT techniques.

II.2 PV systems

A photovoltaic (PV) system is solid state semiconductor devices which generates electricity when it is exposed to the light. The building of a solar panel is solar cell. A photovoltaic module is formed by connecting many solar cells in series and parallel. To get maximum output voltage, PV modules are connected in series and for obtaining maximum output current they are connected in parallel. Solar PV power systems have been commercialized in many countries due to their merits such as long-term benefits and maintenance free. The major challenge which lies in using the PV power generation systems is to tackle the nonlinear characteristics of PV array. The PV characteristics depend on the level of irradiance and temperature. PV array experiences different irradiance levels due to passing clouds, neighbour buildings, or trees. The block diagram of PV generation system is shown in Fig. II.1 [12].

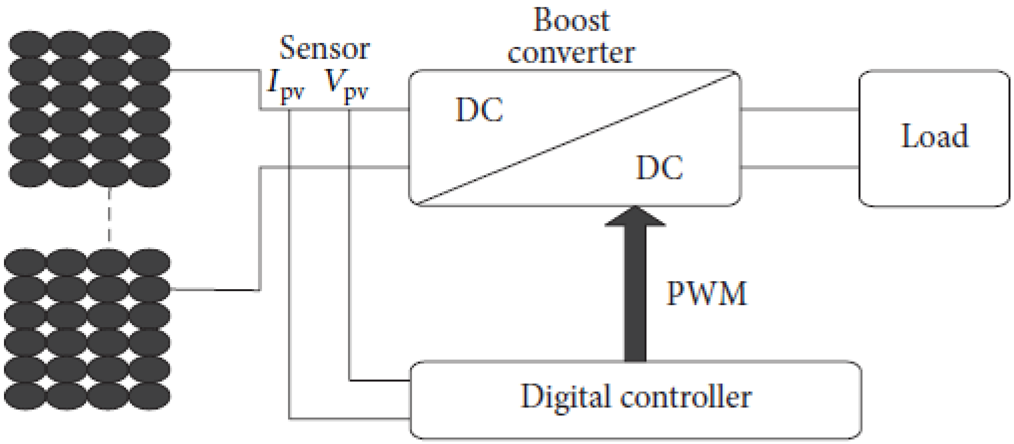

Fig. II.1 Block diagram of PV generation systems [11].

II.2.1 Solar panels

As the most important part of solar PV system, solar cell matrix is in a big role for transforming light into electricity. According to the raw materials, it can be divided into three types, single crystal silicon solar cells, polycrystalline silicon solar cells, and amorphous silicon solar cells. In the solar PV systems , single crystal and polycrystalline maximum battery are the main types currently. From the above analysis, the development of crystalline silicon is closely related to photovoltaic industry and manufacturing industries. The development of photovoltaic industry will directly promote the development of crystalline silicon production industry [13].

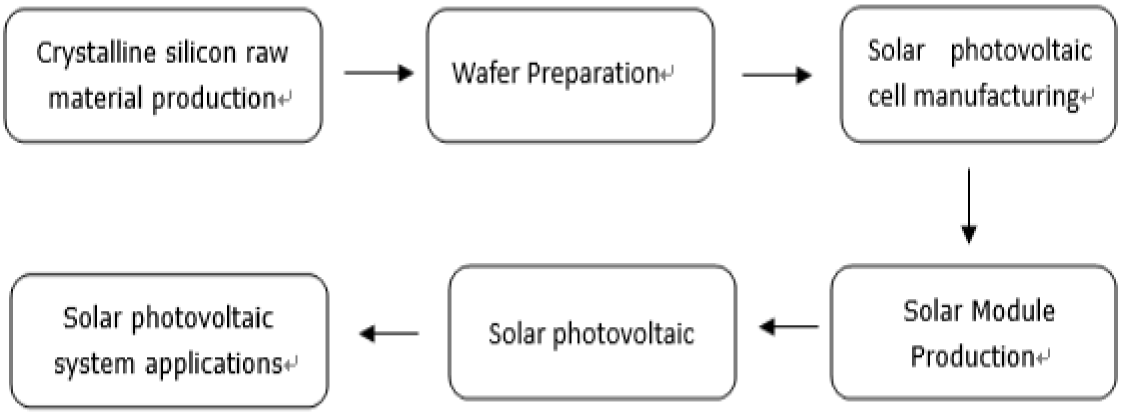

Fig. II.2 PV industry chain.

II.2.2 Batteries

Batteries chemically store direct current electrical energy for later use, during periods of cloudy weather and when a portable power source is desired. Since a photovoltaic system‘s power output varies throughout any given day, the battery storage system can provide a relatively constant power source, even when the photovoltaic system is disconnected for repair and maintenance or producing minimal power in periods of reduced insolation.

Selecting the suitable battery for a PV application depends on many factors. Specific decisions on battery selection depend on physical properties, while other decisions will be much more difficult and may involve making trade-offs between desirable and undesirable battery features. With the proper application of this knowledge, designers should be able to differentiate among battery types and gain some application experience with batteries they are familiar with. Considerations in battery subsystem design include the number of batteries is series and parallel, over-current and disconnect requirements, and selection of the proper wire sizes and types. The energy output from the Solar PV systems is generally stored in a battery or in a battery bank deepening upon the requirements of the system. Mostly batteries or used in the stand-alone system and in the case of grid connected system, batteries are used as a backup system. The primary functions of the battery in a PV system are:

- **Energy Storage Capability and Autonomy:** to store electrical energy when it is produced by the PV array and to supply energy to electrical loads as needed or on demand.
- **Voltage and Current Stabilization:** to supply power to electrical loads at stable voltages and currents, by suppressing or ‘smoothing out’ transients that may occur in PV systems.
- **Supply Surge Currents:** to supply surge or high peak operating currents to electrical loads or appliances.

Fig. II.3 Solar battery.

II.2.3 DC/DC converter buck / boost

DC-DC converters fulfil multiple purposes. In an inverter, DC power is transformed into AC power. The DC input voltage of the inverter often is constant while the output voltage of the modules at MPP is not. Therefore, a DC-DC converter is used to transform the variable voltage from the panels into stable voltage used [14].

II.2.3.1 Step-up Boost DC/DC Converter

Applied to control the PV parameters during sudden changes in the input power of boost converter coming from the PV array. The exact control of converter's outputs is achieved utilizing pulse width modulation. A PWM signal is generated to control the converter's MOSFET-switch ON or OFF by controlling the switching duty cycle. Therefore, the output voltage of the boost converter is related to the input voltage by the expression given by Eq. (II.1). Where, D refers to the duty cycle ratio and is given by Eq. (II.2) [14].

$$\frac{UE}{UA} = \frac{1}{1-D} \Rightarrow \mathrm{UE} = \frac{\mathrm{UA}}{1-D} \Rightarrow D = 1 - \frac{\mathrm{UA}}{\mathrm{UE}} \qquad \text{Eq. (II.1)}$$

$$k = \frac{t_{on}}{T} \qquad \text{Eq.(II.2)}$$

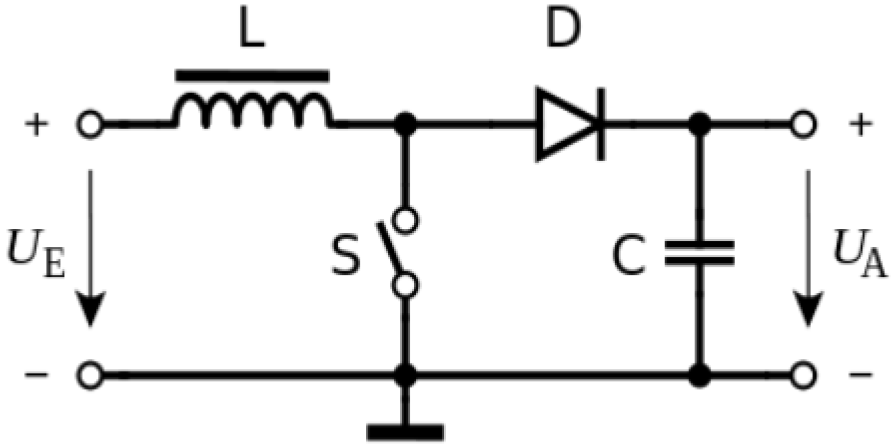

Fig. II.4 Boost Converter.

II.2.3.2 Step Dawn DC/DC Buck Converter

The circuit diagram of the step dawn DC/DC Buck converter is shown in Fig. II.5. The output voltage of the Buck converter is related to the input voltage by the expression given by

Eq. (II.4). the model shown in Fig. (II.5) is built and the duty cycle D is calculated as given by Eq. (II.4). Corresponding to this, the output voltage of the buck converter is as given by Eq.(II.5).

$$\frac{U_E}{U_A} = D \Rightarrow U_E = D^* \underline{U_A} \Leftrightarrow D = \frac{T_{on}}{T_{on}+T_{off}} = \frac{T_{on}}{T} \qquad \text{Eq. (II.3)}$$

$$\Rightarrow (U_E - U_A)\, T_{on} = U_A\,(T - T_{on}) \qquad \text{Eq. (II.4)}$$

$$U_A = DU_E \qquad \text{Eq. (II.5)}$$

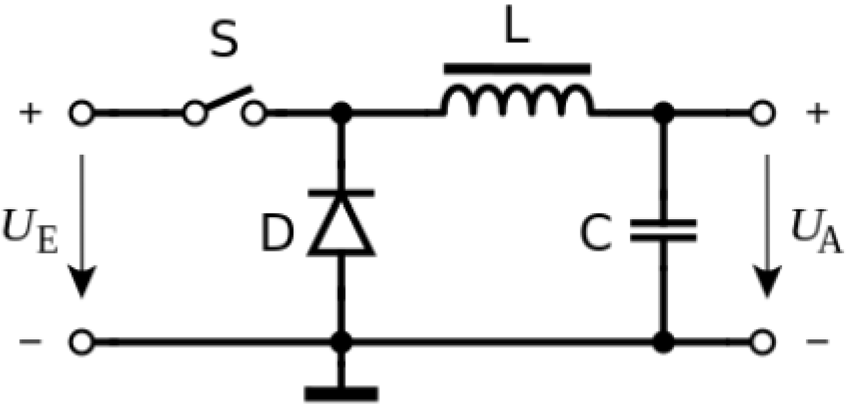

Fig. II.5 Buck Converter [14].

II.2.3.3 Buck-Boost Converter

In a buck-boost converter the output voltage can be both higher or lower than the input voltage. The simplified schematic of a buck boost converter is depicted in Fig.II.6 Using inductor volt second balance as in equation, we find [14].

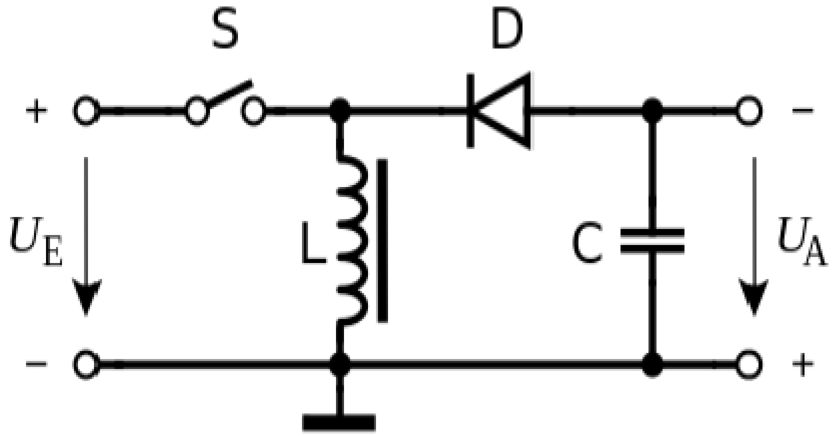

Fig. II.6 Buck-Boost Converter [14].

II.2.4 Inverter

The device can transform direct current into alternating current. Since solar cells and batteries are DC power suppliers so that an inverter is necessary when it is an AC load. According to operating mode, the inverter can be divided into stand-alone inverters and grid inverters. As a stand-alone inverter, it is used in an independently operated solar power generation system for supplying a separate load. Grid inverters are used in network operation solar power generation systems. The inverter can be divided into square wave inverter and sine wave inverter according to the type of output waveform. The circuit of square wave inverter is simple, cost of pro duction is low, but the harmonic component is large. It is generally used for the system which is a few hundred watts or less and low requirements on the harmonic. However, the cost of sine wave inverter is high, but it can be applied to a variety of loads. The inverter can be connected with a charging output controller to drive AC loads [15].

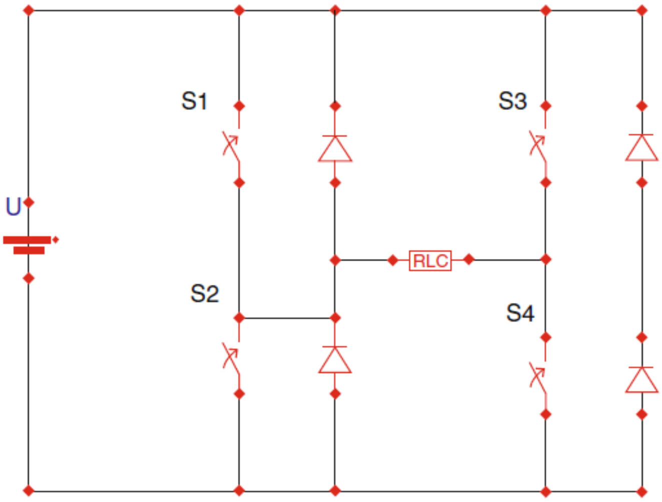

Fig. II.7 Simple inverter circuit [15].

Fig. II.8 Inverter [15].

II.2.5 DC/AC Load

Loads are all the pieces of electrical equipment people want to use in their homes and offices. You can have DC loads or AC loads (and sometimes even both). You just have to make sure you supply the correct type of power to the load. For instance, you can't use a DC light bulb when AC power is provided.

II.3 PV system types

There are myriad end uses for PV, with a broad variety of system complexity. A range of applications is shown in the chart in Figure below. On-grid versus off-grid applications share certain attributes but the PV systems satisfy distinctly different needs. For example, both on-grid and off-grid PV systems may use the same module technology, be mounted in the same manner, be deployed in the same climate, and deliver the same amount of AC energy to a hypothetical customer. The on-grid system will almost certainly be less expensive per kW to install and maintain and will operate more efficiently than its off-grid counterpart [16].

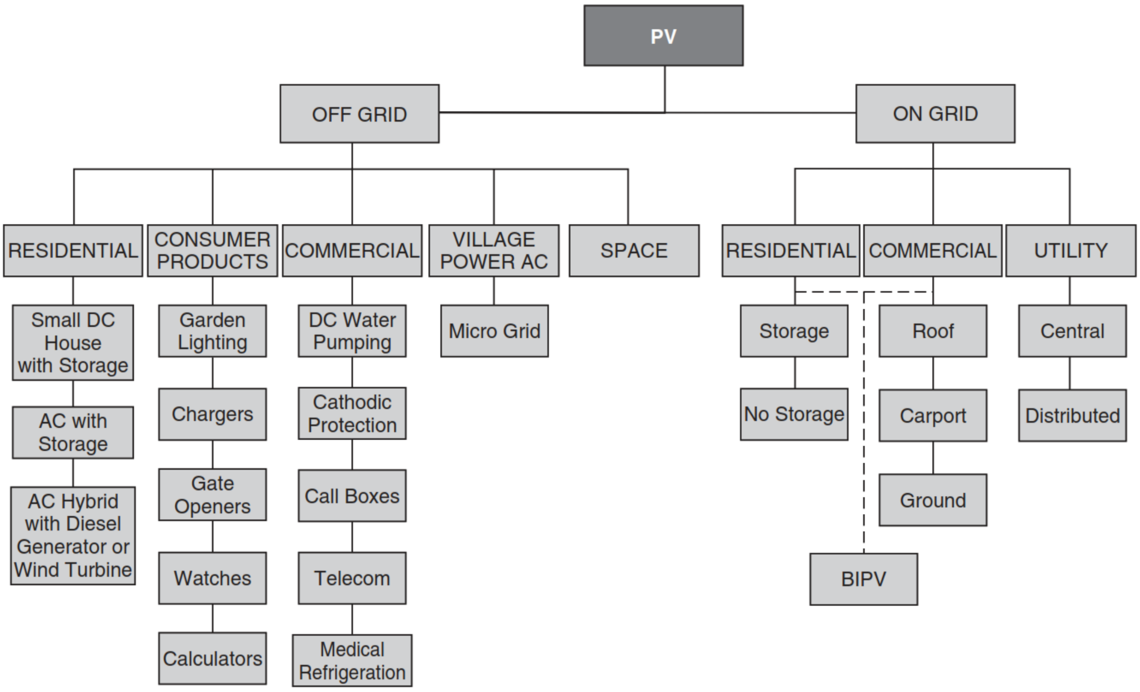

Fig. II.9 PV system taxonomy chart [16].

II.3.1 Stand-alone PV systems

In a stand-alone system, the system is designed to operate independent of the electric utility grid and is generally designed and sized to supply certain dc and/or AC electrical loads. A bank of batteries is used to store the energy in the form of DC power that is produced by the photovoltaic (PV) modules to be used at night or in the no sun days. The DC output of the batteries can be used immediately to run certain low DC voltage loads such as lighting bulbs or refrigerators or it can be converted by an inverter to ac voltage to run AC loads that constitute most appliances. As output power of a solar array deviates with weather conditions, the rewarding activity of the standalone system is to find out the optimal size of a solar array and battery to meet load demand. The reliability of power supply to the load is described by the Loss of Power Supply Probability (LPSP). LPSP is the ratio of the number of hours that the system fails to supply a load to the total number of hours required by the load. Stand-alone PV systems should provide a good quality electricity service to be considered as an alternative to conventional grid extension, for places with no access to electricity. In this way it is promoted in most PV and rural electrification programs and forums [17].

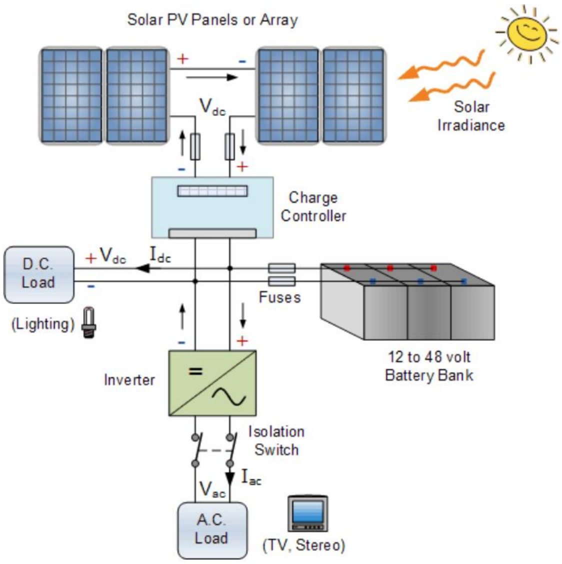

Fig. II.10 Diagram of stand-alone PV system.

II.3.2 Grid connected PV systems

In grid connected PV systems, the inverter is the heart of the system which is responsible for converting the DC power into the required AC form. Various configurations and inverter topologies have been proposed from time to time for grid connected PV systems. Configurations and topologies used in grid connected PV systems aim at generating sinusoidal current with near unity power factor. Based on PV architecture (whether array, string or modules) the configurations can be classified into three categories [19]:

(1) Centralized inverter technology

(2) String inverter technology

(3) AC modules inverter technology

The concept of centralized inverter technology encourages the centralized generation of the PV power [Fig. II.11(a)]. Only one inverter is used for feeding sinusoidal current into the grid for the whole array. Though economical, the rating of the inverter in this category limits further expansion or addition of the array. Further, it suffers from the drawbacks of maximum probability of shading effect, low reliability, costly DC cabling for modules and inverter etc.

To overcome the disadvantage of centralized inverter technology, the concept of string technology is gaining importance. Instead of arrays, strings of modules are connected to the inverter. This minimizes the effect of shading and eliminates the constraint for expansion of the system. However, it still suffers from the problem of shading and requirement of costly high voltage DC cabling for modules and inverter. As shown in Fig. II.11(b) there is individual inverter for each string. The advantages of string converter are:

1. Individual MPPT for each string possible yielding higher efficiency.
2. Has low probability of losses due to mismatch of module's operating point.
3. Ease of maintenance and expansion.
4. More reliable in comparison with centralized technology.

To eliminate the problem of shading and high DC voltage cabling an interesting concept of module inverter technology has been proposed [Fig. II.11(c)]. In this concept, a single inverter is required to handle single module, which removes the drawbacks of power loss due to mismatch between modules due to shading effects, makes the system ‘plug-n play’ type [19].

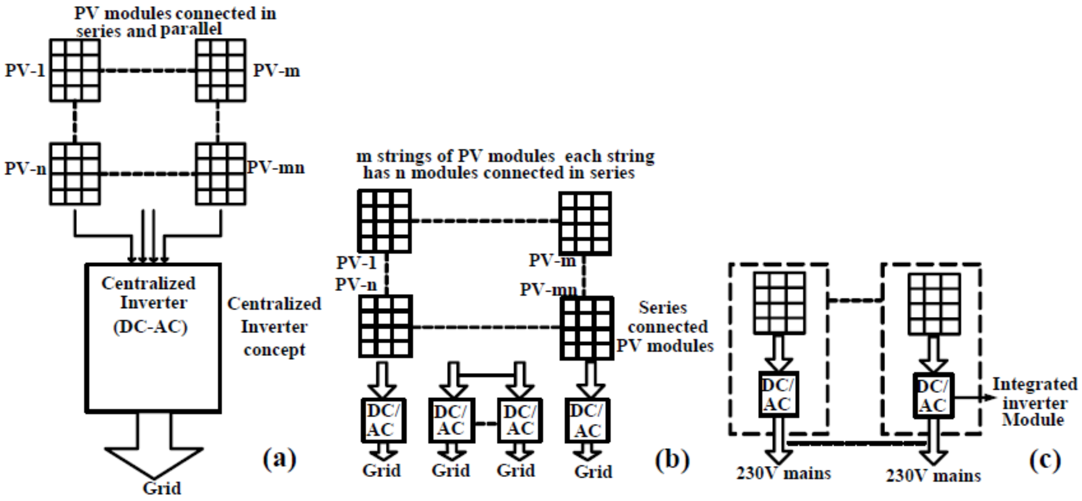

Fig. II.11 (a) PV inverter technologies, (b) Centralized inverter technology; (c) String inverter.

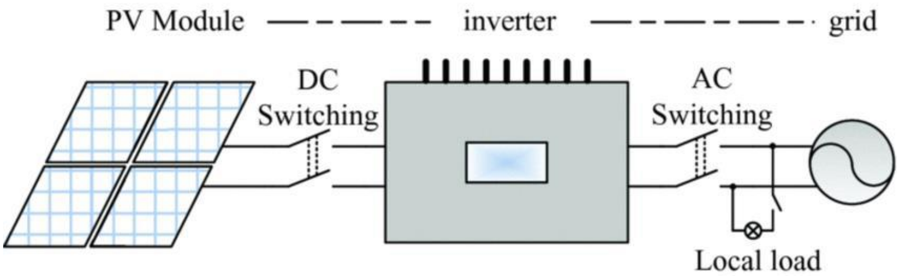

Fig. II.12 Grid-connected photovoltaic power generation systems [20].

II.3.3 Hybrid Systems

Hybrid systems consist of combination of PV modules and a complementary means of electricity generation such as a diesel, gas or wind generator. Schematic representation of a hybrid system. In order to optimize the operations of the two generators, hybrid systems typically require more sophisticated controls than stand-alone PV systems. For example, in the case of PV/diesel systems, the diesel engine must be started when battery reaches a given discharge level and stopped again when battery reaches an adequate state of charge. The back-up generator can be used to recharge batteries only or to supply the load as well [18].

II.4 MPPT for PV systems

Maximum Power Point Tracking, frequently referred to as MPPT, operates Solar PV modules in a manner that allows the modules to produce all the power they are capable of generating. MPPT is not a mechanical tracking system but it works on a particular tracking algorithm and it based on a control system. MPPT can be used in conjunction with a mechanical tracking system, but the two systems are completely different. MPPT algorithms are used to obtain the maximum power from the solar array based on the variation in the irradiation and temperature. The voltage at which PV module can produce maximum power is called ‘maximum power point’ (or peak power voltage). Maximum power varies with solar radiation, ambient temperature and solar cell temperature.

Maximum power point tracking control technique is used mainly to extract maximum capable power of the PV modules with respective solar irradiance and temperature at particular instant of time by MPPT Controller. A number of algorithms are developed to track the MPP efficiently. Most of the existing MPPT algorithms suffer from the drawback of being slow tracking, due to which the utilization efficiency is reduced [11].

The appearance of multipeak output curves of partial shading in PV arrays is common, where the development of an algorithm for accurately tracking the true MPPs of the complex and nonlinear output curves is crucial.

The MPPT efficiency varies depending on cell temperature and fill factor. propose the MPPT performance which improves with the temperature of the PV system; the 4% of the efficiency is affected by the variations of the fill factor with the climatic conditions and features of geographic region. have presented the modelling of MPPT with buck converter with oscillations less than 0.5% in the output power. Also, the PV cell with two-diode model for MPPT controller relies on the fact that the ratio of Vmpp/Voc does not strongly depend on the environmental conditions [11].

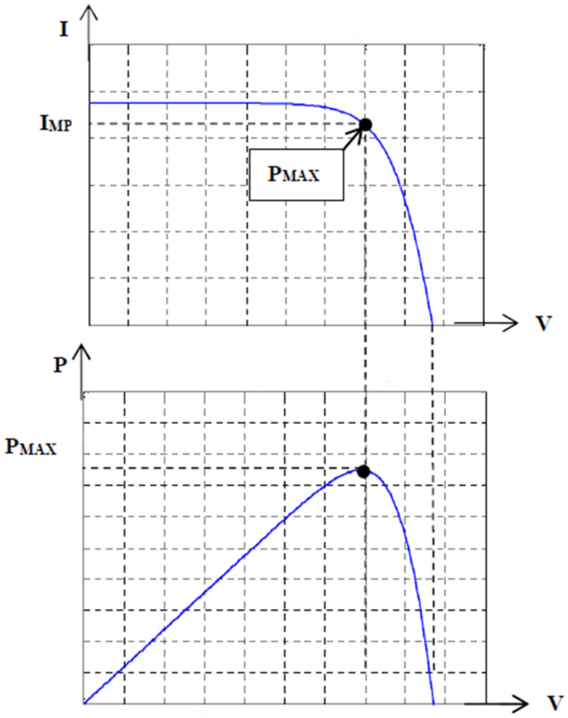

Fig. II.13 Maximum power for an I-V Sweep.

II.5 MPPT techniques

Over the past decades many methods to find the MPP have been developed. These techniques differ in many aspects such as required sensors, complexity, cost, range of effectiveness, convergence speed, correct tracking when irradiation and/or temperature change, hardware needed for the implementation or popularity, among others. Some of the most popular MPPT techniques are:

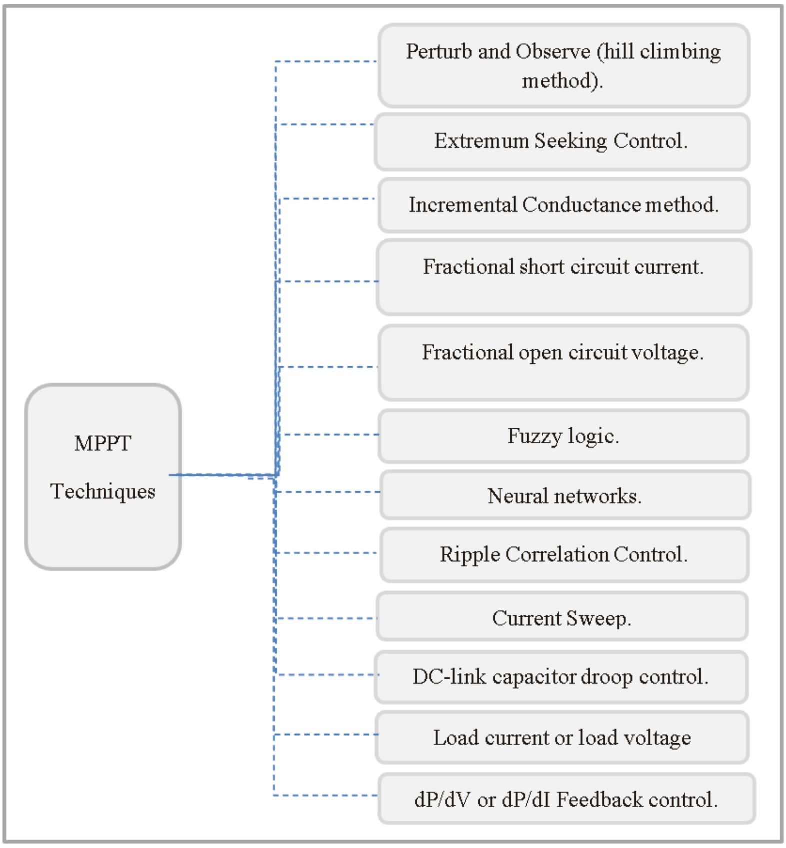

Fig. II.14 Popular MPPT techniques.

II.6 MPPT algorithms

A number of algorithms are developed to track the maximum power point efficiently. Most of the existing MPPT algorithms suffer from the drawback of being slow tracking, due to which the utilization efficiency is reduced.

II.6.1 Perturbation and Observation

The Perturbation and Observation MPPT algorithm is easy to implement; it works based on the PV array which is perturbed of a radiation of direction. If the power drained from the array increases, the operating point varies towards the MPP which in turn suits therefore the working voltage in the similar direction. If the power drained from the PV array decreases, the operating point varies away from the MPP, and thus the direction of the working voltage perturbation has to be overturned. A disadvantage of P&O MPPT method is at steady state. The operating point oscillates in the region of the MPP giving rise to the waste of energy. A number of improvements of the P&O algorithm have been deliberate in order to decrease the oscillations in steady state, but this slows down the speed of response of the algorithm during the atmospheric changes [11].

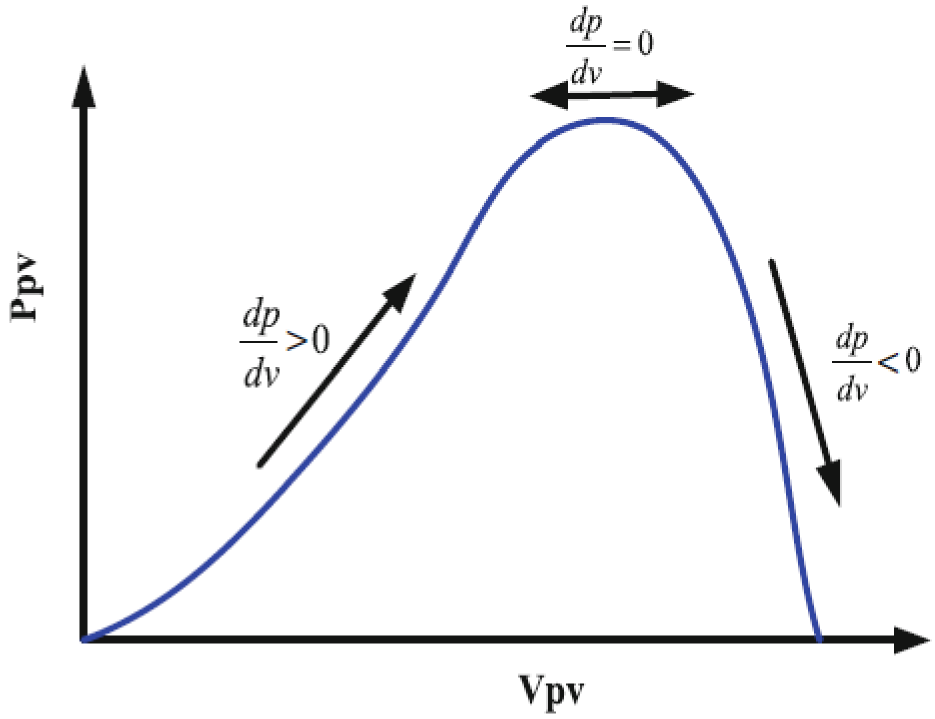

Fig II.15 P–V characteristic of the PV array explaining the P&O concept.

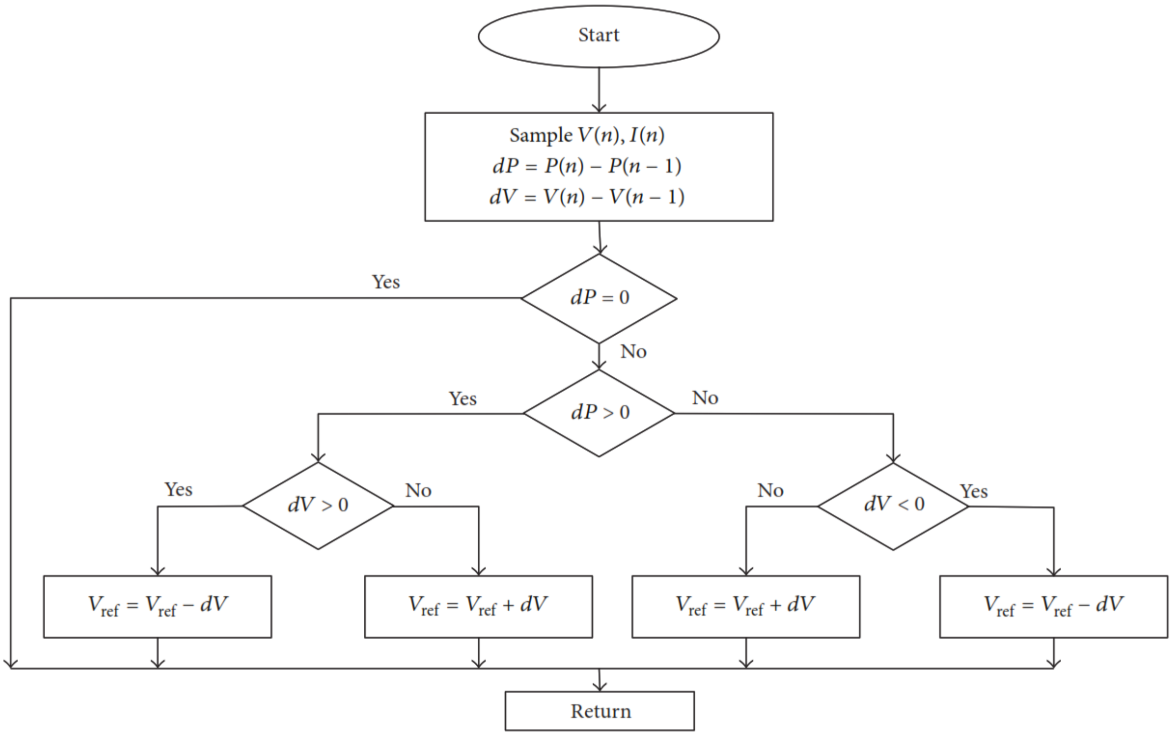

Fig. II.16 Flow chart of Perturbation and Observation method.

II.6.2 Incremental Conductance (INC)

Incremental Conductance method determines the radiation direction to do voltage changing under rapidly changing condition; in addition, it also calculates the MPP. Thus, oscillation problem of P&O algorithm around MPP would have been eliminated. For uniform radiation condition, there is no significant difference between the efficiencies of these two methods. Incremental Conductance method was determined to operate with more efficiency under randomly generated conditions. However, the cost of INC method is high due to requirements of high sampling compliance and speed control as a result of complex structure.

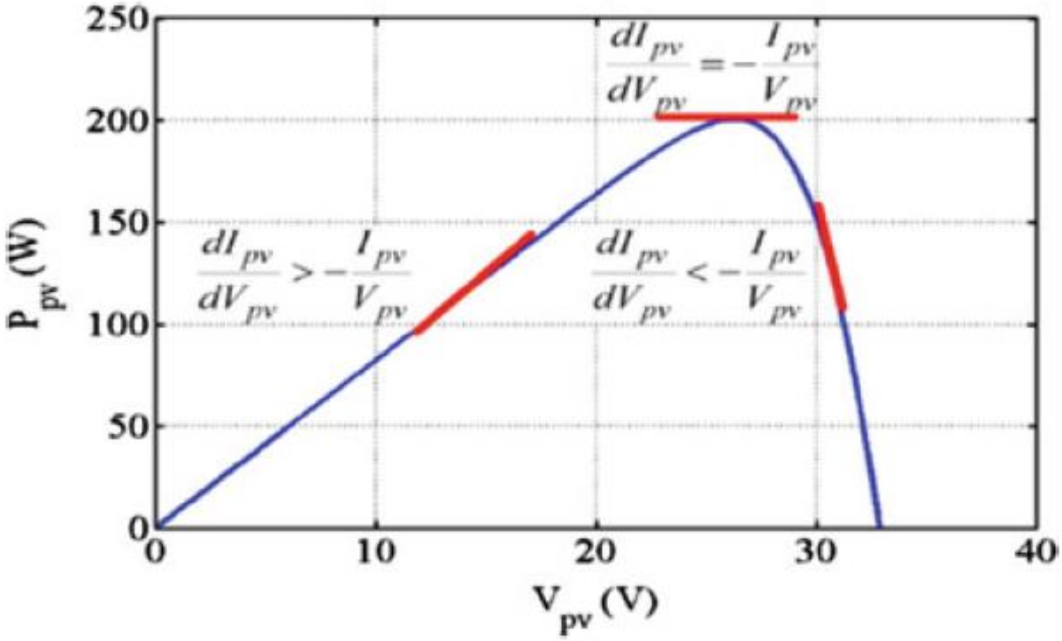

Fig II 17 P–V characteristic explaining the INC concept [21].

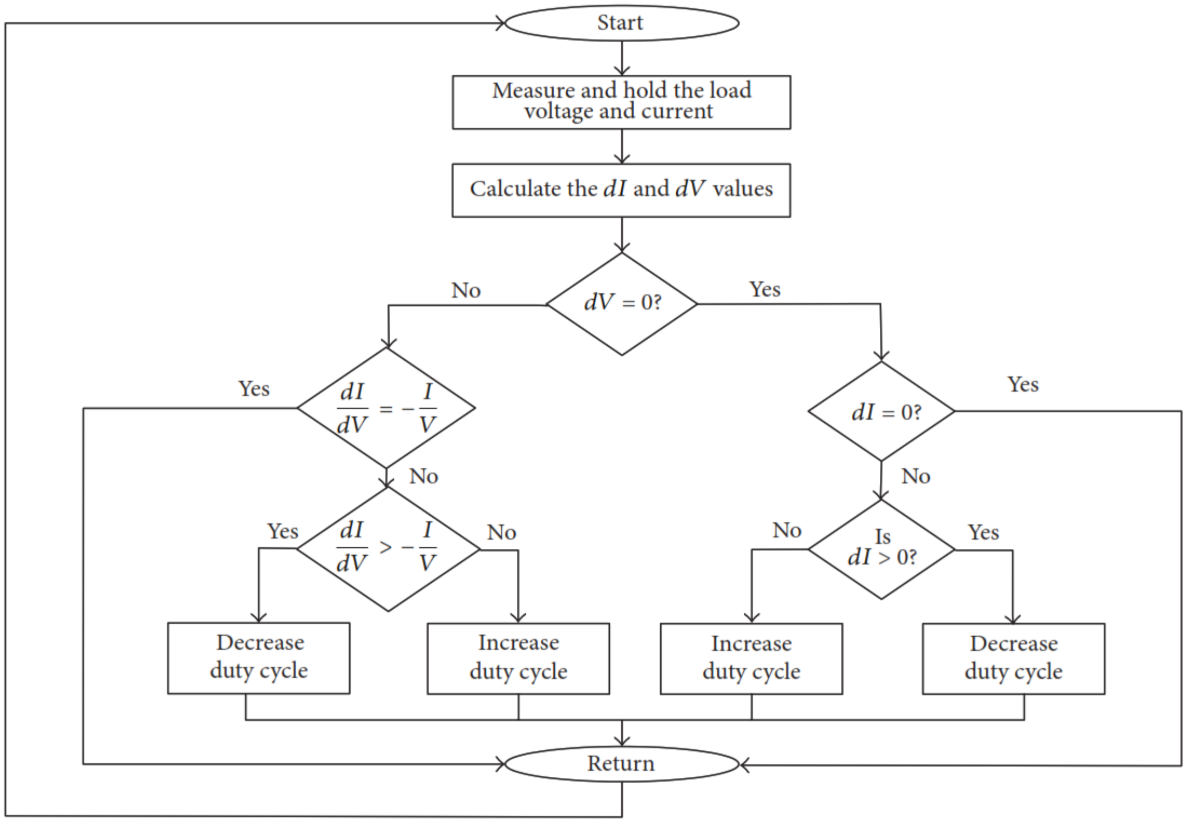

Fig. II.18 Flowchart of IC algorithms for MPPT.

II.6.3 Artificial Neural Networks (ANN)

The ANN control system has to be trained before being used in the photovoltaic system. The neural network is a powerful technique for mapping the input-output nonlinear function. In our proposed design, we incorporate a two-layer cascading neural network technique that predicts the PV array voltage at which the maximum power is attainable. These develop a non-linear relationship between the input and output with a hidden layer that functions with preferences like neurons of our brain. The hidden layer in our model is a two-layer neural network as shown in (Fig. II.19) whose input parameters are an error function of power from the grid and boost converter. This is then sent to layer 1 with 10neurons where a process input synthesizes the signal with weights and generates a tangent sigmoid transfer function. The output of layer 1 is the input for layer 2 with another set of 10 neurons that assigns weightage to the values and generates a pure linear transfer function. The cosine and sine components of array voltage is added to the output signal and is compared to a repeating signal using a relational operator. The relational operator produces binary output which generates the duty cycle responsible for inverter switching operations [22].

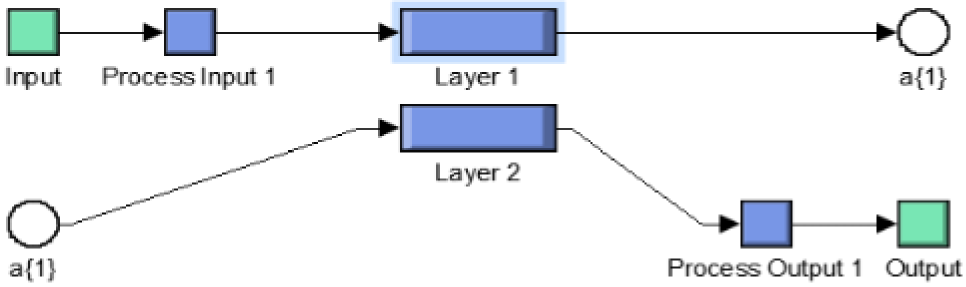

Fig. II.19 Two-layer neural networks [22].

II.6.4 Constant-Voltage (CV)

Constant-voltage (CV) technique forces the PV array’s voltage to a fixed value where the MPP voltage (V_{MPP}) is approximated to 76% of the PV array’s open-circuit voltage (V_{OC}). The shortcomings of this technique are that the V_{MPP} is not always at 76% of the V_{OC}; therefore, it increases the steady-state error and reduces the efficiency. The CV controller has some merits such as only one voltage sensor is needed and the current sensor is not required. Also, it is the easiest technique to be implemented and has low installation cost, but its efficiency is poor with respect to other active MPPT techniques. The block diagram of a CV controller is shown in Fig. II.20 where V_{PV} is only measured in order to provide the duty cycle of the DC–DC converter by PI regulator to track the MPP [23].

- Advantages of CV-based MPPT technique
  - Easy to implement.
  - CV uses one voltage sensor; hence, the cost will be reduced.
  - Economical and more efficient during low radiation.
- Disadvantages of CV-based MPPT technique
  - Priori data is needed.
  - Less accuracy and efficiency due to approximation (VMPP=0.76%V OC), which is not right in some cases.

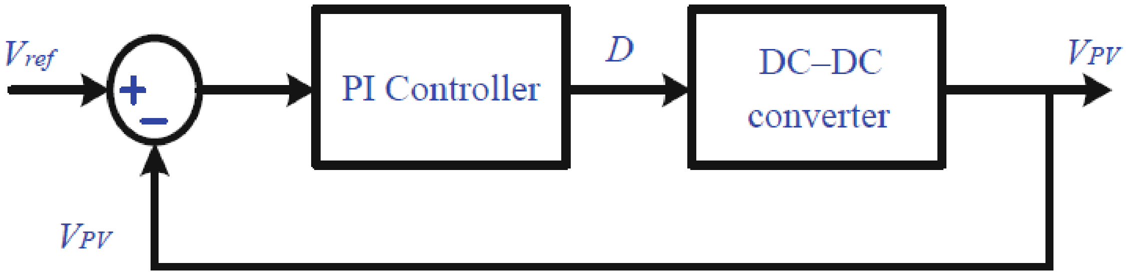

Fig II.20 Block diagram of CV controller [24].

II.6.5 Hill-Climbing (HC)

The hill-climbing (HC) technique is very easy in implementation where no priori data are needed. It relies on the DC–DC converter duty cycle change in order to determine the change of the power until the power change reaches zero (MPP). Rapid change of solar irradiance may cause the HC algorithm to lose MPP fast tracking completely due to lack of fast response. Also, oscillations around MPP during fast-varying environmental conditions are happened [24].

II.6.6 Fractional Open-Circuit Voltage

The near linear relationship between V_{MPP} and V_{OC} of the PV array, under varying irradiance and temperature levels, has given rise to the fractional V_{OC} method

$$V_{MPP} \approx k_1 V_{OC} \qquad \text{Eq. (II.6)}$$

Where k_1 is a constant of proportionality. Since k_1 is dependent on the characteristics of the PV array being used, it usually has to be computed beforehand by empirically determining V_{MPP} and V_{OC} for the specific PV array at different irradiance and temperature levels. The factor k1 has been reported to be between 0.71 and 0.78.

Once k1 is known, V_{MPP} can be computed using Eq. (II.5) with V_{OC} measured periodically by momentarily shutting down the power converter. However, this incurs some disadvantages, including temporary loss of power. To prevent this, uses pilot cells from which V_{OC} can be obtained. These pilot cells must be carefully chosen to closely represent the characteristics of the PV array, it is claimed that the voltage generated by pn-junction diodes is approximately 75% of V_{OC}. This eliminates the need for measuring V_{OC} and computing V_{MPP}. Once V_{MPP} has been approximated, a closed-loop control on the array power converter can be used to asymptotically reach this desired voltage.

Since Eq. (II.5) is only an approximation, the PV array technically never operates at the MPP. Depending on the application of the PV system, this can sometimes be adequate. Even if fractional V_{OC} is not a true MPPT technique, it is very easy and cheap to implement as it does not necessarily require DSP or microcontroller control. However, points out that k1 is no more valid in the presence of partial shading (which causes multiple local maxima) of the PV array and proposes sweeping the PV array voltage to update k_1. This obviously adds to the implementation complexity and incurs more power loss.

Fractional ISC results from the fact that, under varying atmospheric conditions, IMPP is approximately linearly related to the I_{sc} of the PV array [25].

II.7 Advantages and Disadvantages of Solar PV System

II.7.1 Advantages

- Although the feed-in tariff has changed quite a bit since it was introduced, solar PV systems are still a great investment because they substantially lower your electric bill.
- The price of solar panels has gone down by 45 percent or more, which makes the entire system much more affordable.
- Solar PV systems operate differently than solar thermal ones. Solar PV system actually generates free electricity while solar thermal systems heat up your water.
- Solar photovoltaic systems require daylight and so will work in days when the sun is not shining. All you need is light to create energy, so although the effectiveness of the solar PV array will be less when the sun is covered by clouds, it will still generate some electricity.
- Utilizing solar power helps lower your electric bills because you are generating some of the electricity you use. Some systems can generate as much as 40 percent of the electricity you use on an annual basis during the day.
- There is very little maintenance involved in owning a solar PV system. Just make sure that you purchase the system from a company with a solid reputation so that you know you are buying quality panels and a good aftercare service.

- The feed-in tariff is designed to increase the amount of solar power being utilized, but it also makes the installation of solar PV systems look even more attractive to home and business owners.
- By using green energy instead of fossil fuels, you are doing what you can to protect the environment. Our world’s fossil fuel reserves are rapidly decreasing, so we will have to find alternative fuels soon. Solar PV panels provide a green way to produce electricity [26].

II.7.2 Disadvantages

- Solar PV panels are more expensive than panels designed for solar thermal energy. However, they do a lot more for your home or business than solar thermal panels do, and there are some incentives and grants to help pay for them.
- You need an adequate roof space to display your solar PV panels. The larger the panel covering the more the electricity generated.
- Solar PV panels may not be a viable green energy option for your home or business if you have a predominantly north or east facing roof or if tall buildings and/or trees place your roof in the shade [26].

II.8 Conclusion

PV systems are used widely in our daily life in order to ensure the electricity delivery while ensuring the continuity of the voltage and current. MPPT are the techniques that are used in order to do this task, by extracting the maximum output power from the PV panels. The next chapter, will deal with a new method namely extremum-seeking control in order to maximize the output power in the lowest deliver time.

Chapter III

Simulation and results

III.1 Introduction

In both kind of installations of PV systems, the maximum power extracted from the PV panels are needed. As shown in the last chapter, several methods can be found in the literature. However, they are extremely limited due to several factors. Hence, we propose in this chapter a novel control algorithm in order to overcome their problems. The simulation results of using the extremum seeking control method is shown in details in this chapter. The Matlab/Simulink is used in order to perform the simulation and discuss the goodness of the chosen method.

III.2 Extremum seeking control

The block diagram of an extremum-seeking problem is depicted in Figure below, the equations describing the system behaviour are governed by

an integrator, $\frac{dy}{dt} = K\varepsilon$ where $\varepsilon = \pm 1$ and K is a constant

a differentiator $g = \frac{dy}{dt}$ and a logic circuitry subsystem which implements the following function change the sign of ε if $g < 0$ keep the sign of ε if $g > 0$

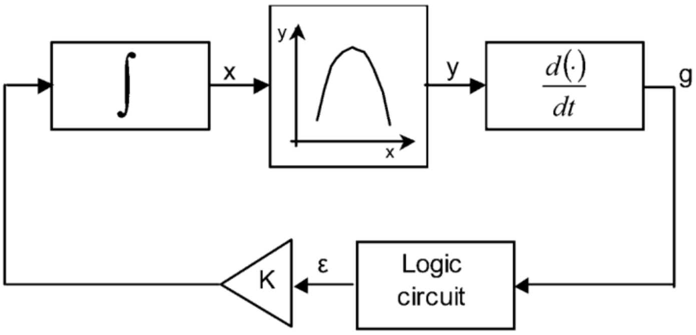

Fig. III.1 Bloc diagram of extremum seeking control system.

Figure below summarizes the behaviour of the extremum-seeking algorithm. Four cases can be distinguished.

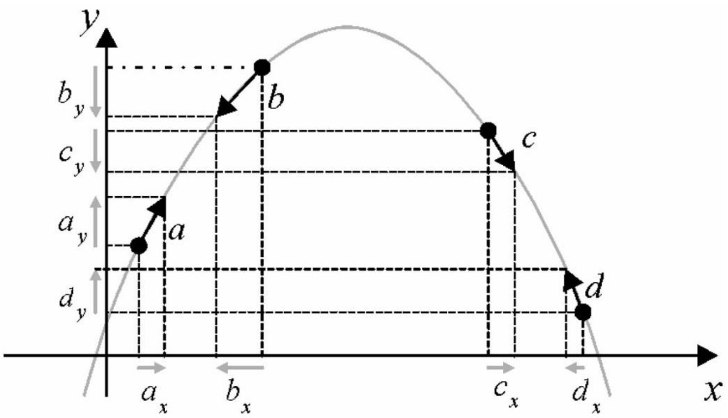

Fig. III.2 Illustrative cases of extremum-seeking mechanism.

Case 1 Vector a describes a movement where both horizontal and vertical components are increasing, i.e., $(dx/dt)\,|_{t-} > 0$, $(dy/dt)\,|_{t-} > 0$, which results in a trajectory directed towards the optimal point from its left side. Therefore, the controller must keep the sign of the horizontal variation, i.e., $(dx/dt)\,|_{t+} = K$.

Case 2 Vector b describes a movement where both horizontal and vertical components are decreasing, i.e., $(dx/dt)\,|_{t-} < 0$, $(dy/dt)\,|_{t-} < 0$, which corresponds to a trajectory moving away from the optimal point towards the left. Hence, the logic circuitry must change the sign of the horizontal variation, i.e., $(dx/dt)\,|_{t+} = K$.

Case 3 Vector c illustrates a movement where the horizontal component is increasing while the vertical component is decreasing, i.e., $(dx/dt)\,|_{t-} > 0$, $(dy/dt)\,|_{t-} < 0$, which represents a movement going t¡ away from the maximum point towards the right. The control action will change in this case the sign of the horizontal variation. Therefore, $(dx/dt)\,|_{t+} = -K$.

Case 4 Vector d corresponds to a movement whose horizontal component is decreasing whereas its vertical component is increasing, i.e., $(dx/dt)\,|_{t-} < 0$, $(dy/dt)\,|_{t-} > 0$; this illustrates a trajectory directed t¡ to the optimal point from its right side. Therefore, the controller must keep the sign of the horizontal variation, i.e., $(dx/dt)\,|_{t+} = -K$.

Since dy/dx =(dy/dt)/(dx/dt), cases 1—4 can be expressed in compact form as follows

$$\frac{dx}{dt}\Big|_{t+} = K \qquad \text{if} \quad \frac{dy}{dx}\Big|_{t-} > 0 \qquad \text{Eq. (III.1)}$$

$$\frac{dx}{dt}\Big|_{t+} = -K \qquad \text{if} \quad \frac{dy}{dx}\Big|_{t-} < 0 \qquad \text{Eq. (III.2)}$$

The equations before can also be reduced to only one expression

$$\frac{dx}{dt} = K sign\left(\frac{dy}{dx}\right). \qquad \text{Eq. (III.3)}$$

Note that the algorithm measures the sign of dy/dt, whereas the resulting dynamics are governed by dy/dx. Also, it can be observed in Eq. (III.3) that the equilibrium point dx/dt = 0 will correspond to an extremum of the x-y curve in Fig. III.2, where dy/dx =0. Note also in Eq. (III.6) that the system dynamics change with constant slope, which can be either positive or negative, this depending on the sign of the slope of the x-y curve. In order to demonstrate that the equilibrium point is stable, a positive definite function V(t) is defined in a concave domain of y(x);

$$\mathrm{V(t)} = \frac{1}{2}\left(\frac{dy}{dx}\right)^{2} \qquad \text{Eq. (III.4)}$$

Hence

$$\dot{V}(t) = \frac{dy}{dx}\frac{d^2y}{dx^2}\frac{dx}{dt} = \frac{dy}{dx}\frac{d^2y}{dx^2}\left(K\ sign\ \left(\frac{dy}{dx}\right)\right). \qquad \text{Eq. (III.4)}$$

The concavity of y(x) implies

$$\frac{d^2y}{dx^2} < 0 \qquad \text{Eq. (III.5)}$$

On the other hand

$$\frac{dy}{dx}\ sign\ \left(\frac{dy}{dx}\right) > 0. \qquad \text{Eq. (III.6)}$$

Therefore, choosing a positive value for K will imply V(t) < 0, i.e., a negative definite function, which demonstrates the global stability of the system.

Since the v-p characteristics of a solar array is a concave function, the previous analysis can be applied to solve the problem of MPPT.

III.3 Simulation and results

In order to verify the theoretical prediction about the behaviour of the MPPT algorithm, a set of simulation has been implemented in MATLAB using the model of the panel available in that software. The general block diagram of the implemented model is depicted in figure below while the PV module parameters are shown in Fig. III.3, Note that a block representing the DC-DC converter (quadratic boost converter) and a block representing the solar panel has been included to evaluate the relation between the MPPT variables and the system variables.

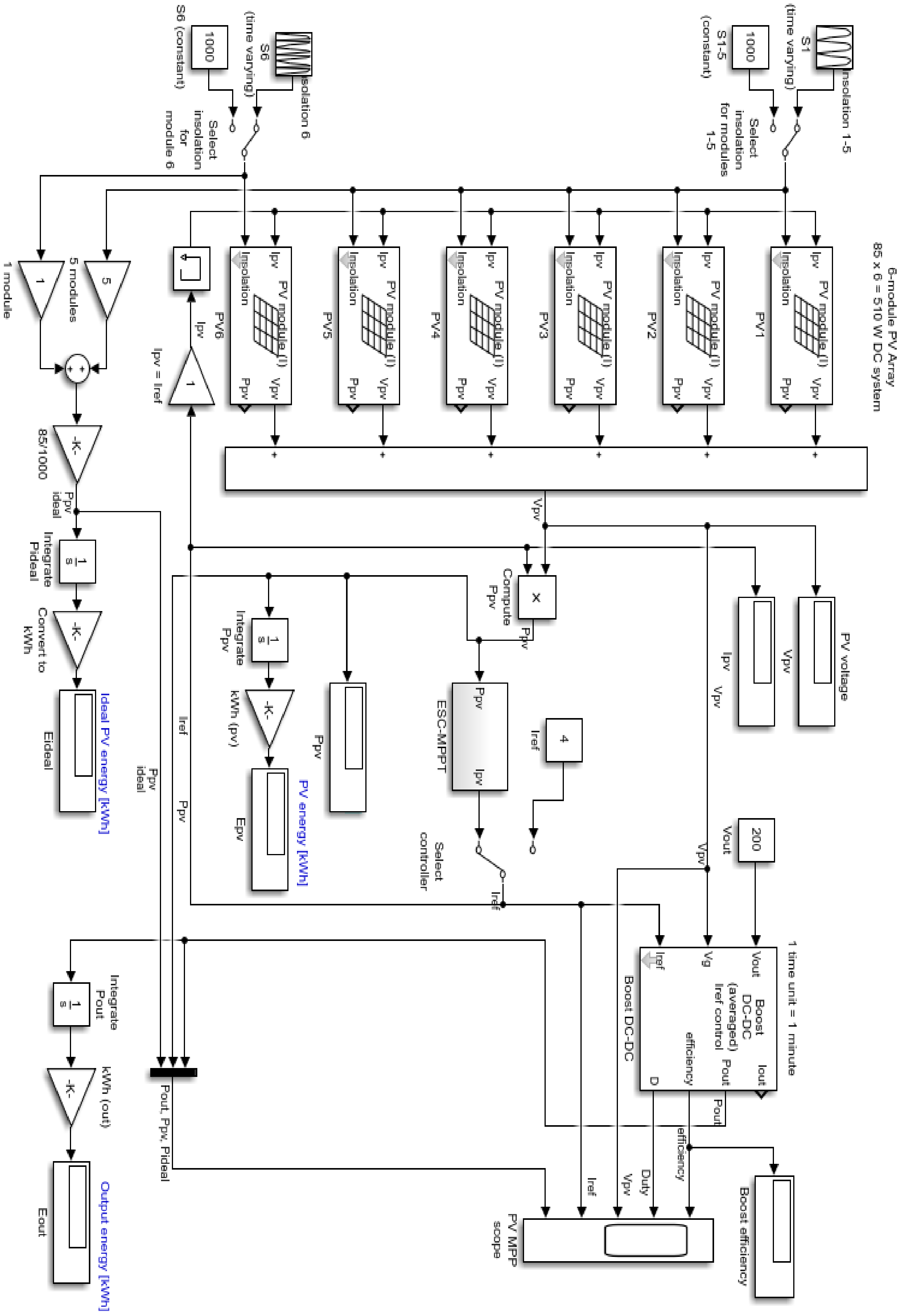

Fig. III.3 Simulation module on MATLAB.

To simulate solar energy as the source of power to the PV panels we use two sets of two blocs, The first set of blocs for modules (1—5) and second for module 6 ,between the two blocs we have a switch to select isolation for modules, simulation blocs are the time varying bloc and second bloc is a constant.

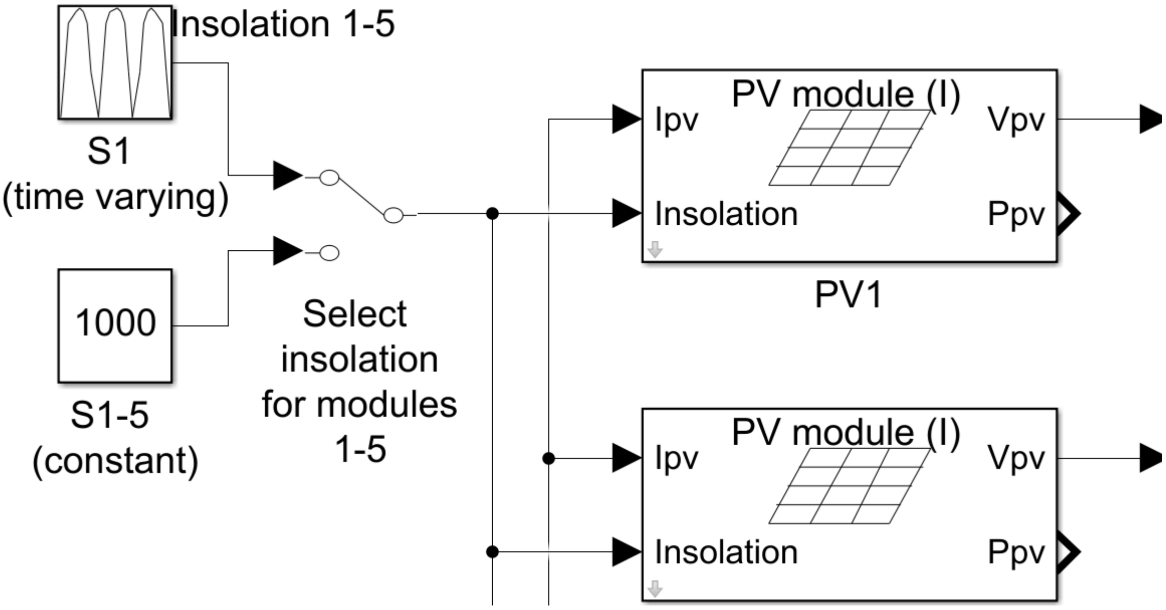

Fig. III.4 PV module bloc, Parameters for PV module.

Bloc parameters for the time varying is shown in table (III.1):

Table III.1 Time varying parameter bloc

Time values	[0 1*60 2*60 3*60 4*60 5*60 6*60 7*60 8*60]
Output values	[0 400 850 950 1000 950 850 400 0]

A solar PV cell is designed in MATLAB / Simulink based on requirements and its input parameters are initialized

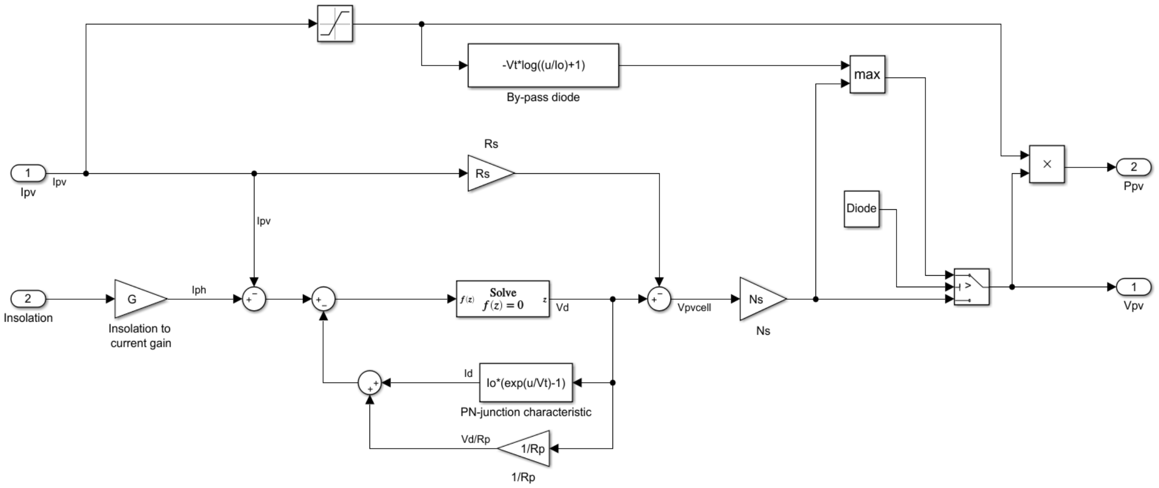

Fig. III.5 PV module Simulink diagram.

The number of PV module array used for this simulation is 6, with 85 W for each module for a total of 510 W DC system.

The configuration of used PV panel on the proposed simulink is given in table III.2:

Table III.2 PV panel parameter bloc

Parameters	**Value**
Sort-circuit current (A)	5.45
Open-circuit current (A)	22.2
Current at Pmax (A)	4.95
Voltage at Pmax (V)	17.2

ESC method diagram on Simulink is shown on Fig. III.6:

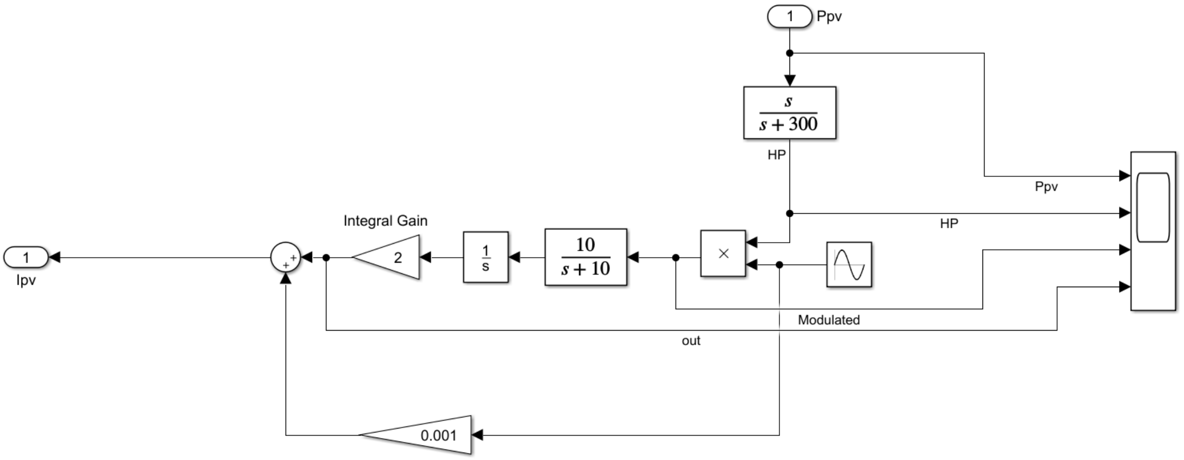

Fig. III.6 ESC method diagram on Simulink.

Boost DC-DC Blok on Simulink is showed on Fig. III.7:

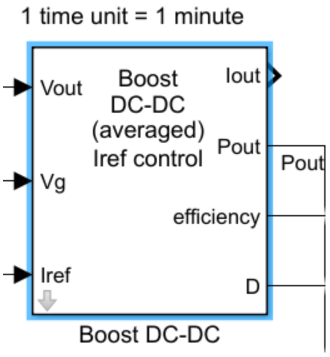

Fig. III.7 Boost DC-DC Blok on Simulink.

The DC-DC boost diagram is showed of Fig. III.8:

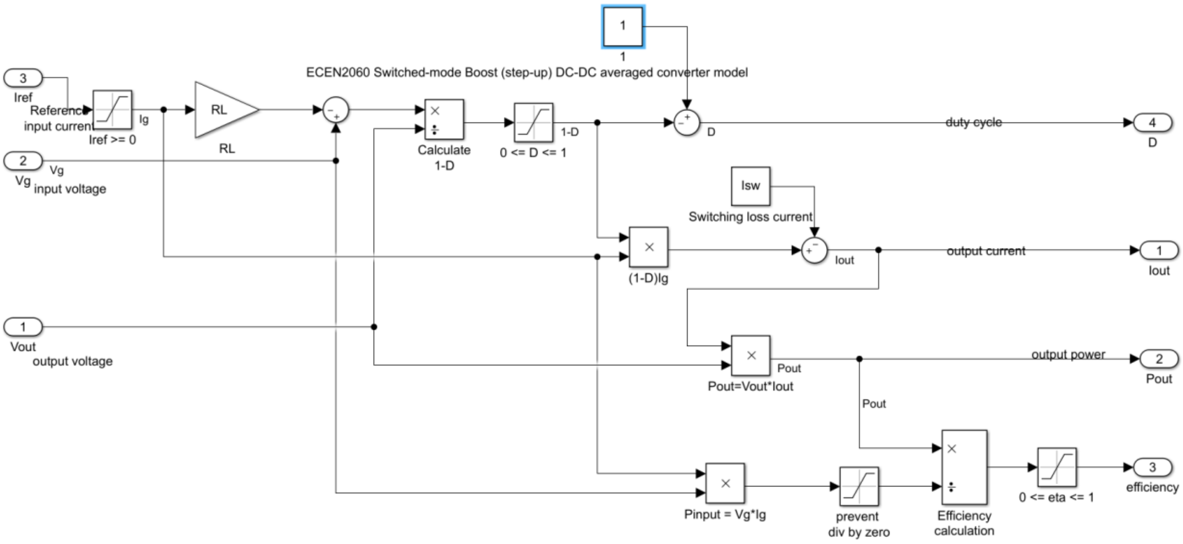

Fig. III.8 DC-DC Boost bloc diagram on Simulink.

In order to obtain a sinusoidal signal, the output from DC/DC boost converter should be transformed in alternative current and to do so we add inverter, but in our simulation, we didn’t simulate AC Load.

III.3.1 PV panels curves

For Irradiation fixed to 1000 W/m^2, and temperature varies [0,25,50,75] degrees we notice that the ideal temperature for best performance and results is 25 degrees.

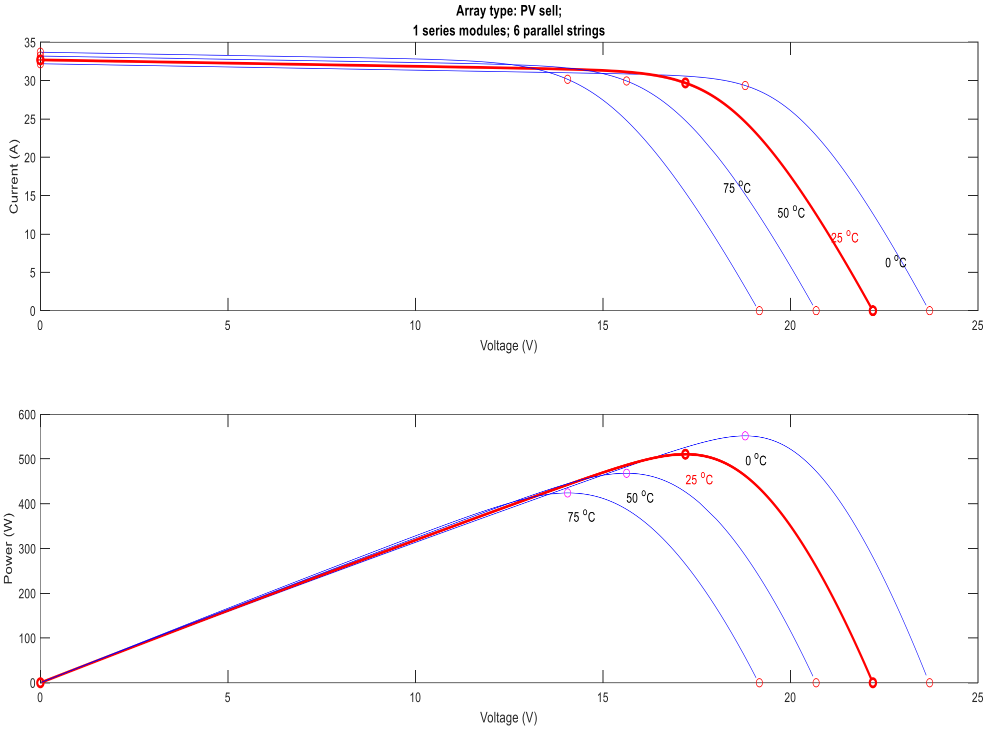

Fig. III.9 PV array characteristics under different temperatures.

For temperature fixed to 25 degree and Irradiation varies [0,400,850,950,1000] W/m^2, we notice that the ideal temperature for best performance and results is 25 degrees.

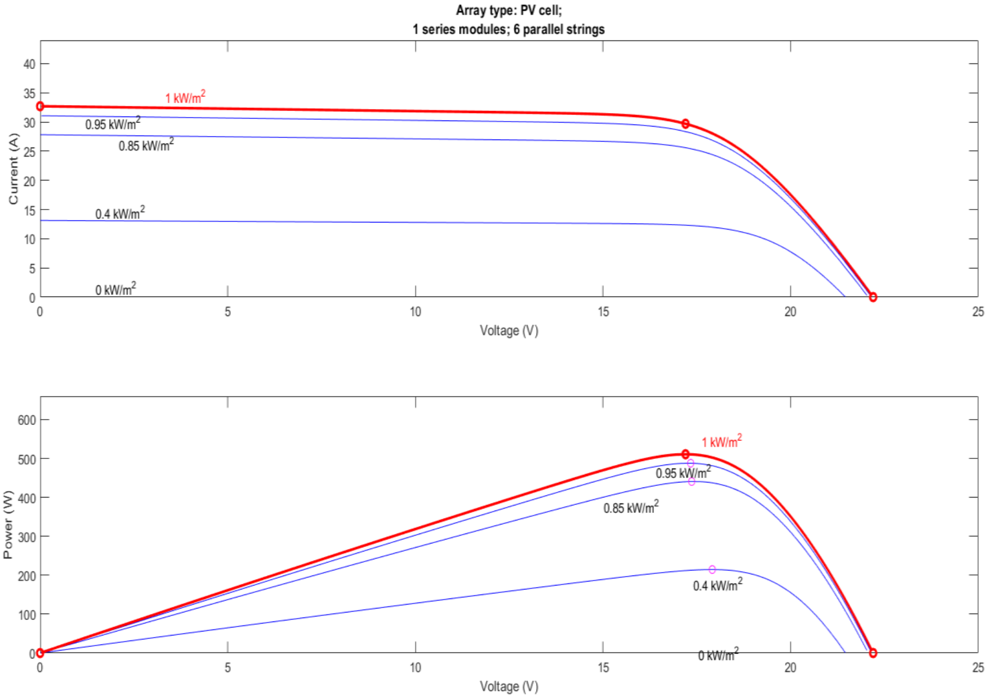

Fig. III.10 PV array characteristics under different irradiation.

We can clearly see here, the influence of the given scenario, the power is depending strongly on the irradiation. The maximum output voltage is 460 V.
The main criteria are to ensure a power output similar to the one generated using the PV system. Hence, a constant DC value should be found in the output of the DC/DC boost converter.

The simulation results of the boost converter, the duty cycle and the output from the grid are shown in Figs (III.11-15).

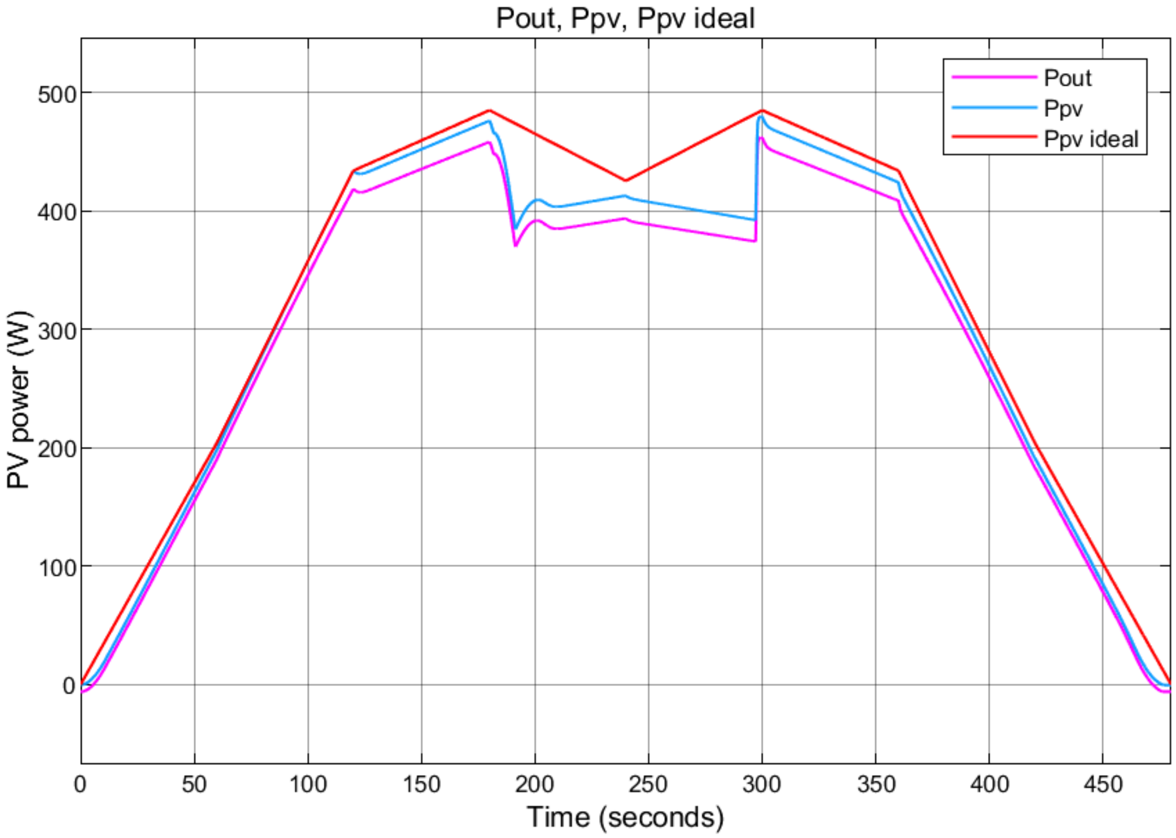

Fig. III.11 Comparison of PV Power output, and PV power and the Ideal PV power.

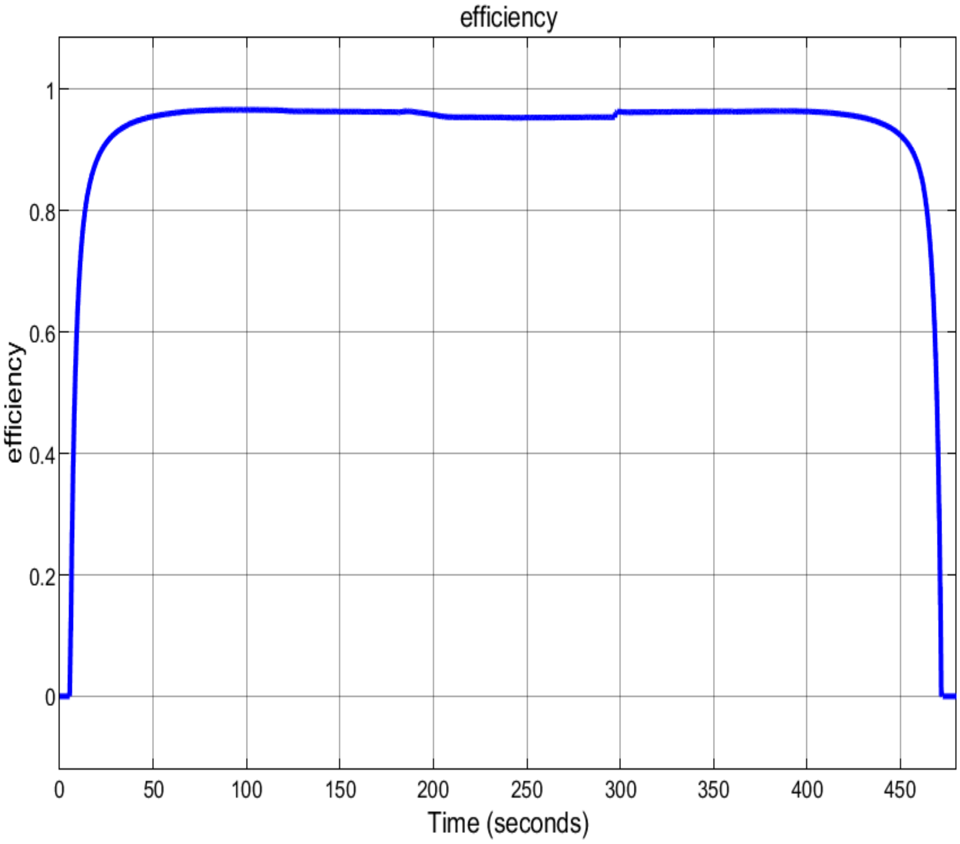

Fig. III.12 Boost DC-DC Efficiency.

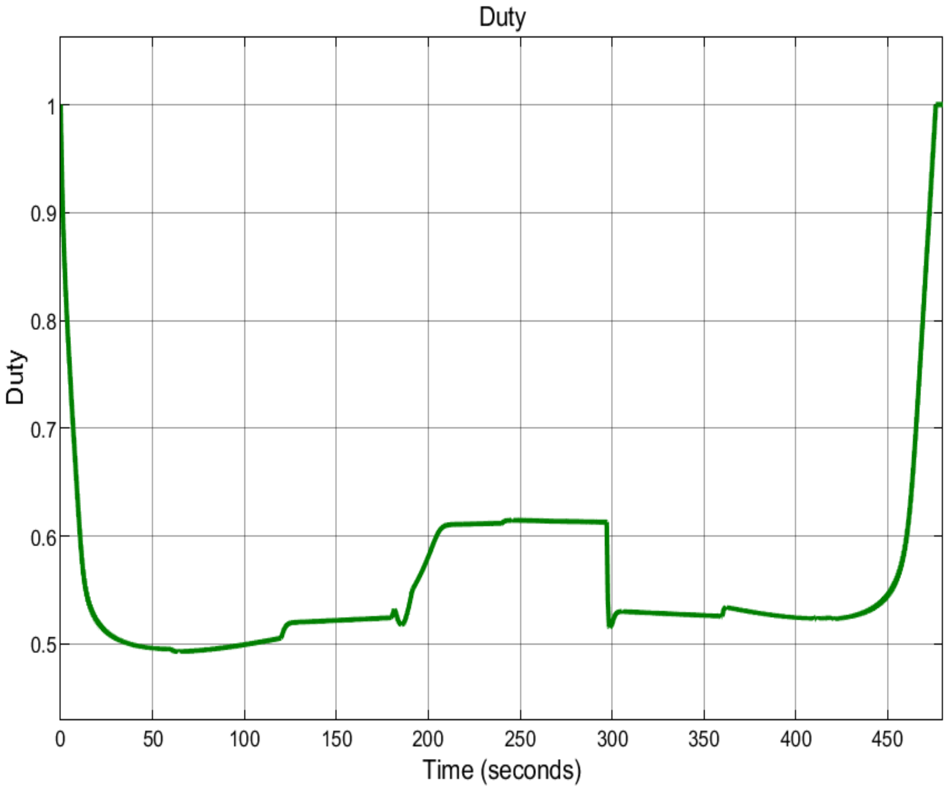

Fig. III.13 Boost DC-DC Duty.

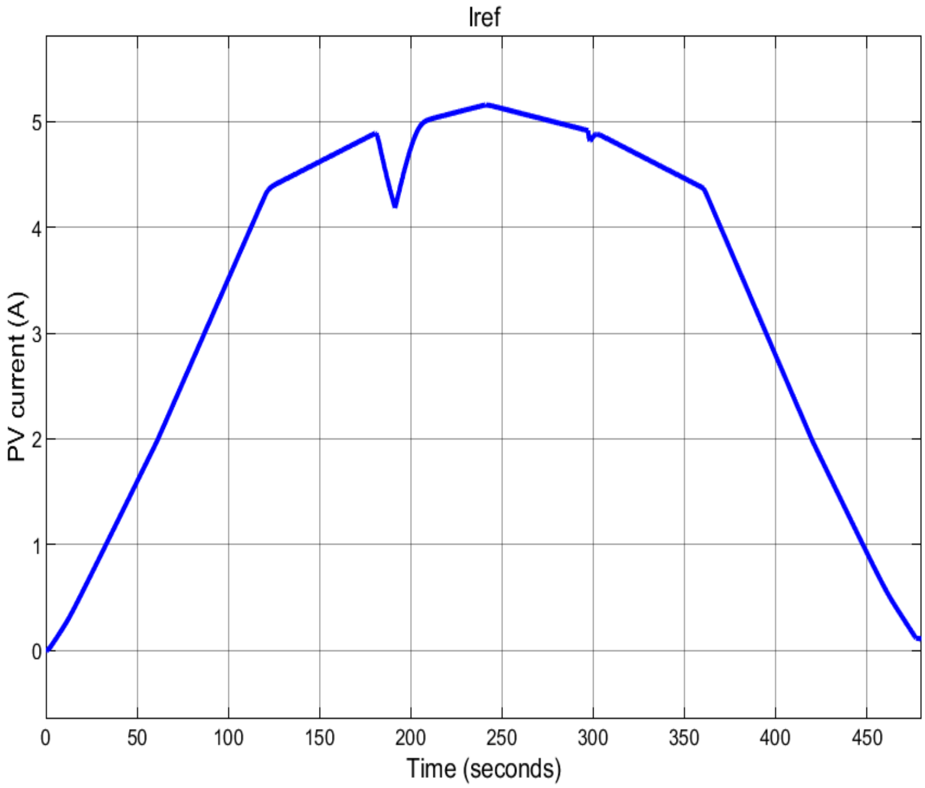

Fig. III.14 PV Reference currant (I ref).

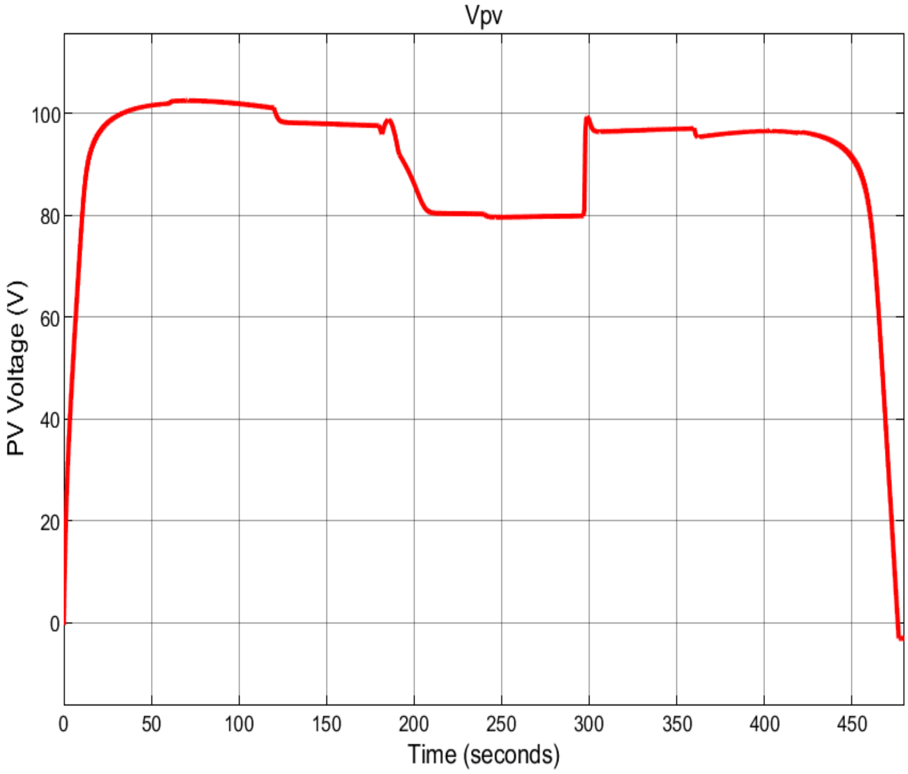

Fig. III.15 PV panel voltage.

From the plots, one can remark that the PV voltage follows its Maximum Voltage values. In the same manner, the output power (PV-power) is kept around its nominal values. The required duty cycle for is depicted in Fig. III.13 and it varies according to the MPPT strategy. The output power is equal practically to the (PV-power) with a little different which is due to the system losses. Finally, the DC voltage is regulated practically to its reference.

III.4 Conclusion

In this chapter, the maximum seeking control algorithm intervenes for achieving the MPPT by determining the needed duty cycle. Good dynamic performances have been observed. In fact, the output power is equal practically to the PV produced power with a little difference which is due to the system losses. In addition, the output power has followed its nominal value with an acceptable time response.

General Conclusion

General Conclusion

The improvement of the voltage at the end of an electrical network is a concern of the electricity distributor. In the rural grid network, the quality of the voltage will be unacceptable when the voltage drop exceeds 10%. The connection of the photovoltaic power plants to the electricity grid is a very popular solution to solve this problem by producing electrical energy at the point of the deficit.

This work has therefore focused on the modelling and simulation of a system: photovoltaic connected to the electrical network using MATLAB software (Simulink). We conducted this study in several steps: state of the art of appropriate renewable energies (photovoltaic), photovoltaic system modelling, static converters, maximum power point tracking method and photovoltaic system and finally, the simulation of the whole set.

The state of the art of renewable energies (photovoltaics) plays a leading role in such work. We started with a theoretical study of the characteristics of a primary source (solar radiation), then we were interested in the modes of integration of a photovoltaic power grid.

The modelling of the PV system consists in putting in equations the various parts constituting them: the primary source (temperature and solar radiation), the static converters: the Boost and Buck harvester, allowing the voltage control of the panel photovoltaic. It is therefore a question of optimizing the overall treatment of the electrical energy within the system and in particular at the level of the generator, by placing it at every moment at its optimum point of operation thanks to a tracking system of the type MPPT.

An MPPT system based on extremum-seeking control has been developed. The MPPT algorithm reported in our dissertation guarantees the stability of the maximum seeking procedure for large-signal operation. The theoretical predictions have been experimentally validated in a PV system consisting of a standard array and boost converter as a system load.

Further research contemplates the use of the MPPT algorithm in other PV systems, i.e., PV systems supplying different loads through different converters. Also, the combination of the MPPT algorithm and state-feedback control can be also searched.

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