A MODIFIED TECHNIQUE FOR MAXIMUM POWER POINT OF TRACKING OF PHOTOVOLTAIC SYSTEM

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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ABSTRACT

Due to the daily increase in energy demand and the sequential lack of non renewable sources of energy, the whole world is looking forward to finding new substitutes. The PV systems are one of the best alternatives for supplying power to individuals and utility. For maximizing the power achieved from PV modules, one of MPPT techniques should be used. Actually, there are various techniques that can be utilized depending on the application and regarding the complexity, cost, efficiency, stability, response time and atmospheric conditions One of the most efficient MPPT techniques is P&O technique which is a hill climbing method for the P-V curve where small perturbation value of voltage is applied and corresponding power is calculated till reaching MPP, while the corresponding voltage at this MPP is the V_{mpp}. Although this P&O technique is pretty known and used over a wide scale plus its simplicity, it still has some problems as relative slow response, oscillations around MPP and inaccuracy under fast changing atmospheric conditions. For better performance, these problems should be diminished as could as possible. Our new modified P&O technique tracked the MPP, analyzed the above problems and improved the response time, decreased the oscillations, increased the stability at steady state condition and increased the efficiency. This new modified P&O technique with the obtained results could be considered as a good reference and offers support to related researchers and manufacturers to the PV industry. By using appropriate micro-controller of normal complexity configurations, this new modified P&O technique could be successfully applied in various PV applications that require high efficient system with relatively low power losses.

Keywords : PV, efficiency, P&O, MPPT, MPP, V_{mpp}, oscillations

ÖZET

Enerji talebindeki artış nedeniyle günlük ve yenilenebilir enerji kaynaklar dışında enerji sağlıyacak kaynak eksikliği, bütün dünyayı mevcut enerji kaynaklarının yerine geçebilecek enerji üretimi arayışına yönlendirmiştir. PV sistemleri bireysel ve yardımcı güç sağlamak için en iyi alternatiflerden biridir. PV modülleri elde edilen gücü maksimize etmek için, MPPT tekniklerinden biri kullanmaktadır. P & O tekniği ile gerilim için küçük pertürbasyon değeri uygulanır PV eğrisi için tepe tırmanma yöntemidir ve bu MPP den gelen voltaj V_{mpp} ise gelen güç, MPP değerine ulaşana kadar hesaplanır. P & O tekniği oldukça bilinen ve geniş bir ölçekte kullanılmasına rağmen, hala hızla değişen atmosferik şartlarda göreceli yavaş tepki veren, MPP etrafında salınımları ve bazı sorunları var olan bir tekniktir. Bu tezde yapılan modifikasyonlar ile P & O tekniği ile ilgili yukarıdaki sorunların analiz edilmiş ve tepki süresi geliştirilmiş, salınımlar azalmıştır, MPP izlenen kararlı durum koşullarında stabilite artışı ve verimlilik arttışı sağlanmıştır. Elde edilen sonuçlarla bu yeni modifiye P & O tekniği iyi bir kaynak olarak Kabul edilebilir ve PV sektöründe ilgili araştırmacı ve üreticilere yön verebilir. Normal karmaşıklık yapılandırmaları uygun mikro denetleyici kullanarak, bu yeni değiştirilmiş P & O tekniği başarıyla nispeten düşük güç kayıpları yüksek verimli bir sistem gerektiren çeşitli PV uygulamalarında uygulanabilir.

Anahtar Kelimeler: PV, verimlilik, P & O, MPPT, MPP, V_{mpp}, salınımlar

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LIST OF ABBREVIATIONS

PV: Photovoltaic

DC: Direct Current

AC: Alternative Current

I: Electric Current

W: Watt

V: Voltage

P: Power

R : Resistance

V_{mpp}: Maximum Power Point Voltage

I_{mpp}: Maximum Power Point Current

MPPT: Maximum Power Point of Tracking

P&O: Perturb and Observe

Inc.Cond: Incremental Conductance

O.C: Open Circuit

S.C: Short Circuit

C.V: Constant Voltage

AGM: Absorb Glass Matt

C: Celsius.

F: Fahrenheit

M: Mega

OCC: One Cycle Control

FL: Fuzzy Logic

ANN: Artificial Neural Network

PSO: Particle Swarm Optimization.

GA: Genetic Algorithm

CHAPTER 1
INTRODUCTION

1.1 Introduction

Along the recent decades the whole world is looking forward to finding and developing efficient substitutes to the conventional non renewable sources of energy as coal, natural gas and petroleum. One of the most important issues that is subjected to continuous developments and updates and grapping enormous concern and attention is the photovoltaic system. The global installed capacity of solar power is more than 100GW and that makes it the biggest renewable source of energy just after Hydro and wind power. If we assumed that we will supply the whole world need of energy from PV systems only, we will need about 500,000 square Km area which is approximately equivalent to the area of Spain (Landart, 2013). For exploitation of spaces and areas, installation of PV cells may be ground mounted integrated with farming and grazing or roof or wall mounted of a building. The operating cost of PV is nearly negligible as there is no fuel used and maintenance cost is low as there are no moving parts among the the system and solar panels life time > 30 years and inverter may be changed only twice. The installation cost is still relatively high but due to government policies and recent developments there is significant cost reduction occurs about 5-7 % per year.

One of the main issues that are continuously under research and development is the MPPT. Where maximum power point of tracking technique is a developed control feature combined with the PV systems in order to maximize the efficiency output from the modules by tracking the maximum point. MPPT techniques are influenced by environmental conditions and changing temperature values where the temperature is related to the irradiance levels. As a result, the MPPT techniques should be dependent on the irradiance. There are several methods or techniques that are developed in order to obtain maximum power from the PV system according to the irradiance and the application. The PV system may be a standalone off-grid system and may be connected to the utility grid depending on the application and economics that differ from place to place and from one country to another. Connecting the PV system to utility is usually preferred due to ease of installation where there is no need to attached battery system as a must plus being more economic as it reduces cost of bill by selling extra electricity to the electric company and for both types, MPPT is an essential component that should be imbedded in the PV system.

Recent developments and researches are in continuous progress where PV applications are not limited to supplying power to small buildings and appliances only but they included wide scale of applications as mega power stations, space craft, telecommunication, float voltaic, transportation, hybrid systems and lighting roads ways.

The highest efficient solar cell was produced on April 2011 with (η=43.5%) using multi-junction concentrator while the highest efficiency without concentrator was produced on 2009 reached 35.8% using triple junction technology (Greentech, 2011). Hereunder in Figure 1.1, we can see the percentage share of production of Photovoltaic modules among the world.

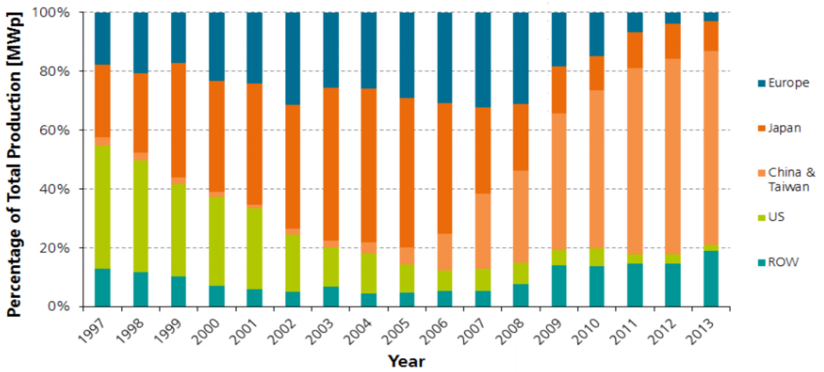

Figure 1.1: PV productions by regions (Paula mints, 2014)

1.2 Aim of Thesis

The aim of this thesis is developing an efficient technique for MPPT that takes into consideration the main problems that are facing current MPPT techniques and try to overcome them. The new modified technique should be able to eliminate or minimize the errors that are produced in achieving the MPP specially those oscillations that occur around maximum point.

1.3 Thesis Structure

In this thesis, first chapter generally talks about the photovoltaic system; its main components, production share among the world and a brief introduction to the MPPT. Second Chapter will involve the PV system types according to grid connection then the causes, the effects and the solutions for anti islanding problem among the PV system will be discussed. Mentioning the types, used materials and some considerations regarding the solar panels followed by an overview of the PV batteries, wiring and cables and cost of PV system installation. Chapter Three will include the DC-DC converter topologies, types and relation to the MPPT controller. Chapter Four will involve a brief review to most of MPPT techniques and the criteria among which the MPPT different techniques are evaluated. Chapter Five is presenting the methodology of my new modified technique; analyzing and discussing the problems then developing a proper solution and comparison with other techniques after obtaining the results. Finally in Chapter Six a new conclusion and some recommendations will be stated for future work.

1.4 Basic Components of PV System

1-PV modules/arrays: single solar cells are connected together to form a module and then modules are connected together to form a PV array.

2-Solar tracker: for more efficient system, solar trackers aim to receive more light on the surface by adjusting the panels to face sun rays in a perpendicular angle.

3-DC-DC converter integrated with MPPT controller: in order to generate a controlled duty cycle to achieve maximum power tracking

4-Inverter: Responsible for converting the produced DC current from the PV into AC so it can be connected successfully to the utility grid.

5- Rechargeable Battery: Rarely used due to high cost but nowadays they are increasingly used these batteries for energy storing in order to be used at night or feed the grid in case of extra high demand

6-Utility Meter: measure the amount of power consumption or even the power fed into the grid.

7-Monitoring: for tracking the performance of the PV system.

1.5 Advantages of Integrating MPPT Controller Within a PV System

- Guarantee maximum power achievement
- Ease of installation as it is an embedded algorithm in microcontroller
- Variety of techniques that can be implemented
- Absence of noise due to absence of mechanical motion
- No extra space is needed due to being small sized component

1.6 Constraints for Implementing MPPT System

- Having only 1 maximum point for operation
- Need of additional microcontroller and DC-DC converter system
- Requires current or voltage sensors or even both
- Partial shading may affect the performance of MPPT
- Different efficiency obtained from each technique

CHAPTER 2
SOLAR ENERGY PV SYSTEM

Sun transfers 2 main types of different energy to earth. The first type is the heat energy that is used as thermal power form for warming and heating applications.

The second type is the solar irradiance that can be converted into electric energy by means of photovoltaic system.

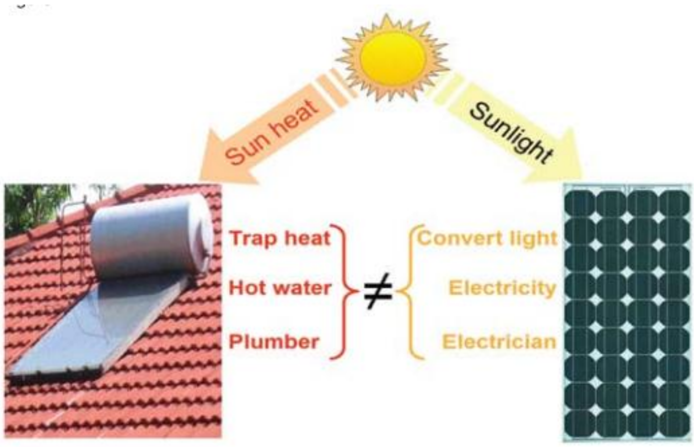

Figure 2.1: Difference between Solar thermal& solar PV systems

Related to the end-user, we can classify PV system to 2 main types; grid connected type and off grid type.

2.1 Grid Connected PV System

The grid connected PV system is widely used in some countries and preferred over off grid types as in USA and Europe (90% and 99%) respectively as a percentage, where the PV system is connected to the utility grid (Epia, 2014). Grid connected PV systems can be small systems mounted on the top the roof of some buildings or they can be as large as installed mega power stations.

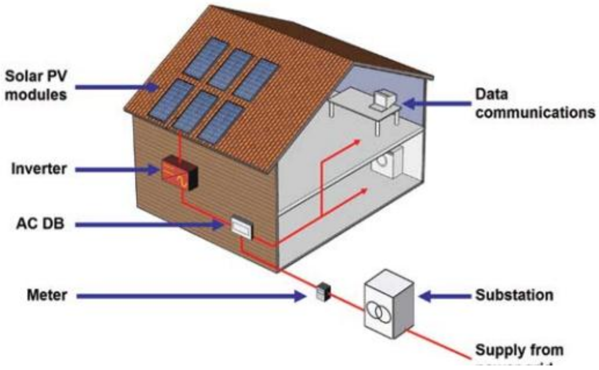

Figure 2.2: Grid connected PV systems

The rechargeable battery within the PV system is rarely used due to its high cost and not very useful benefit as the system is already connected to the grid. A capacity of 10 kW of a PV system roof topped can successfully satisfy the load of a house. In some times of the day, there may be excess in the power produced than the power demanded. At this condition, the excess power can feed the utility grid. In other times at cloudy or rainy weather or even at night, the consumer will have to deliver power from the utility grid in case of absence of attached storage battery system to the PV system. The operation with a grid connected PV system comes with an economical benefit to the consumer as the power generated from PV system can be sold to the electric company at excess conditions. While the amount of electricity delivered from the electric company to the consumer at shortage times of PV system operation can be subtracted from that delivered to it. Even in case of low capacity installed PV system, at least the electric bill will be reduced to a comfort level than before. Of course there should be a detailed agreement between the electric company and the consumer for the interconnection between the PV system and the grid. This agreement should consider the safety standards as well as the expenses and running mechanism.

Another important feature that should be taken into consideration is the grid connected inverter that converts the DC power produced from PV into AC; so that it can successfully synchronize with the AC grid system. The inverter may have 2 different configurations; one large inverter or small inverters each one attached to a solar panel independently. The inverter should be attached with monitoring features to monitor frequency, voltage, and power and wave form for 2 main reasons:

- To facilitate connection with the grid by synchronizing the wave form and producing a voltage slightly higher than the grid voltage for smooth flow of power to the grid
- In case of grid failure, the inverter should automatically disconnect the PV from the grid for safety rules and standards.

2.1.1 Advantages of grid connected system

- Ease of installation as there is no need to battery system
- Economical benefit due to selling electricity or even reduction of bills
- Reduces energy losses due to absence of storage criteria

2.1.2 Disadvantages of grid connected system

- Appearance of some power quality problems as voltage flicker due to fast PV voltage change
- Voltage regulations may exceed the acceptable levels (±5%) due to voltage difference between grid and PV system
- Increase the percentage of connected PV systems to a grid may cause protection problems as Islanding.

2.2 Off Grid PV System

Off grid PV systems is unconnected to the utility grid unlike the previous type. This isolation from the utility may come for several reasons as below:

- In case of faraway regions as islands and rural areas
- Avoiding high cost of connection with the grid
- Some people like complete independence of living including energy consumption
- Having the advantage of silence and being clean energy standalone alternative

This type of PV system has to be attached with a battery system for energy storing. This energy is used at times of leakage PV system or even at night where there is no power output from PV produced. In this type "off grid PV system", we can work on DC power directly without the need of installing inverter system to produce AC. These cases are wide among some applications as RV, boats and small cabins where the lights, televisions, radios and refrigerators can be driven on DC supply instead of bearing additional expenses and high cost of inverter system installation.

2.3 Anti-Islanding

Islanding in a PV grid connected system means continuing of supplying power to a location where the grid is out of service or blacked out at that time. Islanding may cause some problems to the power system as preventing automatic re closure of circuit breakers and other electronic devices among the system. Islanding can even represent safety problems to the utility workers as they assume that the power is switched on the system. So these problems have to be detected by means of anti-islanding process. Anti-islanding means detecting the above condition "islanding" and stop producing power automatically. The word "islanding" actually came from the condition that occurs; in case of the utility failure, the solar panels continue to supply power as normal to the utility as the sun is shining. Supplied power to the utility at this condition comes only from solar panels so it looks like an island surrounded by a sea of off-power lines. So the solar PV inverters have to be characterized by added features of detecting islanding condition and automatically anti-island it from the circuit.

2.3.1 Reasons for anti islanding

- Crew safety: The crew working on maintenance may be subjected to danger due to unexpected live cables.
- End user equipment damage: may happen due to change in power parameters
- Ending failures: Automatic reclosing the system on an island may cause failure of noticing the problem as the reclosure might re energize again leading to problems with utility equipment problems and distributed generation system may not match the grid again.
- Confusion of Inverters: confusion of inverter devices may happen if the circuit is closed on an island

Regarding the first reason related to the crew safety, actually the electrical workers are continuously exposed to similar cases of unexpected line wires in their normal daily work. That built an accumulated experience before starting working to always test the line -hot line or even dead line. These followed rules can widely decrease the danger of receiving an electric shock to be negligible. United Kingdom based studies state that danger of exposing to electric shock under worst case of PV scenarios is than $1x10^{-9}$ per year (Neil, 2002). Regarding the second reason, most equipments and devices have a threshold value that can protect them from damage. While the remaining third and fourth reasons are the issues that should have more concern than previous ones. As a result of Islanding problem; some electric companies refuse to install distributed generation systems or even make some limitations regarding the branch capacity to be 50 % and even less (Hydro One, 2010). An Experiment carried out in Netherlands on 1999 reported that island condition problem couldn't last more than 1 minute. Moreover, in order to form a real island problem a balance condition should exist and the Grid disconnects at the same time.

2.3.2 Islanding detection methods

A. Passive methods

It depends on detecting the transient events on the grid as:

- Under or over voltage
- Under or over frequency
- Voltage phase jump detection
- Rate of change of frequency
- Harmonics detection

B. Active methods

Depends on sending small signals across the line and then detect the grid failure if these signals change as:

- Negative sequence current injection
- Impedance measurement
- Slip mode frequency shift

C. Utility methods

Also the utility itself has some methods to force system to stop in case of failure as using:

- Manual disconnection
- Automatic disconnection
- SCADA system

2.4 Solar Panels

The idea of solar panels first started as early as 1839 when Antoine Cesar exposed a chemical battery to sunlight and it produced voltage. That was the first conversion of solar energy to electricity with efficiency 1 percentage (Williams, 1960). In 1873, Willoughby Smith discovered Selenium material is sensitive to light (Smith, 1873). In 1877, Adam & Day found that Selenium material on exposing to light can produce electric current (Adams, 1877). In 1880, Charles Fritts invented the first solar cell from gold coated Selenium with efficiency 1 percent (Fritts, 1883). In 1905, Albert Einstein explained the photo-electric effect that states that metals can gain and absorb energy from light and retain it which increased the hope of having higher efficiency from solar cells. Afterwards, researches on diodes and transistors began to increase. In 1954, Bell, Chapin, Pearson and Fuller succeeded to invent a silicon solar cell of 6% efficiency (Chapin, 1954).

By the time, the efficiency of solar cells increased to reach 15% and were also used in far regions from power stations to supply the telephone systems. Recently, solar cells become the best alternatives used to supply power for several applications as artificial satellites where other sources of energy are much heavier and need long journeys to transfer to the specified regions. Nevertheless, solar cells are till nowadays not large scaled wide to supply domestic and industrial needs. Only 1 percent is the share of solar power compared to other sources of energy with an average annually increase about 50 mega watts (Epia, 2015). As a result, there are still more efforts and researches should be accomplished to improve the efficiency of PV systems.

2.4.1 Three main types of solar panels

1- *Mono crystalline solar panels*

They consist of extremely high pure silicon solar cells and sophisticated crystal process. The wafers are cut from long rods of silicon with thickness of slice varies from 0.2 to 0.4 millimeter. Mono crystalline solar cells are considered the most expensive cells but with highest efficiency.

2- *Poly crystalline solar panels*

These types of solar cells are not single crystal configuration but many crystals are combined together. This crystalline configuration gives the cell glass shape. Poly crystalline solar cells are less expensive than mono crystalline and with lower efficiency. They can also be called multi crystalline solar cells.

3- *Amorphous solar panel*

Unlike the mono crystalline and poly crystalline solar panels, Amorphous solar cells are not actually of crystal structure. They are formed from thin layers of silicon that are deposited on glass or metal to form a solar panel. Of course this type appears to be much cheaper than the first two types with lower efficiency. As a result, it is recommended on choosing Amorphous solar panels as an alternative, to maximize the surface area of solar panels as possible to produce a satisfying power need. The roof surfaces can be covered with Amorphous layers to achieve the recommended large exposed surface area of solar panels.

2.4.2 Shading, temperature and wind considerations affect

On choosing a location for installing the solar panels, it is very essential to check the sunlight path during the day and during the peak hours to ensure that there are no shadows on the solar panels during this period. Shadow effect as well as decreasing the output and efficiency, it can also cause damage for some types of systems where there are no protection schemes against shading exist. In some cases, it is obligatory to remove some obstacles like trees if there are no wide scale choices regarding the location of solar panels installation. Not only caring for the sunny and non shaded locations is important as it is recorded that as the temperature increases, the efficiency of solar panels decreases so there should be spacing between solar panels in order to allow circulation of air between them so the temperature can be decreased and the cell will be cooled.

2.4.3 Types of mounting of solar panels

1- *Fixed solar panels*

Fixed solar panels are of course the simplest and cheapest mounting type of solar cells. The stationary position of this type should always face the equator.

The angle of inclination should be adjusted carefully regarding the mounting height as well. Setting more latitude is perfectly facing the sun at winter while lowering the latitude perfectly faces the sun at summer.

2- Adjustable solar panels

The adjustable mounting solar panels are like a modification on the fixed type by allowing 2 or more angles of inclinations. For 2 angles of inclinations, it is recommended that the latitude will be -15° in summer and +15° in winter. This modification can increase the efficiency of solar panel by 25 %.

The perfect time to adjust the angle of inclination in summer is at the middle of March while in winter, it is recommended to be in the middle of October. For more output, the angle of inclination could be adjusted till 4 times per year (Landau, 2012).

3- Tracking solar panels

Tracking solar panels have the best efficiency of the 3 types as the panels are designed to track the sun path all over the day time. By using single axis tracker, the panels can track the sun from east to west. While using double or 2 axis tracker, the solar panels can track the sun from east to west plus an extra axis for seasonal adjustments for the declination of the sun.

Although the tracking solar panels record the highest efficiency, the cost should be regarded and calculated. The tracking solar panels can give an average increase in power output from 20 to 30 % but this extra price can be paid by buying 25 % more panels of cheaper type that produce this difference in power increase (Feldman, 2012). Moreover, comparing the mechanical failures due to technical or environmental effects, it is preferred to install adjustable mounting type of solar panel.

2.4.4 Classification of solar cells According to used material

Actually there are 2 main types of materials used in the manufacturing of solar cells. The widely known and globally used material is silicon based type. The silicon material is generally expensive and requires extra efforts and special requirements to form a finalized solar panel. This issue has a great role in increasing the price of solar panels installation. After many researches, a new material called Perovskite has been found to compete with traditional silicon in forming photovoltaic cells.

2.4.4.1 Silicon solar cells

A-Raw materials

The main component of the solar cell is pure silicon material which is derived from silicon dioxide. The next step is doping the pure silicon with phosphorus and baron to increase the production and the efficiency of the electrons so the product become conducting semiconductor to electricity. The silicon is shiny material that needs a reflective coating as titanium dioxide. The solar module which is mainly consists of silicon should be surrounded by protective material made of encapsulated transparent silicon rubber bonded around the cell and then embedded with ethylene vinyl Acetate.

B- Manufacture process

1-Purifying Silicon

Silicon dioxide is put in an electrical furnace where carbon arc is applied and oxygen is released to produce molten silicon. The product is 99 percent pure silicon but with 1 percent impurities (Pizzini, 2010). This ratio may be good for wide industrial applications except solar cells. For further purification, a rod of silicon is passed by a heated zone many times in one direction; resulting in forcing impurities to drag towards one end**.** This process is called floating zone technique.

2-Making single crystalline silicon

Silicon boules are polycrystalline structures that form the atomic structure of a single crystal. In order to construct these bouls, a common method called "Czochralski method" is used where seed of crystalline silicon is dipped into molten polycrystalline silicon. Boule of silicon is then formed when the seed crystal is withdrawn and rotated. But the boule produced is not pure as impurities are still remaining in the liquid (Czochralski, 1918).

3-Making silicon wafers

After forming the boule, silicon wafers are cut into slices using one circular saw or multi-wire saw to cut multi slices at the same time of 5 millimeter thick. This process wastes about 50% of the silicon boule. Moreover, if the wafers are cut into rectangular or hexagonal shapes, the losses will be even more. These rectangular and hexagonal wafers are used in solar cells for better configuration as they can get together better so this will utilize all available space in front of the cells. An added process may be applied, is polishing the wafer in order to remove the marks of the saw.

4-Doping

Doping is done to add impurities as boron and phosphorous to the silicon wafers. Then the wafers are arranged back to back and are heated to a level just before melting point of silicon in the presence of phosphorous gas. While the temperature should be tightly controlled so that the junction become uniform and with proper depth (Synopsys, 2012). Another new method for doping is using small particle accelerator to shot the ions of phosphorous. The penetrating depth is determined by controlling the ions speed shooting. This method of doping is unfortunately not accepted by commercial manufactures for technical reasons.

5-Placing electrical contacts

Each solar cell is connected to each other and connected to the receiver of the produced current by 7 electrical contacts. In order to not block sunlight, these contacts have to be very thin. After the contacts become in right places, thin strip fingers of tin coated copper should be placed between cells.

6-the anti-reflective coating

The pure silicon can reflect about 35% of the sunlight due to its shiness. Anti-reflective coating should cover the silicon to reduce the losses produced from reflection of sunlight. Silicon dioxide and titanious dioxide are the most known coatings used. This anti-reflective material by time is heated resulting in boiling its molecules and condensing on silicon or even sputtering.

7-Encapsulating the cell

The last step among the manufacturing process is encapsulating the solar cell by sealing into silicon rubber or ethylene vinyl acetate. Then putting these cells in an aluminum frame of plastic cover or maylar back sheet.

C- Quality control

The efficiency of solar cells can be badly affected by many factors and processes that occur on them. So the quality control is very essential to demand the highest efficiency for long period of time. Besides the efficiency, the cost of solar cells and arrays is a very important issue that has gone under many developments and research to minimize the cost as possible. The most important and one of the biggest researches was initiated by US department of energy in 1970 and it was named the low cost solar array project. Silicon goes under several tests for resistivity, purity and crystal orientation. Presence of oxygen is also an important test that affects the strength and warping of the material. As well as oxygen, carbon dioxide presence should also be tested because it causes defects. After finishing the silicon disk, they should be inspected for bending, sawing, etching, damage and polishing. While during manufacturing process of the silicon disks, several variables should be monitored as pressure, temperature, speed and doping quantities. The impurities should also be taken into consideration to be kept to minimum value. After that, some electrical tests should be applied to test voltage, current and resistance to ensure whether they follow the appropriate standards. Partial shading may cause solar cells to stop working. So shunt diodes are recommended to be added to reduce critical high voltage on the solar cells. The solar cells also go under essential test to examine the intensity of light that they could encounter at normal conditions. The other tests are tests against vibration; twisting, heat and cold are carried out. The last test is actually carried out at the site in the place where the PV modules will be installed in order to get real values of efficiency and effective time under normal working conditions and ambient temperature.

2.4.4.2 Perovskite solar cells

Perovskite is a material consists of hybrid lead or tin halide based material. The use of Perovskite in the manufacturing structure of solar cell is a good alternative to silicon due to its lower cost with high efficiency. In 2009, Perovskite solar cells had efficiency of 3.8% (Hyeoh, 2011). But this percentage has dramatically increased to reach 20.1% in 2014. While it has concluded that the maximum efficiency level the Perovskite solar cells may reach is 31%. As a result of these advantages, Perovskite became an attractive alternative select for solar cells and by 2017, companies promise to supply huge product line for PV modules made of Perovskite. Figure 2.3 shows a Perovskite solar cell model configuration.

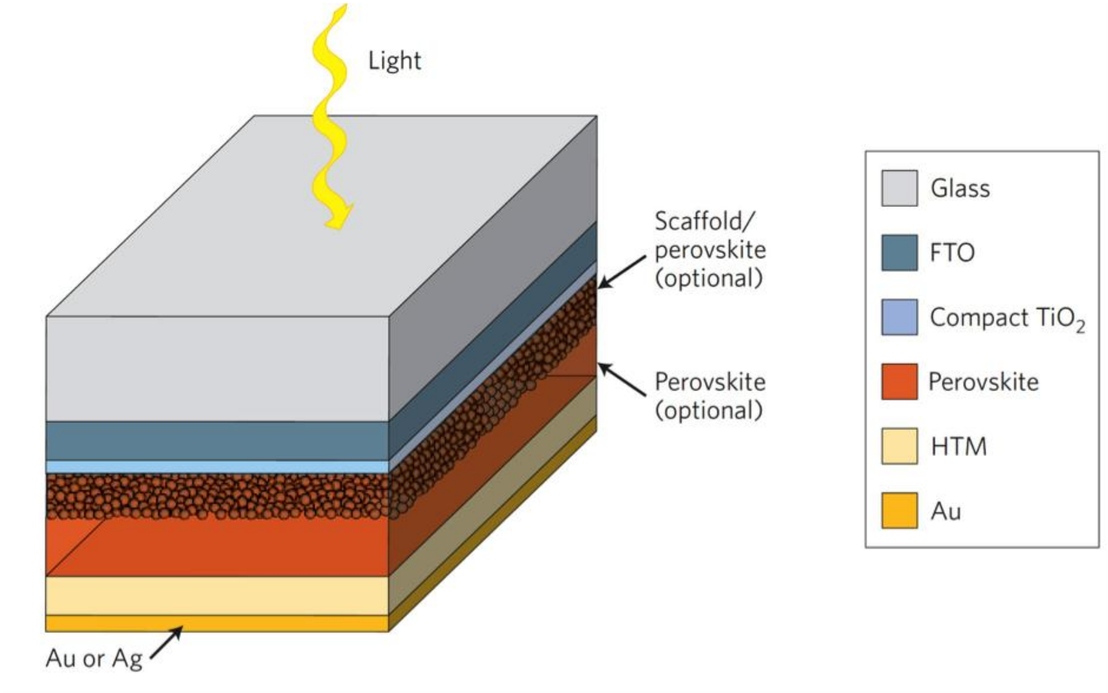

Figure 2.3: Perovskite solar cell model (Martin, 2014)

A- Manufacture

Regarding the manufacturing and the processing step, Perovskite is much simpler. As we showed before in details, many steps should be occurred on silicon that require very high temperature, high cost and clean environment to produce the purified silicon wafers. While the Perovskite is easier in manufacturing using wet chemistry and simple technology that can be available in a tradition lab without any complications.

B- Challenges

The solar cells efficiency is determined from observing the behavior of (I-V) curve either in the field environment or using a solar simulator. Unfortunately, the behavior of (I-V) curve of Perovskite solar cells has been observed to be in converse to other types of solar cell materials as it has hysteresis behavior. Several proposals and justifications have been stated for this hysteresis behavior such as polarization, ions movement and ferroelectric effects. Certain justifications for this behavior haven’t been reached yet and so this issue still requires further research. The hysteresis behavior may cause problems regarding the solar cells efficiency calculations because of the inflated values that can be produced. These inflated values are resulted from exceeding the time scale that Perovskite needs to reach steady state condition. There are two proposed solutions for this problem. The first is stated by "Unger" that the PV system can settle down at steady state for each measuring point just by using a very slow voltage scans (Unger, 2014). The second proposed solution is stated by "Henry Snaith" which is using a stabilized power output for solar cells efficiency measurement. The value stated can be achieved by keeping the test device at maximum power point with a constant voltage and tracking the output power until reaching constant value (Snaith, 2012). Regarding the two previous solutions, it has been observed that they decrease the efficiency of the Perovskite solar cells due to their slow (I-V) scanning. However the hysteresis characteristics have been observed, it has not taken the equitable concern yet. Very few publications and articles discuss generally this subject. In contrast the rapid (I-V) curve scan characteristics are assumed and all results depend on it. Nevertheless, some accredited certified laboratories regard the hysteresis effect. Where NREL has recorded in 2014 Perovskite solar cells efficiency regarding the hysteresis effect to be 20.1% but has also stated that it isn’t stabilized.

2.5 PV Batteries

Battery systems are used in PV systems especially in the off-grid systems in order to save energy to be used in the absence of sunlight at night.

2.5.1 Four main types of batteries that can be used among PV system.

1-RV/Golf/Marine

This type of deep cycle battery is basically used for boats, RVs and very small systems. Unfortunately, this battery is not durable i.e. can't sustain working continuously for many years of charging and discharging. A smarter type of batteries is used for golf carts but they are more expensive than that ones used among boats. Now we can move to heavy industrial batteries that are deep cycle as well and usually made of Lead acid and with thicker internal plates that can sustain deep charge and discharge cycles.

2-Flooded types

These types of batteries are widely used among PV industry. The flooded types are basically made from Lead acid. It is not recommended to keep the flooded batteries inside home as they produce some gases on charging. For enclosed batteries, a good ventilation system should be installed to avoid the risk of explosion. Flooded batteries are not very expensive besides being durable.

3-Gel types

These types of batteries unlike the flooded types don't produce any gases during charging so they can be sealed and don't need any types of ventilations. As a result, Gel type batteries can be used indoor and have better operation characteristics as they can be maintained at a constant temperature.

4-AGM types (absorb glass mat batteries)

These batteries are considered the best choice for PV system despite their relatively high cost. Like the Gel types AGM batteries don't produce any gases during charging. In the structure of the battery a woven glass mat is put between to keep the electrolyte hold between the plates. They are also proof against spilling and leaking. They even have better performance than the Gel types regarding the voltage maintain, the quality, durability and slow discharge (Yu Chang, 2009). As a result, AGM types are widely used in hospitals, aero planes and faraway telephone system.

2.5.2 Other features

Temperature and humidity are considerable variables that affect the batteries where the battery rating is mostly specified at 77 degree Fahrenheit. At cold environment, the performance and voltage drop on the battery increase. Another feature should be taken into account is the "Depth of Discharge" that means that at how much depth is the battery discharged i.e. how much is the voltage drop before reaching the next cycle of charging. Average depth of discharge value for batteries is about 50% while the Lead acid batteries have higher values of depth of discharge that can reach 100% in some types.

2.6 Wires and Cables

It is very important to choose the right wires and cables to connect between the components of PV system. The sizing of the wires should be carefully selected to avoid overheating, fire and damages. The voltage drop across the wires should be also calculated and to be minimized as could as possible where as voltage drop decreases, power losses decrease as well. It is recommended that the voltage drop along the wires don't exceed 4 %. Generally for a home installed PV system, copper conductors are recommended and preferred over aluminum conductors. Although aluminum conductors are cheaper, they have higher voltage drop and strength than copper conductors. For calculating the regular size of wires, the following steps should be carefully regarded.

- Modules and array configuration
- Specifications of the inverter
- Presence of junction box or not
- Coldest and hottest temperature
- Number and specifications of over current devices
- Type of conductors used in wiring
- Distance will be extended/ traveled by wires

2.6.1 Conductor and wire types

PV systems use exposed single conductor wires for the connections of the circuits in PV array. Another accepted new types of conductors are "USE-2" and "PV wire" that are single conductors with double jack. Most manufacturers supply the PV module attached with 2 pre-installed single conductors to the junction box. USE-2/ PV wires are usually used to connect between the combiner box and the PV modules with an over current protection device (Ryan, 2013). Different types of wires can be used depending on the environment and atmosphere as following

- USE-2 and PV wires are preferred for outdoor wet conditions as they can resist ultra violet rays and moisture
- THHN wires are preferred for indoor and dry locations
- USE and UF are preferable for underground and moisture applications
- THW,TW and THWN are used in conduits and are preferable for outdoor wet applications

For more details Table 2.1 can illustrate the wires applications and their insulations.

Table 2.1: Conductors applications and insulation (NEC, 2011)

Type Letter	Name	Max Provisions	Application Provisions	Insulation	Outer covering
THHN	Heat Resistant Thermoplastic	90 C,194 F	Dry or Damp Locations	Flame retardant, heat resistant thermoplastic	Nylon jacket or equivalent
THW	Moisture & Heat Resistant Thermoplastic	75-90C,167-194 F	Dry or Wet Locations	Flame retardant, moisture heat resistant thermoplastic	None
THWN	Moisture & Heat Resistant Thermoplastic	75 C, 167 F	Dry or Wet Locations	Flame retardant, moisture heat resistant thermoplastic	Nylon jacket or equivalent
TW	Moisture Resistant Thermoplastic	60 C, 140 F	Dry or Wet Locations	Flame retardant, moisture resistant thermoplastic	None
UF and USE	Underground Feeder & Branch Circuit Cable- Single Conductor	60-75 C, 140-167 F	Service Entrance	moisture and heat resistant	Integral with insulation and Moisture resistant

2.6.2 Conductors' colors

Figure 2.4: Conductors colors

According to NEC, coloring of wires is an essential issue as by the aid of the colors of the wires, we can discriminate between different types of wires. Generally, the black color is used for wires that are not undergrounded as the black conductors are specified by longer life time and good resistance to ultra violet rays. White color wires are used for the grounded second conductor. While the third wire that is used for grounding the equipments is mostly green (Bas, 2010). The following Table 2.2 is an illustration of color coding for AC and DC extracted from NEC article 310 P.15

Table 2.2: Conductors Colors (NEC, 2011)

Alternating Current(AC)		**Direct Current (DC)**	
Color	**Application**	**Color**	**Application**
Black, Red or Other Color	Un-Grounded Hot	Red	Positive
White	Grounded Conductor	White	Negative or Grounded Conductor
Green or Bare	Equipment Ground	Green or Bare	Equipment Ground

2.6.3 Solid or stranded

Standard wires are preferable in case of large sized wires where the cable consists of small wires. This alternative increase the flexibility of the wires as well as the conductivity as the surface exposed to current is larger.

2.6.4 Wiring management

PV modules that are attached with pre-installed conductors are actually very useful and save a lot of time at installation in site. But there are some requirements that may differ from one place to another depending on the environment. As example, snowy, rainy, windy, forest environments. The presence of some kinds animals can also damage or chew the wires. Generally, the wires should be tightly secured and protected against any type of damage as the warranty period for PV systems may reach 25 years with rare maintenance during this period. So the expert or the installer person should have a good knowledge and experience about managing this issue.

2.7 Cost of PV Systems Installation

The cost of installing a PV system generally is in continuous reduction day after day. Although the cost till nowadays is considered relatively high compared to other sources of energy, there were many plans to reduce the prices of PV systems about 75 % from 2010 till 2020. This great reduction policy is widely supported by many governments for environmental and economical reasons. This lead to the rapid growth of clean PV market. Figure 2.5 shows the historic curve for PV prices starting from 1992 till reaching 2012. As observed from the curve, the cost for PV installation was dramatically very high at 1992. The prices start to decrease gradually until reaching 2000. From 2000 till 2008, the prices recorded high overshoot and then began to decrease until reaching 2012 (Paula Mints, SPV).

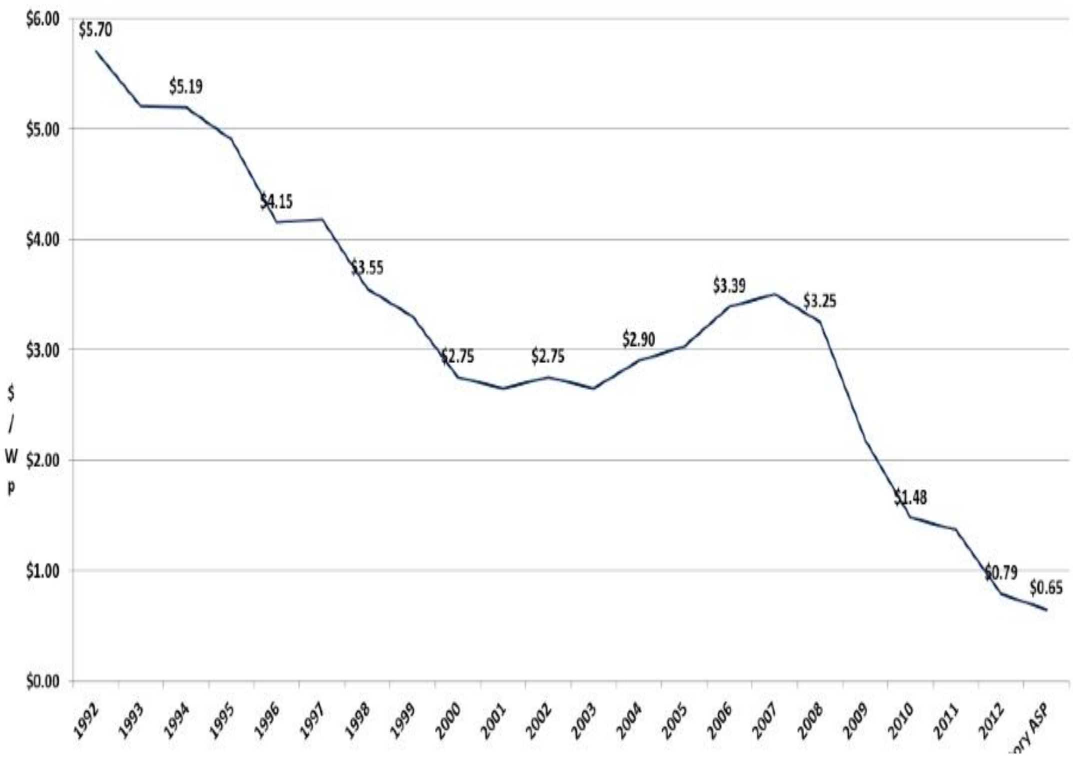

Figure 2.5: Historic curve of PV prices (Paula Mints, 2013)

Regarding prices of PV installations in USA in 2013, the following data are recorded (Paula Mints, 2013).

- Average small commercial and residential recorded \$4.69/W (≤10 kW)
- Average Large commercial recorded \$3.89/W (>100 kW)
- Average Utility scale recorded \$3.00/W (≥5 MW)

Comparing other countries prices to US regarding the residential PV installations, we can take Germany as an example as shown in Figure 2.6. It is clear that there is a price difference between US and Germany as US recorded 3.29\$/ watt in 2013 while Germany at the same year recorded 2.05\$/ watt. This is also noticed with comparing US to other leader countries in the PV industry. As a result of extra tariffs and taxes, US records higher prices for PV modules than that Chinese, Taiwanese and global average in general. The cost of hardware components of US and Germany are approximately the same, nevertheless US record higher PV prices due to difference in software prices. But generally, there will be a short term reduction in PV residential installations in US.

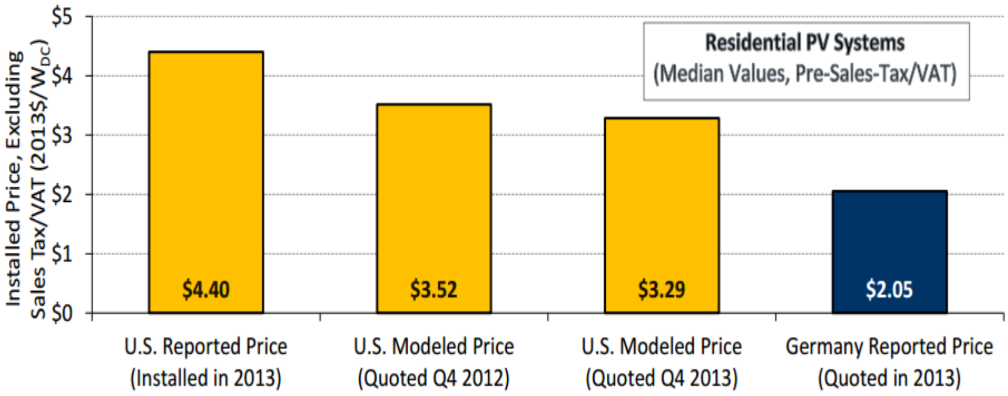

Figure 2.6: Residential PV US vs. Germany (National Renewable Energy Laboratory, Lawrence Berkeley National Laboratory, 2014).

Regarding the global average selling price of PV modules and making further expectations for the few following years compared to the recent historic years, we can see the chart in Figure 2.7. As shown in Figure 2.7, the PV modules generally record relatively low prices in the past few years. Nevertheless, after 2013 the prices of PV modules began to be constant and small reduction in prices is observed. At the 90`s, the module price represented the biggest share in PV system pricing. By the time the industrial progress and technologies used decreased the price of the modules to a proper level as well as the price of silicon wafers (Barbose, 2013).

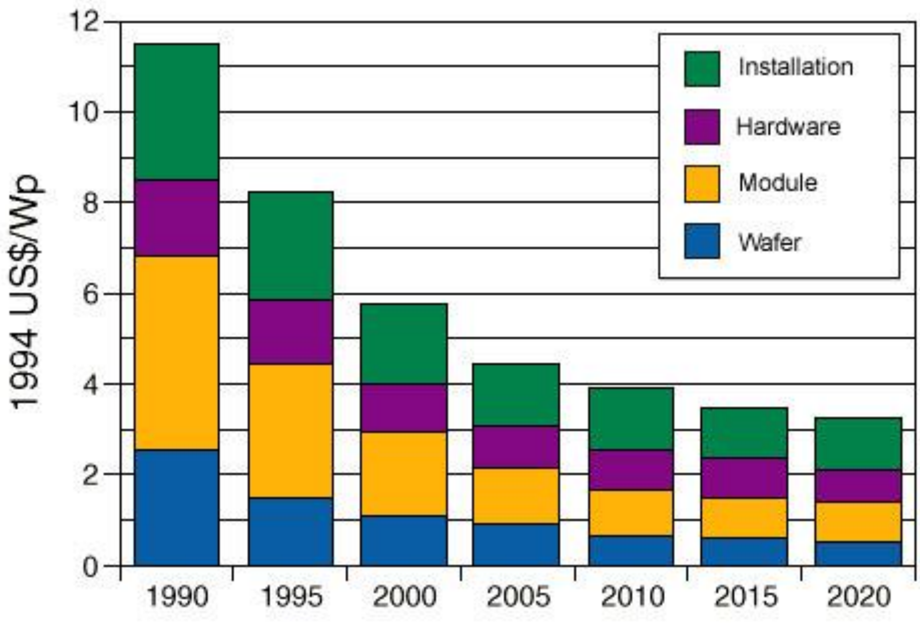

Figure 2.7: PV components cost historic and future (El Paso Solar Energy Association, 2007)

As shown in Figure 2.16, among the previous years, the reduction in prices of PV systems installation came basically from the reduction in PV modules. While in the future, the reduction in PV systems installation will come from other factors as well like hardware and installation cost. It is also important to know that the current today prices of PV installation are lower than what was expected to be in the past due to the continuous upgraded technology and industrial processes and research. The same may also happen regarding the expectations of the future.

Finally we can say that regarding the future, it is all between hands of renewable sources of energy as solar energy in spite of the current relatively high cost. All expectations and market analysis is saying that the cost is in continuous reduction among years as we showed in the above section. While the other sources of non renewable energy as fossil fuels -petroleum, coal and natural gas are going to be higher in prices and lower in validity with less support from governments and global societies.

CHAPTER 3
DC-DC POWER CONVERTERS

3.1 Introduction to the DC Power Converters

As a result of the non linear I-V characteristics of the PV module output as shown in Figure 3.1 for several irradiance levels as well as the unregulated output voltage wave form as shown in Figure 3.2, the produced out power from the PV modules is unregulated varying output power that should be optimized by some ways. DC-DC converter is usually used besides the MPPT system among the PV systems in order to regulate the output voltage to a certain level so that it can match the load operating point.

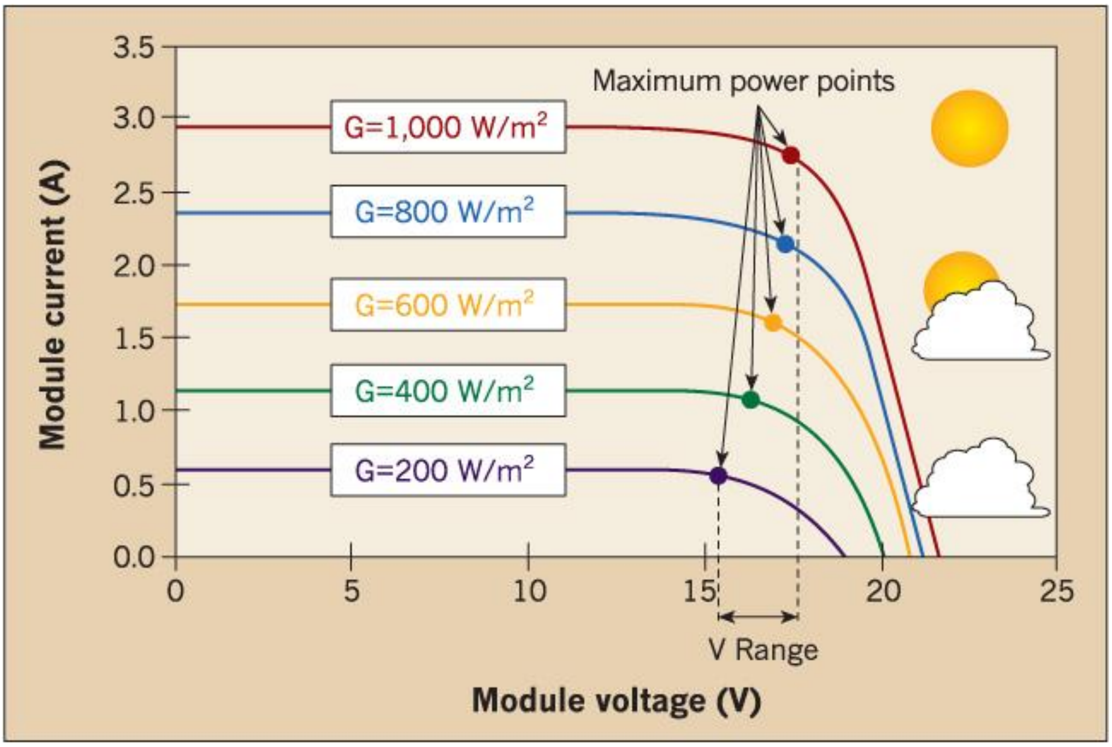

Figure 3.1: I-V characteristics of PV module (Ryan Mayfield, 2012)

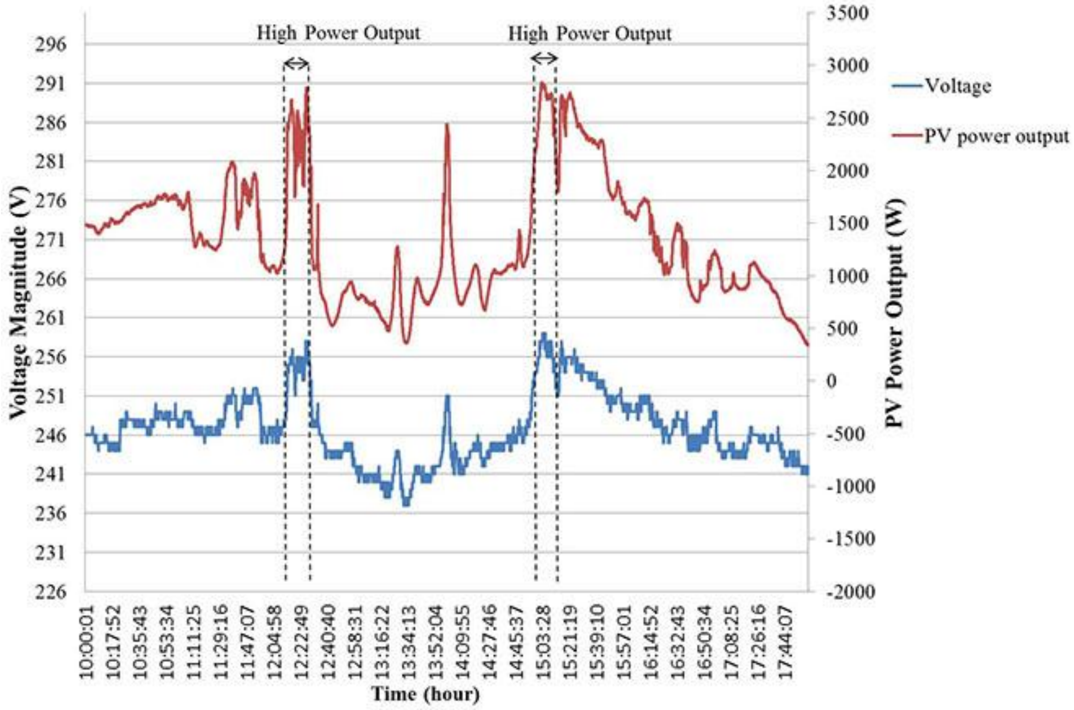

Figure 3.2: Varying P,V versus time (Lim, 2012)

Before going further through the DC-DC converters, first it is necessary to define some terms and explain the operation mode for the switching regulators. The switching mode regulators can actually be DC choppers that are used to convert or regulate the unregulated input voltage to a regulated output voltage. By the aid of some switching pulse width modulation circuits using BJT or IGBT, this regulation can be achieved. The output voltage is chopped into discontinuous rectangular wave form as shown in Figure 3.3. This shape of wave form would produce harmonics and ripple current among the output that should be treated by some kinds of R-L-C circuits. The obtained voltage is then compared to a reference value to produce the control voltage (Vc). This controlled voltage is again compared to a saw tooth wave form as shown in Figure 3.4 to generate the PWM at a fixed frequency that in turn regulates the operation of DC choppers as shown in Figure 3.5.

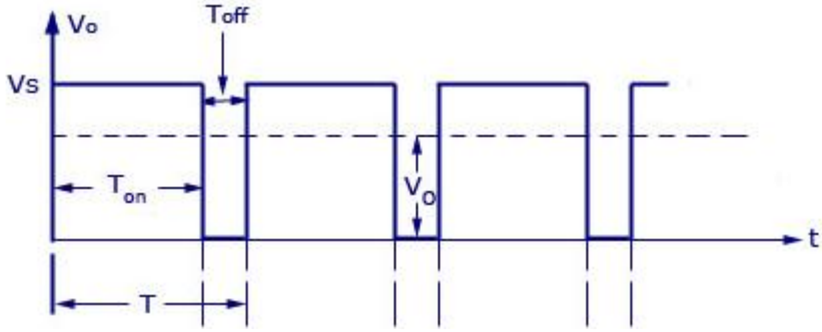

Figure 3.3: Discontinuous chopped output voltage

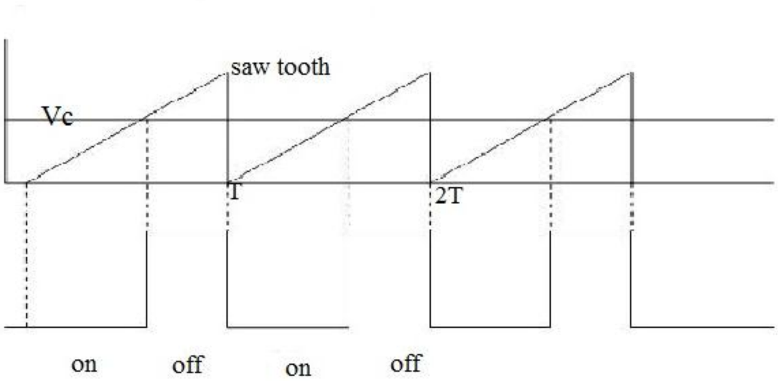

Figure 3.4: PWM with fixed frequency

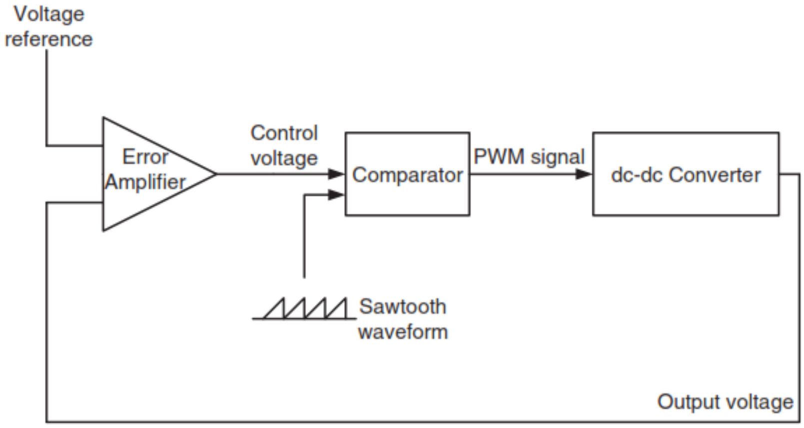

Figure 3.5: DC chopper-switched mode regulator (Rashid, 2007)

3.2 Four Basic Topologies of DC-DC Converters That May Be Used as Switching Regulators

1- Boost converter: it is considered a step up chopper that increases the value of the input voltage.
2- Buck converter: it is considered a step down chopper that decrease the value of the input voltage.
3- Buck- Boost converter: it may be step up or step down chopper with output voltage opposite in polarity with input voltage.
4- Cuk converter: similar to the Buck-Boost converter where it may be step up or step down chopper with output voltage opposite in polarity with input voltage.

Relating the DC-DC converters to our work in MPPT in PV system, we will explain the Buck converters in more details because it is mostly used among the different converters in PV systems as its role in limiting the output voltage plus its simplicity. We will start by analyzing the circuit, explaining the modes of operation, showing the different wave forms, stating the relation between circuit parameters that indicate how to design the converter and then the operation with MPPT in PV system.

3.2.1 Buck converters

It is considered a step down chopper that reduces the input value of the source voltage. The circuit parameters of this converter are input voltage (Vs), controlled switch (BJT), series inductor (L), shunt capacitance (C) and resistive load (R) as shown in Figure 3.6. There are two modes of operation; ON Mode and OFF Mode.

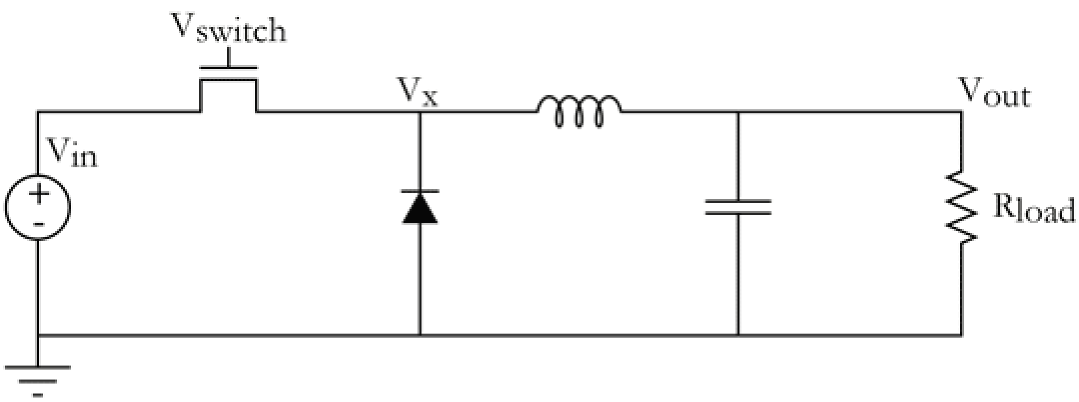

Figure 3.6: Buck converter circuit diagram (Rashid, 2007)

3.2.1.1 ON mode

This mode is assumed to start at time t=0, where the controlled switch is closed as shown in Figure 3.7, the diode is reverse biased i.e. open circuit and the current passes through the inductor (L), the capacitance (C) and resistive load (R). During the ON Mode period, the capacitor is charging and the inductor is opposing the input current, while an increasing voltage drop across the conductor is formed so the output voltage is reduced while the output current is rising until the switch is opened again as shown in wave forms of Figure 3.9.

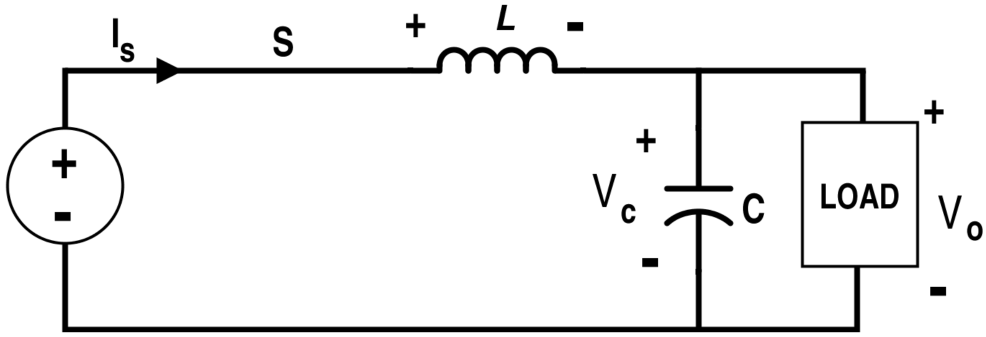

Figure 3.7: Buck Converter ON Mode (Rashid, 2007)

3.2.1.2 OFF mode

This mode is assumed to start at time t=t1, where the controlled switch is opened as shown in Figure 3.8, the diode is forward biased i.e. short circuit, so the energy stored in the inductor and capacitor during the previous mode is now discharged to supply the circuit where the inductor current starts to fall down until the switch is closed again, the capacitor also filters the output voltage from the produced inductor fluctuation and the voltage across the inductor inverse its polarity but remains with the same absolute value, see wave forms shown in Figure 3.9, so the total output voltage average is successfully reduced to a certain value that can be determined by adjusting the circuit parameters.

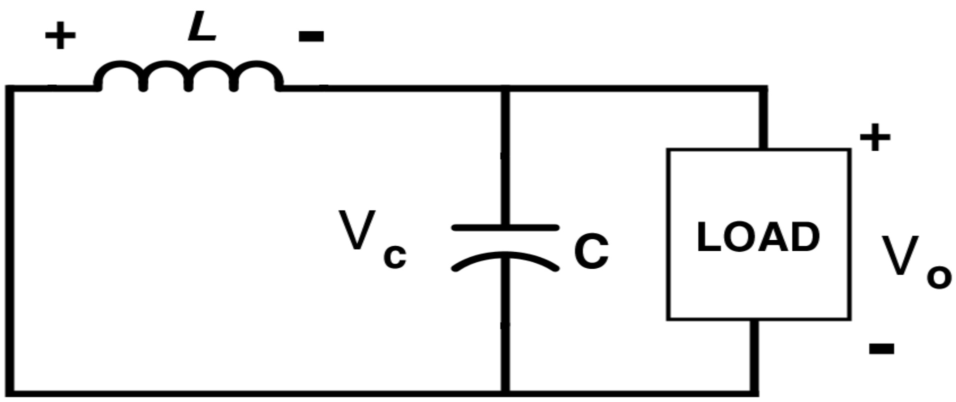

Figure 3.8: Buck converter off mode (Rashid, 2007)

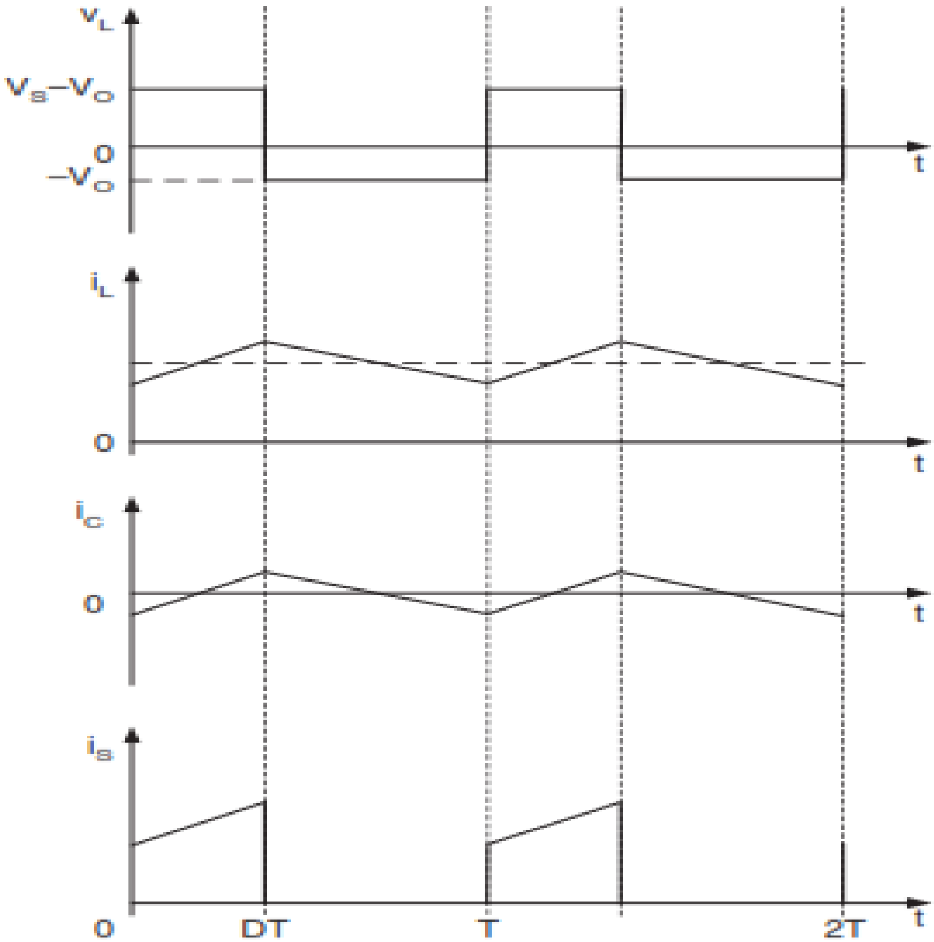

Figure 3.9: Buck Converter wave forms (Rashid, 2007)

3.2.1.3 Design of the Buck converter

The voltage across the inductor is calculated from Equation 3.1

$$VL = L.di/dt \tag{3.1}$$

The duty cycle ratio (D) can be determined from Equation 3.2

$$D = \frac{V0}{Vd} = \frac{Id}{IO} = \frac{ton}{Ts}\text{ , } 0 < D < 1 \tag{3.2}$$

Vd is the voltage across the diode, Id is the diode current and Ts is the switching time where Ts = TON+TOFF. While the conductance (L) should be related to the duty cycle and the frequency as shown in Equation 3.3, where any larger values than this value for inductance will force the system to operate continuously in ON Mode.

$$L = \frac{(1-D)R}{2f} \tag{3.3}$$

The ripple current that is caused by the inductor is directly proportional with the duty ratio (D) and inversely proportional to the inductance (L) as shown in Equation 3.4

$$\Delta I = \frac{(Vin-Vout).\ D}{Fs\ .\ L} \tag{3.4}$$

The ripple voltage in the output is also dependent on the duty ratio (D) and the capacitance (C), as shown in Equation 3.5

$$\Delta V = \frac{(I_O)(D)(\frac{T}{2})}{C} \tag{3.5}$$

3.2.1.4 Operation with MPPT in PV system

While integrating the DC-DC Buck converter within the PV system, the maximum power tracking should be regarded and kept. The operation of the Buck converter in the transient period between ON and OFF state can affect the performance and tracking maximum power. As shown in Figure 3.10, the current flow through the inductor and supplied to the load may be continuous or discontinuous depending on the values of the inductance (L), the capacitance (C) and the switching frequency. In the continuous mode of operation, the current when drops from ON to OFF state it doesn't reach zero so the maximum power can be achieved without disturbance. Adversely to the continuous mode, in the discontinuous mode the current drops to zero for a small period of time between transferring from ON to OFF state or vice versa. This zero current period can reduce the power output to a certain level.

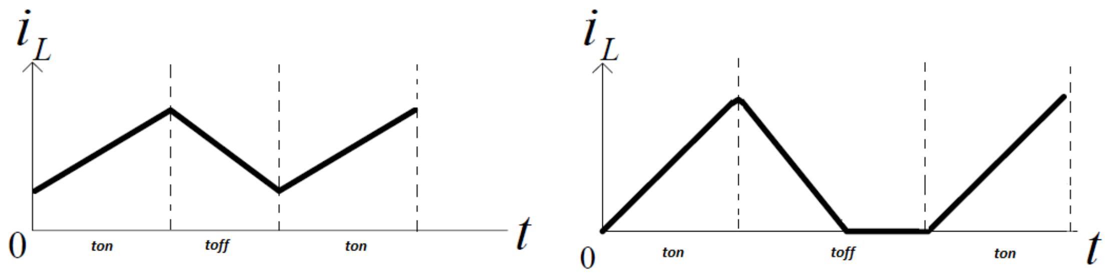

Figure 3.10: Buck Converter load current (Rashid, 2007)

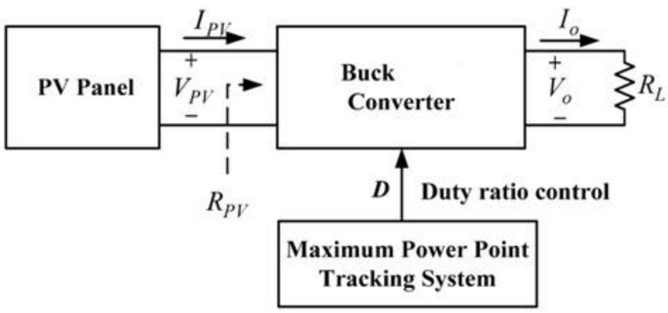

Figure 3.11: Buck Converter Integration with MPPT

As shown in Figure 3.11, the PV panel output current and voltage are entering as input values for the Buck Converter. The converter is actuated by adjusting the switching mode which is determined using some kind of MPPT techniques so that the output voltage from the Buck converter is regulated to a constant value. The duty cycle ratio control which is obtained from the MPPT system is determining the pulse width modulation value which in turn defines the switching scheme of the Buck converter so the amount of power needed can be achieved as shown in Figure 3.12.

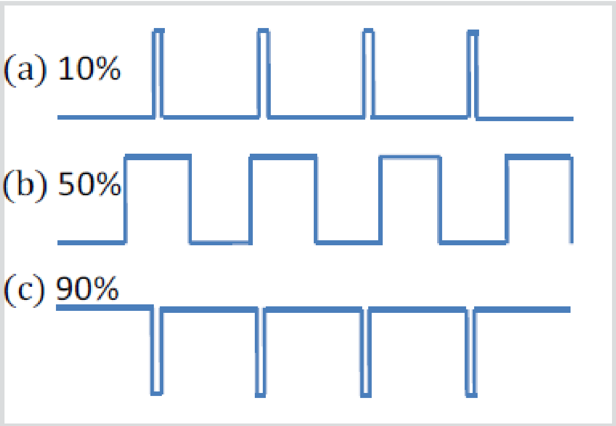

Figure 3.12: PWM defines the amount of power needed on switching the Buck Converter

The maximum power tracking for the PV system is actually a complex operation because of the non linear relation between current and voltage that changes also with irradiance. The MPPT can only be achieved at one point for each I-V curve at the corresponding convergence with the resistive load curve as shown in Figure 3.13.

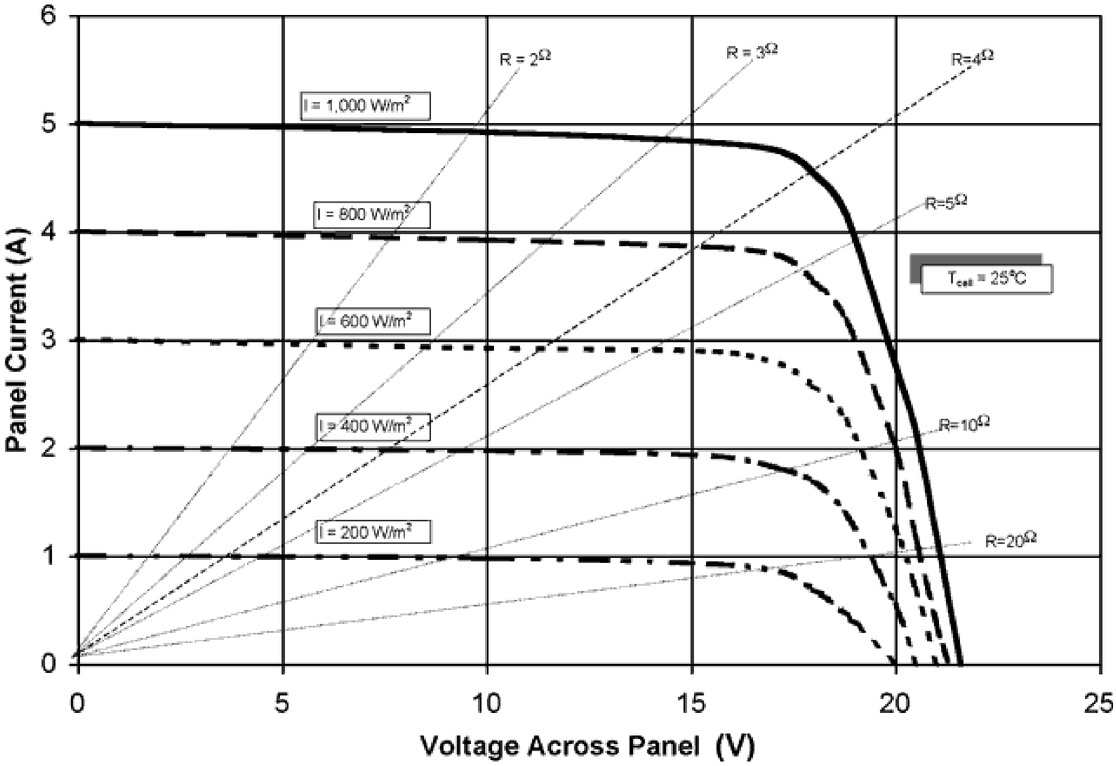

Figure 3.13: Operation point for each I-V curve of PV module with resistive

CHAPTER 4

MAXIMUM POWER POINT OF TRACKING OF PV SYSTEM

Maximum power point of tracking technique is a developed control feature combined with the PV systems in order to maximize the efficiency output from the modules by tracking the maximum point. MPPT techniques are influenced by environmental conditions and changing temperature values where the temperature is related to the irradiance levels. As a result, the MPPT techniques should be dependent on the irradiance. Hence, $P_{mppt} = V_{mpp} \times I_{mpp}$. There are several methods or techniques that are developed in order to obtain maximum power from the PV system according to the irradiance and the application. Some of these methods may be direct methods achievement for maximum power while other methods are considered in direct ones. Actually, these indirect methods sense the voltage and current values to form mathematical Equations that approximate the value of maximum power by estimation so it is not considered true tracking techniques. As a result, the indirect methods are relatively very simple, inexpensive and usually affected by environmental conditions and temperature changes. Direct methods in converse, are exact seeking methods where there is no need to big memory or database. Achieving MPPT along the direct methods is independent on varying PV module parameters. By measuring only 1 variable in the direct methods, it is possible to track maximum power point. The several MPPT techniques can be evaluated depending on the performance and efficiency with regarding the complexity, cost, stability and atmospheric conditions in order to reach a satisfied practical approach of maximum power achievement. Before 2007, we can find few researches that discuss the issue of MPPT techniques. But after that date, several techniques has appeared like linearization technique, fuzzy control technique, Hybrid MPPT techniques, Parasitic capacitance technique, sliding mode based techniques, Artificial neural network technique, etc.

4.1 Brief Review on All Mppt Techniques

This review will be arranged according to the idea of the implemented tracking technique control that depends on. All the MPPT techniques can be classified into groups and explained as shown below.

4.1.1 Voltage control methods

4.1.1.1 Open circuit voltage technique

This technique has the same basic idea of short circuit technique; the only difference that we measure the open circuit voltage instead of short circuit to relate it to the V_{mpp} not I_{mpp} (Ferdous, 2012). Also a linear relation is found to relate the V_{mpp} to $V_{o.c}$ as shown in Equation 4.1

$$V_{mpp} = K \bullet V_{o.c}. \tag{4.1}$$

The value of $V_{o.c}$ has to be calculated and updated occasionally to get real values for V_{mpp}.

4.1.1.2 DC link capacitor droop control technique

This technique is applied with the PV array that is attempt to be connected in parallel with AC system so that the duty cycle will be equal to

$$D = V - \left(\frac{V}{Vlink}\right). \tag{4.2}$$

Where v is voltage across the PV system and V_{link} is the voltage across DC link. Keeping V_{link} constant, by increasing the inverter current, the power output increases such that the power maximum limit of the PV array is not exceeded. Otherwise, the value of V_{link} decreases so the AC system line feeds back to the DC link to stop V_{link} from decreasing so the duty cycle is re adjusted to satisfy the MPPT condition (Hohm, 2000). The DC link capacitor droop control technique can be illustrated in Figure 4.1.

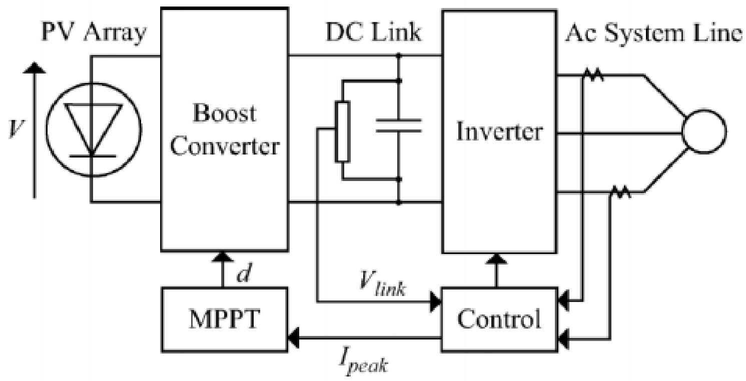

Figure 4.1: DC link capacitor droop control (Kitano, 2001)

4.1.2 Current control methods

4.1.2.1 Current sweep technique

This technique depends on obtaining sweep V-I curve and update it every small period of time. The V_{mpp} can be obtained from the curve at the identified time intervals (Esram, 2007).

4.1.2.2 Short circuit current technique

By reaching the electric current value (I_{mpp}) of the PV system and succeed to control it, it will be possible to track the maximum power point easily. This can be achieved using a linear relation found to relate the I_{mpp} to the short circuit current value (I_{sc}) as shown below in Equation 4.3 (Masoum, 2002).

$$I_{mpp} = K \bullet I_{sc} \qquad (4.3)$$

Where K is a constant can be gotten from the P-V curve. The value of I I_{sc} has to be updated occasionally to get true values of I_{mpp}.

4.1.3 Iteration methods

4.1.3.1 Perturbation and observation technique

In this technique by measuring the current and voltage, we can get the power. The voltage value is perturbed by small value to be increased and the corresponding power is observed. If the change in voltage is positive and the change in power is also positive then dp/dv is positive then the perturbation of voltage and observation of power is continued till reaching the maximum value where dp/dv will change to zero then to negative value; where the process is stopped. While perturbing the voltage value, it may be noticed that searching process starts with negative value of dp/dv , at this case the voltage value is perturbed to be decreased gradually and the corresponding power is observed. The search is stopped when dp/dv turns into positive value or zero where the maximum point is achieved (Liu, 2008). In this technique the step values should be carefully chosen to adapt proper response time with low oscillation. So these steps should not be very large and have not to be very small.

4.1.3.2 Incremental conductance technique

In this iteration technique, the voltage and current are changed until maximum power is achieved. By using the following formula in Equation 4.4

$$\frac{dP}{dV} = \frac{d(IV)}{dV} = I + V\frac{dI}{dV} = I + V\frac{\Delta I}{\Delta V} \tag{4.4}$$

Where the controller changes in the values of V and I until the Equation is satisfied. The micro controller that is used in this technique has to be with high configurations to perform rapid and complex calculations. This technique has approximately the same efficient output of P&O technique but with slower response time due to complex computations (Calavial, 2010).

4.1.3.3 Differentiation technique

By solving the Equation 4.5 as shown below, we can achieve Mppt

$$\frac{dP}{dt} = \frac{d(IV)}{dt} = I\frac{dV}{dt} + V\frac{\mathrm{d}I}{\mathrm{d}t} = 0 \tag{4.5}$$

A problem within this technique is having eight measurements required to be solved; which of course needs a complex micro controller with smart and fast features to analyze the previous Equation quickly to not affect the calculation period negatively (Jian, 2004).

4.1.3.4 Estimated perturb and observe technique

It is a modified technique that is occurred on the perturb and observe technique but more complex where an estimation value is defined between 2 successive perturbation values. The Perturb is responsible for the search process over the P-V curve while the estimated value is responsible for compensation of changing irradiance process. This technique guarantees better performance and response time for MPPT (Liu, 2004).

4.1.3.5 Parasitic capacitance technique

The working principle of the parasitic capacitance technique has the same idea of operation as the incremental conductance technique with an added term that represents the value of the junction capacitance of the PV cells. This capacitance leads to storage of charges that can be represented in a form of capacitive added current to the PV Equation (Pongratananukul, 2005). Block diagram for the Parasitic capacitance technique is shown in Figure 4.2

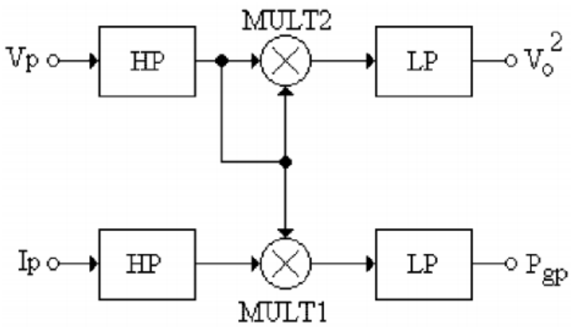

Figure 4.2: Parasitic implementation circuit (Brambilla, 1998)

4.1.4 Converter based methods

4.1.4.1 One cycle control technique

From the name it is clear that this technique involves only 1 controllable cycle for the achievement of MPPT. This control cycle is a conversion cycle for current from DC into AC using 1 cycle/ stage conversion. The obtained current from the inverter is controlled regarding the voltage value of the PV system such that maximum power can be tracked (Chen, 2002).

4.1.4.2 Forced oscillations technique

By forcing a small perturb value in the switching frequency and using a comparative to compare the voltage AC and average values, MPPT can be reached through observing the voltage terminal value by adjusting the converter duty cycle as well as the circuit parameters and varying the frequency (Chung, 2002).

4.1.4.3 Ripple correlation technique

In this technique, the presence of a converter within the PV system is used for control process as well. Where normally ripple current and voltage are produced due to the switching procedure that occurs by the converter. Ripple correlation control technique is meant to equalize the ripple to zero so as to get Mpp condition where the values of the V and I at this condition are measured (Esram, 2006). Where ripples that are observed are $\frac{dP}{dt}$, $\frac{dV}{dt}$ and $\frac{dI}{dt}$.

4.1.4.4 Load current or voltage maximization technique

When the load is directly connected to the PV module, there will be a problem in reaching a maximum power point condition. In this case there should be a matching MPPT network between PV side and the load side. This MPPT network basically consists of a controller for the duty cycle and a power stage of the switched converter (Shmilovitz, 2005).

4.1.4.5 Sliding mode technique

This technique uses the derived relation for the incremental conductance technique

$\frac{dIPV}{dVpv} + \frac{IPV}{Vpv}$ and be equal to h

$$\text{Where } \frac{dIPV}{dVpv} + \frac{IPV}{Vpv} = h, \text{ where } h = 0 \text{ at MPP} \tag{4.6}$$

The switching signal to the converter will be called u where u=1 if h is less than zero and u=0 if h is greater than or equal zero. If u equals zero that means that the switch of the converter is opened while if u equals 1, the switch is closed and MPP is achieved (Zhang, 2004).

4.1.5 Feedback control methods

4.1.5.1 Feedback voltage technique

In this technique the voltage value is forced to stabilize at certain value where the voltage is taken as a feed back to be compared with reference value. As a result, this technique is usually used with PV systems that are not attached with battery systems and it requires simple micro controller with low cost (Salas, 2006). The feedback control technique for voltage is shown below in Figure 4.3

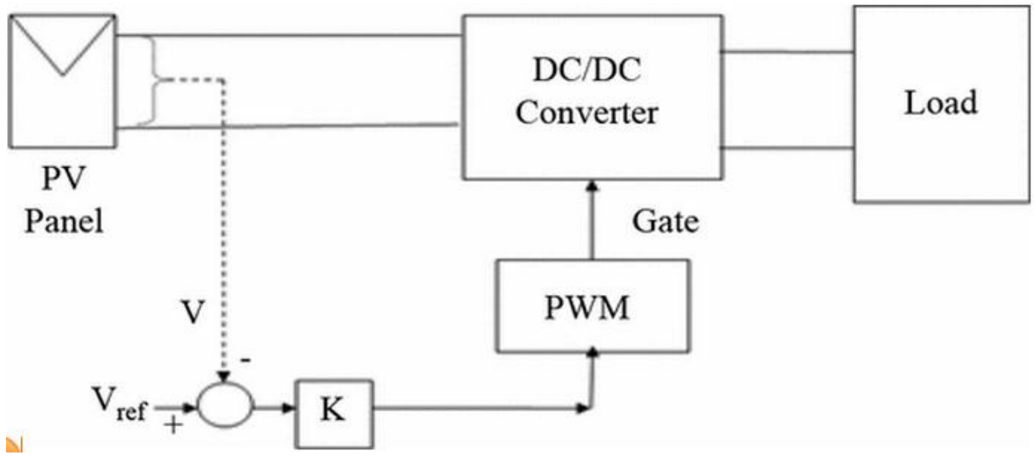

Figure 4.3: Feedback voltage control technique

4.1.5.2 Feedback power variation with voltage technique

The idea of this technique depends on taking a feedback from the derivative of power versus voltage and controls it to be equal to zero in order to obtain the maximum value condition of P-V curve (Bhide, 1992).

4.1.5.3 Feedback power variation with current technique

The same idea and procedure of the feedback power variation with voltage is applied in this technique but with measuring the derivative of power versus current instead of voltage and force to equal zero (Bleijs, 2001).

4.1.6 Mathematic equations based methods

4.1.6.1 Curve fitting

As shown in Equation 4.7, we can model the relation between the power and voltage with a third order Equation. The PV system in this case may be analyzed off Line with taking into consideration the voltage and power values to be sampled every period of time in milli seconds (Takehara, 1997).

$$P = aV^3 + bV^2 + cV + d \tag{4.7}$$

a,b,c,d are constants.

By taking differentiation for both sides we get

$$\frac{dP}{dV} = 3aV^2 + 2bV + c \tag{4.8}$$

Maximum condition occurs at $\frac{dP}{dV}$ equals zero

$$\text{Then} \quad V_{mpp} = -b\,\frac{\pm\sqrt{b^2-3ac}}{3a} \tag{4.9}$$

4.1.6.2 Gauss Newton technique

This technique is found to be one of the rapidest techniques to achieve MPP. Gauss Newton technique is based on the algorithm of root finding as shown in Equation 4.10

$$v(k+1) = v(k)\,\frac{\left.\frac{dp}{dv}\right|_{v=v(k)}}{\left.\frac{d^2p}{dv^2}\right|_{v=v(k)}} \tag{4.10}$$

By deriving the power with respect to voltage first and second derivatives; the iterations number for solving the Equation to reach MPP is estimated as well as the direction of solving (Xiao, 2007).

4.1.6.3 Steepest descent technique

Using the Equation 4.11, the MPP can be determined as following

$$f\big(v(k), p(k)\big) = \frac{p(k+1)-p(k-1)}{2\Delta V} + O(\Delta V^3) \tag{4.11}$$

Then from Equation 4.11, dp/dv is calculated to be substituted in Equation to get V_{mpp}

$$v(k+1) = v(k)\,\frac{\left.\frac{dp}{dv}\right|_{v=v(k)}}{k_e} \tag{4.12}$$

Where $O(\Delta V^3)$ is the differentiation second order error and K_e is is the step size (Xiao, 2007).

4.1.7 Intelligent methods

4.1.7.1 Fuzzy logic technique

This technique represents a new generation of science applied in MPPT. The main idea of the fuzzy logic technique is quite different than other techniques where the working PV conditions are not meant here. Two inputs for this system are entered and one output is achieved. The two inputs are the error function and the error change function as shown in Equations 3.13, 3.14 (Veerachary, 2003)

$$e(k) = \frac{dP}{dV}(k) - \frac{dP}{dV}(k-1) \tag{4.13}$$

$$c_e(k) = e(k) - e(k-1) \tag{4.14}$$

At instant (k), the error function determines the relative operating point position while the change in error identifies the direction of movement. The calculated output is the duty cycle ratio. It is observed that fuzzy logic technique obtains better performance with less oscillations and improved response time.

4.1.7.2 Artificial neural network technique

Generally, the artificial neural network is a new smart science used in many engineering, medical, agricultural and economical applications to solve problems by gaining experience through training. The advantage of this method is being like a black closed box that does not mean for inside operation details. The ANN technique cares only for the input and output to solve problems. In MPPT, the input to the ANN may be voltage or current or environmental conditions while the output is a duty cycle for a converter to obtain MPP or even the MPP itself. The training relations are values of V_{mpp} and irradiance to gain the ANN a valuable experience to track the maximum power during operation (Aweya, 1998). Inputs and output for the ANN can be shown in Figure 4.4.

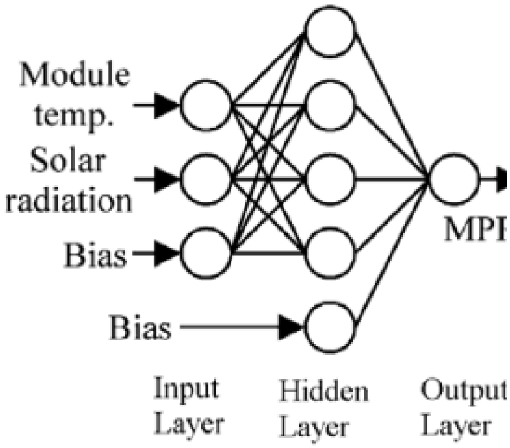

Figure 4.4: ANN

4.1.7.3 Particle swarm optimization technique

There is a problem called multiple maxima occurs with the multi PV array structures in case of partial shading. This problem affects the P-V characteristics. Particle swarm optimization technique is an efficient approach criterion which is meant to solve these multi variable problems to achieve MPPT (Kondo, 2010).

4.1.8 Linearization based MPPT techniques

The main problem we have among the different techniques in estimating maximum point and various methods tend to track it, is the non linear characteristics of the relation between PV parameters. In this technique successive linear relations will be suggested to approximate the non linear relation. The analyzing of PV module stated that the relation between current and voltage at high irradiance levels is nearly linear. By using this information and apply it in this technique, the maximum point locus could be simply linearized and achieved (Hua, 2011).

4.1.9 Hybrid MPPT techniques

Recent techniques of MPPT involve combination of several techniques. The perturb and observe technique is usually preferred due to its accuracy, simplicity and high efficiency. But the step size is still being a problem within the P&O technique causing low response time in case small steps and less accuracy in case of large steps. These problems introduced the need of the combination of hybrid technique with ANN and P&O

techniques as an alternative where ANN techniques offer a good approximation for the step size without being affected with environmental conditions (Amrouche, 2007). While interfering the P&O method with Neuro Fuzzy intelligence system can successfully improve the stability and decrease oscillations.

4.1.10 Mismatched MPPT techniques

Mismatched conditions for MPPT in a PV system actually may occur due to different reasons. These reasons may be due to shading of people, trees, animals and clouds. Other reasons are like difference between PV modules in temperature or circulation of air or even due to some errors in the manufacturing process. Mismatching of the PV panels can seriously affect the total efficiency and may give different MPP for connected PV modules due to mismatching PV characteristics. Moreover, in some cases mismatching may cause PV system failure. As a result of this problem, some techniques were developed to overcome the mismatched problems. One of the most used techniques is the distributed maximum power tracking techniques that guarantee an individual MPP for each module alone. Other new techniques work on equalizing the output operating points by controlling the input values so there should be a separated converter for each panel and all converters are controlled together by single block control (Tsao, 2009).

4.1.11 Experimental/ memory based techniques

4.1.11.1 Look up table

Simply, the idea here is saving all data related to the various environmental conditions in a look up table where before installation the PV system is attached with a memory attached with this table (Jiang, 2005). After installation the system configure the proper condition from the look up table that suits the working environmental conditions.

4.1.11.2 Analytic MPPT technique

In this technique, the mean value theorem is used to achieve the MPPT. By using experimental and observation results, the values of V and I can be determined. A ball is put in each PV panel for finding the MPP using analysis techniques that are based on mean value theorem (Rodriguez, 2007).

4.2 Criteria among Which MPPT Are Evaluated

There are different criteria among which MPPT different techniques can be successfully compared and evaluated. Evaluation can be done depending on the control strategies, control variables, cost, implementation and applications. We have to specify and explain each of these evaluation templates before making further comparisons between the MPPT techniques.

4.2.1 Control strategies

There are many different methods and techniques that are attempt to achieve working condition of PV system at or near by maximum power point. These techniques vary depending on the control strategies applied in the MPPT technique. The strategies can be classified into direct, indirect and probabilistic control- based techniques.

Direct methods are exact seeking methods for MPPT where there is no need to big memory or database as the P-V curve is sampled and the values of current or voltage can be identified at any instant so it can be controlled. Indirect methods in converse to the direct methods are actually not true tracking techniques but they estimate the value of maximum power by measuring current or voltage or both then using mathematical formulas. As a result, indirect methods are usually cheap, simple and affected by atmospheric conditions.

4.2.2 Control variables

In order to track MPP in the PV system, some parameters should be measured or sensed as current, voltage, temperature and irradiance depending on the applied MPPT technique. Some techniques need only to measure one variable, usually current or voltage, regardless the other variable values. Other techniques require measurements on two variables at least to perform tracking. Regarding the cost and expenses it is preferable to track voltage rather than tracking current as the voltage sensors are easier to implement and cheaper with smaller size compared to the current sensor.

4.2.3 Cost

Regarding the MPPT techniques, we can find that there is wide variation in prices of implementing some techniques rather than others. Actually, there are some applications that don’t give any care for the cost provided that an efficient technique with high accuracy and fast tracking is implemented. These applications may include space craft, float voltaic and solar vehicles. Other applications require just power supply to small or low current appliances and they don't search for high accuracy as irrigation water pumps. Most PV systems are preprogrammed before installation in the site. This make a difficulty in defining specified separated prices for the MPPT techniques from the whole PV system. Nevertheless, we can specify general cost rates comparison for different techniques**.**

4.2.4 Implementation

The implementation of MPPT techniques can also vary between being analog circuit or digital circuit. Some techniques are implemented with analog circuits only, other techniques are adapted with digital circuits and some techniques can adapt with both analog and digital circuits. The client may also prefer to use digital circuits than analog ones or vice versa.

4.2.5 Applications

The MPPT techniques as mentioned in cost section are important to be found among some applications of PV systems. These applications as space craft, float voltaic, solar vehicles, telecommunications, small electronics and large residential scales usually use one or more of MPPT techniques. Countries leaders of the MPPT techniques production are Germany, USA, Japan and China.

4.2.6 Comparison of the mentioned techniques

Table 4.1: Comparison between MPPT Techniques (Subudhi, 2013)

	Control parameters	Complexity	Implementation	Converter Type	System Type	Cost
Open circuit voltage	V	Simple	A & D	DC - DC	Off Gird	Low
DC link capacitor	V	Simple	A & D	DC - DC then DC - DC	On Gird	High
Current sweep	I	Complex	D	DC - DC	On Gird	High
Short circuit	I	Simple	A & D	DC - DC	Off Gird	Low
perturbation & observation	V or I	Medium	A & D	DC - DC	Off Gird	High
Incremental conductance	V & I	Complex	D	DC - DC	Off Gird	High
Differentiation	V or I	Complex	D	DC - DC	Off Gird	High
Estimated P & P	V & I	Complex	A & D	DC - DC	Off Gird	High
Parasitic capacitance	V & I	Simple	D	DC - DC Or DC - AC	Off Gird	High
One cycle control	I	Simple	A & D	DC - AC	On Gird	Low

Forced oscillations	V or I	Complex	A	DC - DC	Off Gird	High
Ripple correlation	V or I	Complex	A	DC - DC	Off Gird	High
Load I or V max	V	Medium	A	DC - DC	Off Gird	Low
Sliding mode	V or I	Complex	D	DC -DC Or DC - AC	On/Off Gird	High
Feedback voltage	V or I	Simple	A& D	DC - DC Or DC - AC	Off Gird	Low
Feedback power var.with voltage	V & I	Complex	D	DC - DC Or DC - AC	Off Gird	High
Feedback power var.with current	V & I	Medium	D	DC - DC Or DC - AC	Off Gird	High
Curve fitting	V	Simple	D	DC - DC	Off Gird	Low
Gauss	V or I	Medium	D	DC - DC	Off Gird	High
Steepest descent	V or I	Medium	D	DC - DC	Off Gird	High

Intelligent techniques	V or I	Medium	D	DC -DC Or DC - AC	On/Off Gird	High
Linearization		Medium	D	DC - DC	Off Gird	Low
Hybrid	V or I	Complex	D	DC - DC Or DC - AC	On/Off Gird	High
Mismatched	V or I	Medium	D	DC - DC Or DC - AC	On/Off Gird	High
Lookup Table	V & I	Simple	D	DC - DC	Off Gird	Low
Analytic	V or I	Medium	A & D	DC - DC	Off Gird	High

CHAPTER 5
EXISTING METHODS

5.1 Energy Comparison of Most Used MPPT Techniques of PV Systems

In this chapter, a comparative study of widely known MPPT techniques will be presented. The performance of these techniques will be evaluated in details by applying same experiment with same environmental conditions and hardware components on each technique. The same Solar simulator will be used to simulate solar irradiance variations to be applied in all techniques. Before we start the experiment, the used techniques in the experiment should be specified and explained in details as following

5.1.1 Short circuit current method.

By giving the controller an appropriate reference value for electric current, the maximum power could be achieved. This reference value of current is directly proportional to the current at short circuit condition for various irradiance levels.

$$I_{ref} = K.I_{sc}, \text{ K is a constant.} \tag{5.1}$$

For getting I_{ref}, I_{sc} measurement should be obtained; by making a short circuit condition on the PV array. At this instant moment, the voltage across the array is equal to zero, i.e. there is no power generated from the system (Maysoum, 2002).

5.1.2 Constant voltage method

It is considered the simplest method for maximum power point of tracking. Actually, it is not attempt to track maximum power point which may be useful in cases of failure of MPPT. The output voltage is regulated to constant value under all operating conditions. This value may be pre programmed using external resistor attached to current source pin of the Ic control circuit. In this case the resistor may be part of a thermistor network so its value can be temperature compensated. This method may take a rating of 80% that means for various different irradiance 80% of maximum power may be collected. It is regarded that operating at low irradiance levels conditions, the performance may be better. The constant voltage method as a result is neglecting the effect of temperature and solar irradiance. It requires only the PV voltage measurements for operation (Dolara, 2009).

5.1.3 Open circuit voltage

Open circuit voltage method can be considered as an improvement of the previous "constant voltage" method where instead of keeping output voltage constant under all conditions, the system here calculates the open circuit voltage and the maximum power voltage can be assumed to equal 0.7 to 0.8 of the open circuit voltage value (Ferdous, 2012)

$$V_{mp} = k * V_{oc},\ k=0.7 \text{ to } 0.8. \tag{5.2}$$

It is stated that the $V_{o.c}$ changes with irradiance, as irradiance increases the $V_{o.c}$ increases. So it is urgent to update the $V_{o.c}$ occasionally to compensate any temperature change. This can be achieved by monitoring the input current that is proportional to the irradiance and so we can determine when the $V_{o.c}$ should be re measured. An added feature to this method for better performance is making the constant "k" function of irradiance as well i.e. the constant will change with irradiance. In this method, in order to measure the open circuit voltage the power delivered should be momentarily interrupted so the current at that moment will equal to zero so there will be a waste of energy and decrease in the efficiency. As a result for purpose of interrupting current this technique needs a special procedure for regular switching or disconnection of PV. For further developments, there is no need to interrupt current for measuring $V_{o.c}$ as by using temperature methods, the $V_{o.c}$ can be related to the temperature by linear function. So by using a temperature sensor, the $V_{o.c}$ value can be directly obtained.

5.1.4 Perturb and observe method (P&O)

It is mostly common method due to ease of implementation and it may result in top level of efficiency. In this method the controller searches for maximum power point by changing PV voltage or current and then detecting the change in power output. By adjusting voltage by a small amount and then observe power, if power increases then continue adjustment until power no longer increase i.e. $dp/dv > \text{zero}$, where the direction of the change is reversed when power decreases i.e. $dp/dv < \text{zero}$. A common problem within P&O method is that voltage is perturbed every cycle, resulting in oscillations in output around the maximum point when MPPT is achieved (Zhang, 2013). It is observed that at lower irradiance levels, oscillations are more effective while fast irradiance may result in wrong choice of search direction. So it is recommended to choose proper step size for search as too large steps may result in oscillation while too small steps may result in slow response. It is also observed that Vmp is close related to Ln (irradiance) i.e. it is less sensitive to change in irradiance. There are too many works and methodologies developed or even under current researches for perturb and observe idea.

We can consider 2 of them that can be the most applied methodologies as following:

- the classic P&O method
- three point P&O method

The value of perturbation $\Delta\delta$ is equal to 0.35% of the open circuit voltage (Vov) which is constant perturbation. In the three point's weight comparison method, the perturbation direction is obtained by comparing the 3 points on the output P-V curve. Where the 1st point is the current value, the 2nd point is perturbed from the 1st point and the 3rd point is double perturbed but in the opposite direction to 2nd point (Noguchi, 2002).

5.1.5 Incremental conductance method

This method locates the maximum power at the condition $\frac{dIPV}{dVpv} + \frac{IPV}{Vpv} = 0$. Those values of Ipv, Vpv that verify this Equation are values that give maximum power. This algorithm is done by changing Vpv and computing the above Equation , when the verification of the Equation is occurred, searching is stopped unless a change in dIpv is noted i.e. when $dIpv \neq 0$. When the left side of the Equation $\frac{dIPV}{dVpv} + \frac{IPV}{Vpv} > 0$ then the search increments Vpv, while if the left side of the Equation $\frac{dIPV}{dVpv} + \frac{IPV}{Vpv} < 0$ then the search decrements Vpv (Ogboenyira, 2009). It is noticed that incremental conductance method is good for rapidly varying irradiance conditions but the noise may cause continuity of search so it needs some ways for reduction or a comparison with a nonzero value. The incremental conductance method requires more computations so it is slower than Perturb and observes method but generally it has fewer oscillations than P&O method.

5.1.6 Numerical results

By making practical comparison between the previous techniques and by caring to maintain the environmental conditions nearly constant for all tests where the most important environmental condition that can affect the behavior of the PV is the temperature. This can be achieved by applying all tests starting from PV panel temperature and the tests duration is recommended to be as short as possible and sampling time may be taken as 10 msec. We can consider a single module PV panel for simplicity with parameters shown in Table 5.1.

Table 5.1: Single PV module panel parameters (Dolara, 2009)

Sympol	**Quantity**	**Value**
P_{mpp}	Maximum Power	70 W
V_{mpp}	Voltage at P_{MPP}	17 V
I_{mpp}	Voltage at I_{mpp}	4.11 A
I_{sc}	Short – Circuit Current	4.35 A
V_{oc}	Open- Circuit Voltage	21.8 V
NOCT	Nominal operation cell Temperature	43 ± 2 ^{0}C

We can also consider two different irradiance diagrams as shown in Figures 5.1 and 5.2 to make better analysis and comparison between different MPPT techniques.

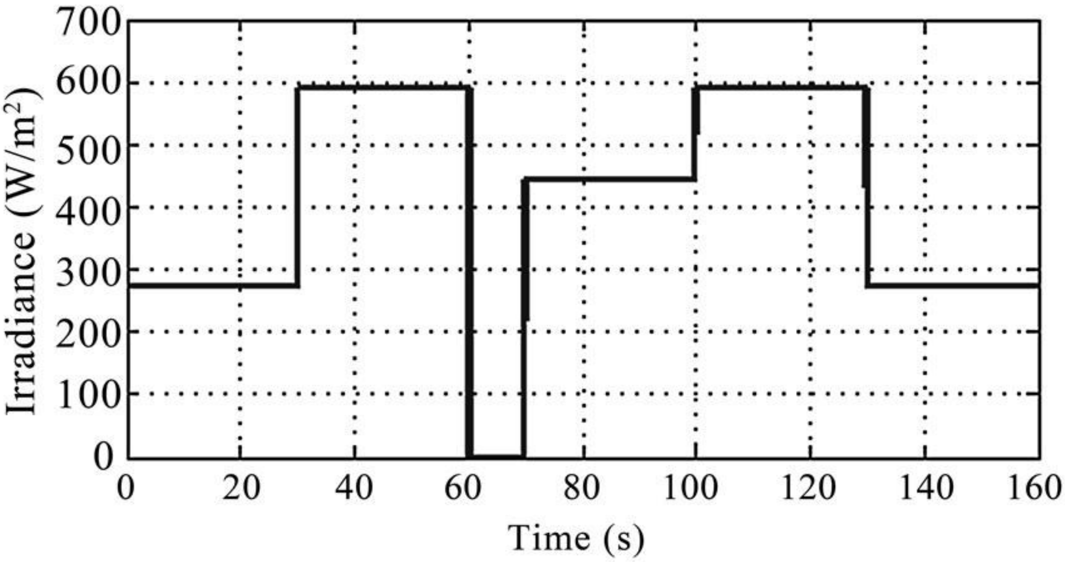

Figure 5.1: Irradiance levels scheme (a) (Dolara, 2009)

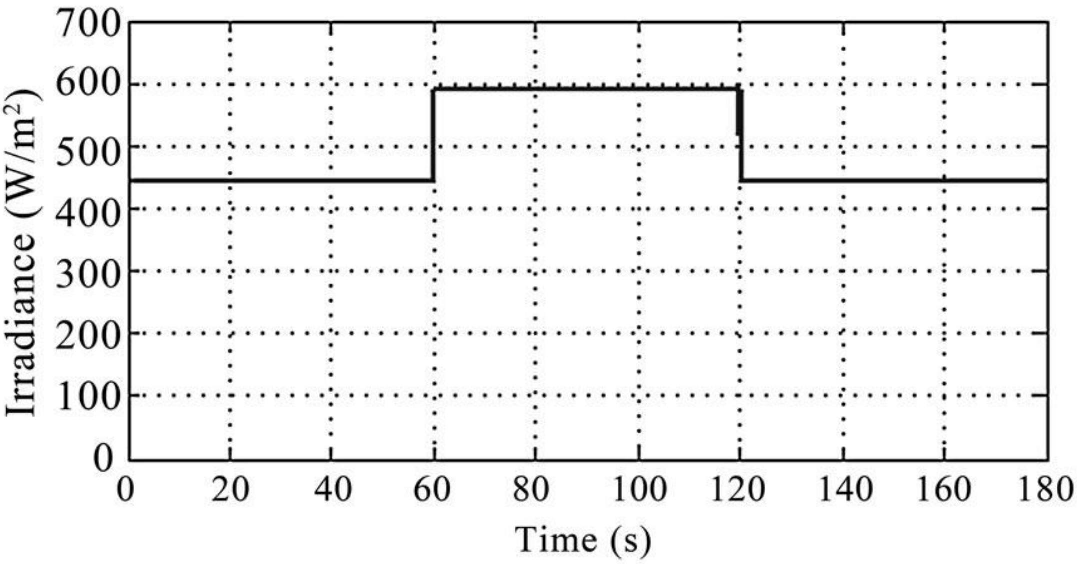

Figure 5.2: Irradiance levels scheme (b) (Dolara, 2009)

At low irradiance levels, the P&O(a) technique has good performance where the P-V curve is very near to the maximum power point. The main disadvantage of P&O(b) technique is observed at low irradiance levels where there are oscillations near the Maximum power point and so the output energy is reduced. In Figure 5.3, we can see a comparison between the different MPPT techniques that are held by the same converter configuration. These tests results are considered for ideal power obtained, so the MPPT is assumed ideal and can be taken into consideration as qualitative precious reference for comparison between the results of different methods.

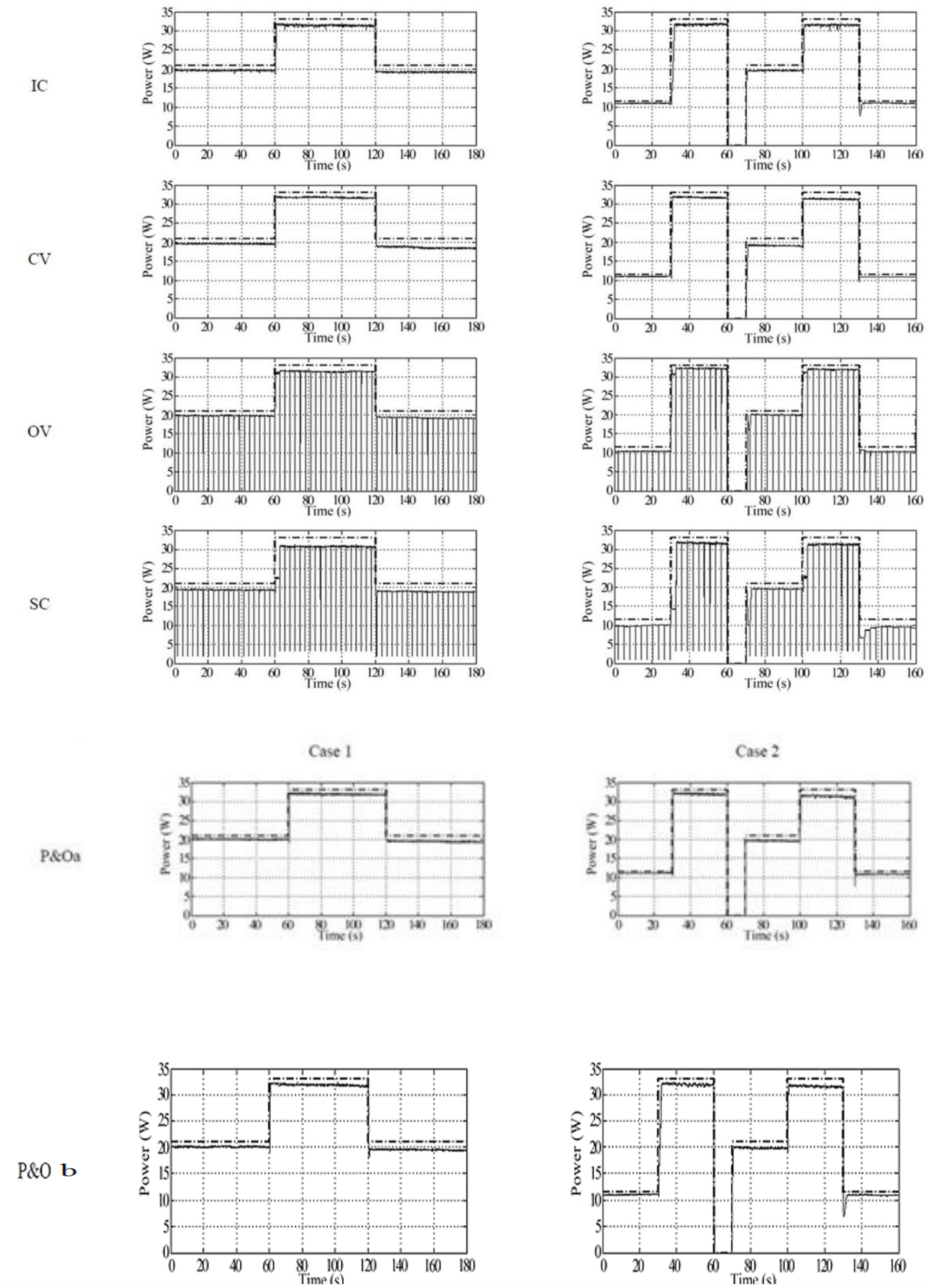

Figure 5.3: The power generated from the PV-panel with the same converter& different MPPT techniques in the two cases (Dolara, 2009)

There is also uncertainty in the PV voltage & current measurements and uncertainty in the environmental difference between tests. Although the uncertain calculations may not be very far from exact ones (about 0.5 %), this could produce uncertainty in power losses may reach 10%.So it is recommended to calculate the efficiency of each single MPPT technique a lone and take it as a confident reference.

5.1.7 Conclusion

In Table 5.2, we can summarize the different techniques performance for the two irradiance cases and compare with the ideal ones.

Table 5.2: Different techniques performance for 2 irradiance (Dolara, 2009)

MPPT Technique		**Case 1**			**Case 2**	
	Energy [J]	Rank	Difference respect to the ideal case	Energy [J]	Rank	Difference respect to the ideal case
Ideal	4493	-	-	3298	-	-
P&Oa	4282	1	-4.7%	3144	1	-4.7%
P&Ob	4278	2	-4.8%	3135	2	-4.9%
IC	4215	3	-6.2%	3117	3	-5.5%
CV	4201	4	-6.5%	3100	5	-6.0%
OV	4200	5	-6.5%	3104	4	-5.9%
SC	4088	6	-9.0%	2942	6	-10.8%

The above experiment is considered as a valuable comparison between different MPPT techniques at different levels of irradiance that is done at the Power Quality Laboratory of Department of Energy of the Politecnico di Milano.

CHAPTER 6
ANALYSIS, DISCUSSIONS AND NEW TECHNIQUE MODIFICATION

6.1 Comparison between Different Algorithms

There are many algorithms and different implementations that are regarded for each technique separately. In spite of being one technique, several proposed algorithms may be designed for it and can differ from one designer to another. The implementations of the technique as well can vary from one company to another and from one country to another to suit the environmental conditions and the clients need. As a result, results that are obtained from one technique can differ depending on the designed algorithm. When setting up a comparison between the new modified technique and the main widely used techniques among the world, we have to specify clearly the algorithm that is implemented for each in the form of flow charts so that fair discussion can be deduced from the results that are obtained from the proposed algorithms. Here, we will state the flow charts of the short circuit current technique, constant voltage technique, open circuit voltage technique, perturb and observe classic technique, three points perturb and observe technique and the incremental conductance technique as shown in Figures 6.1, 6.2, 6.3, 6.4, 6.5, and 6.6 respectively. All the flow charts of the used techniques are selected and possessed from the designers (Dolara, 2009).

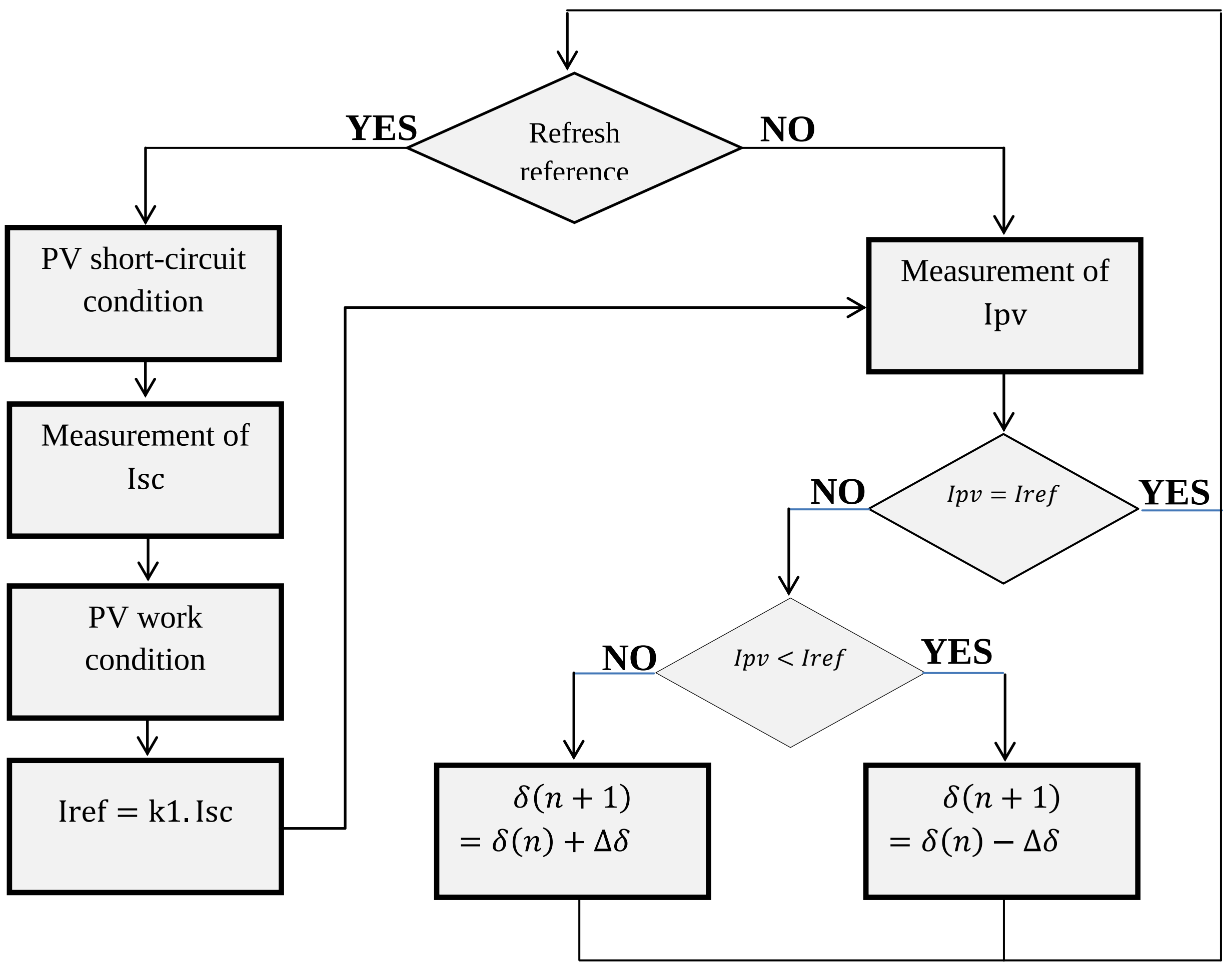

Figure 6.1: Short circuit current method

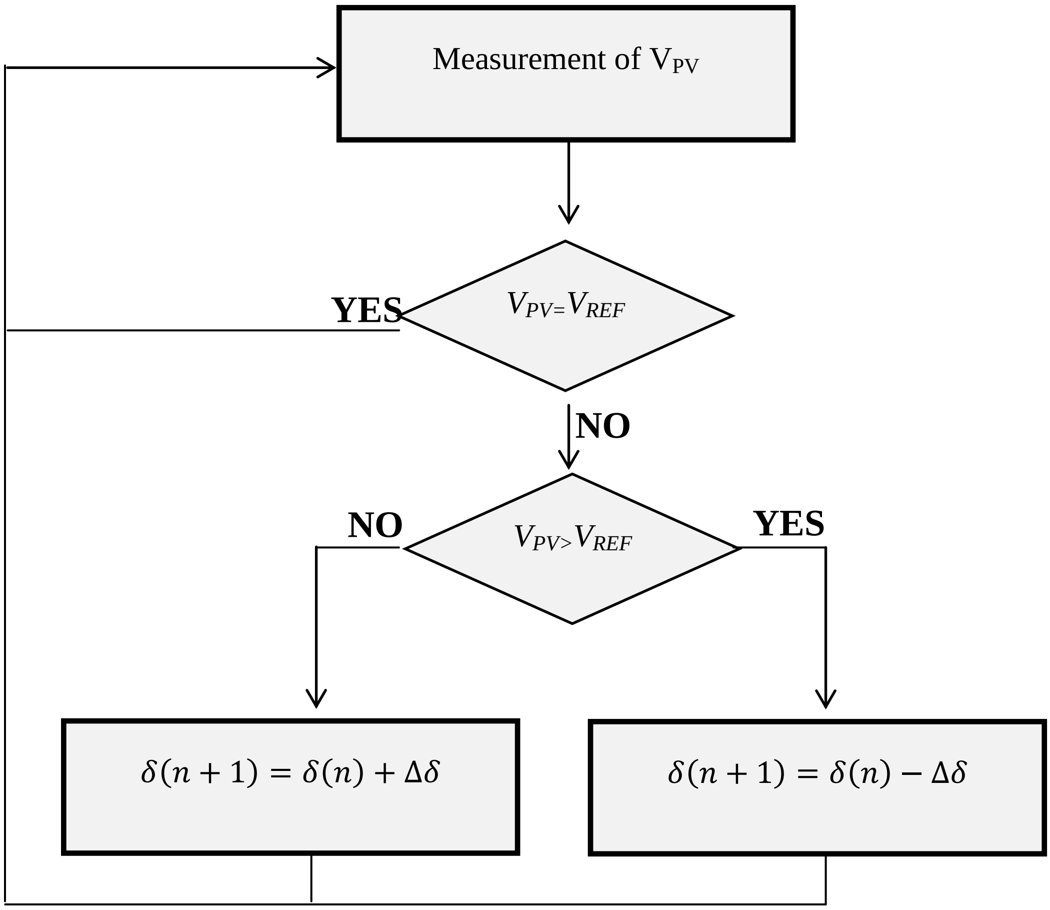

Figure 6.2: Constant voltage method

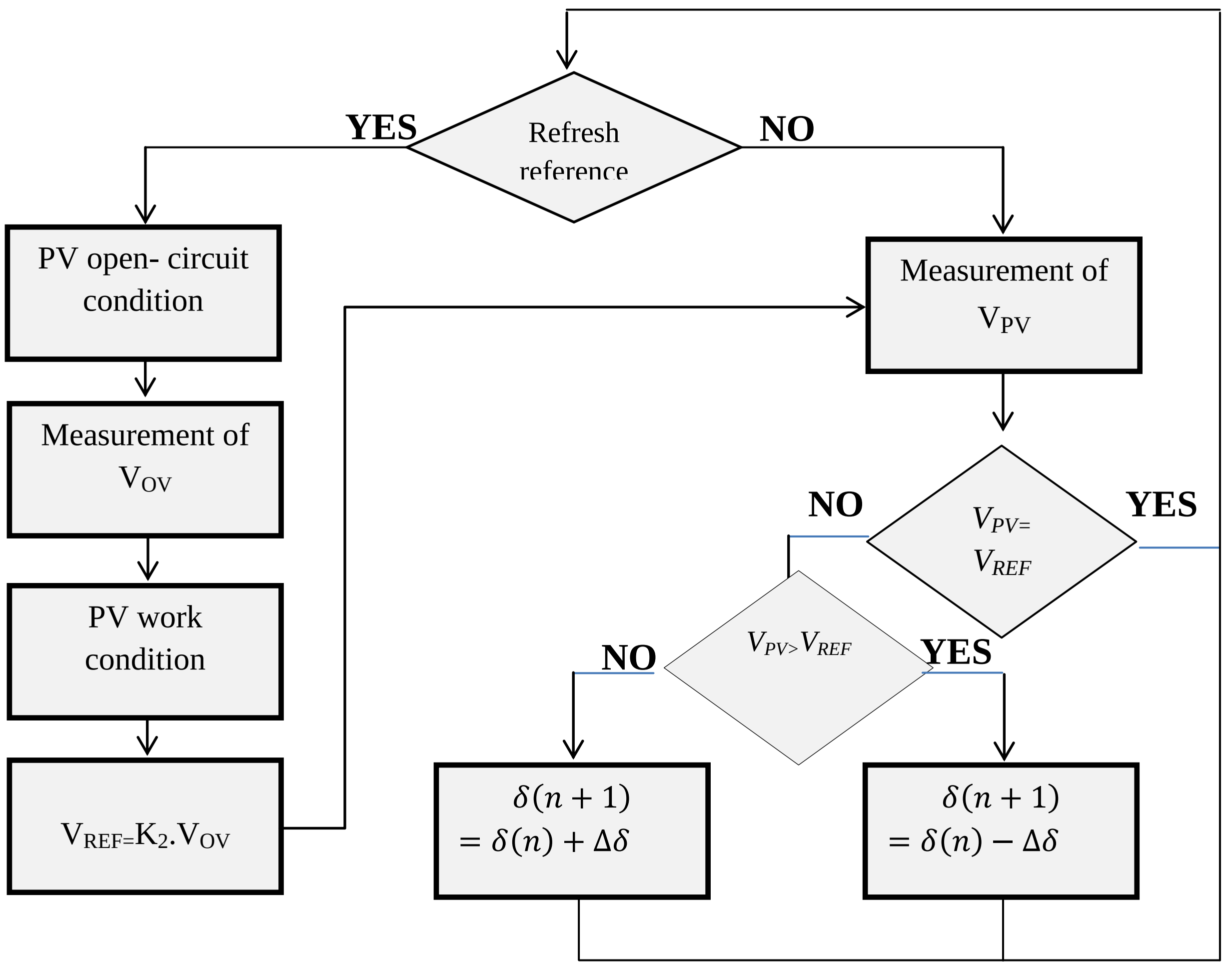

Figure 6.3: Open circuit voltage method

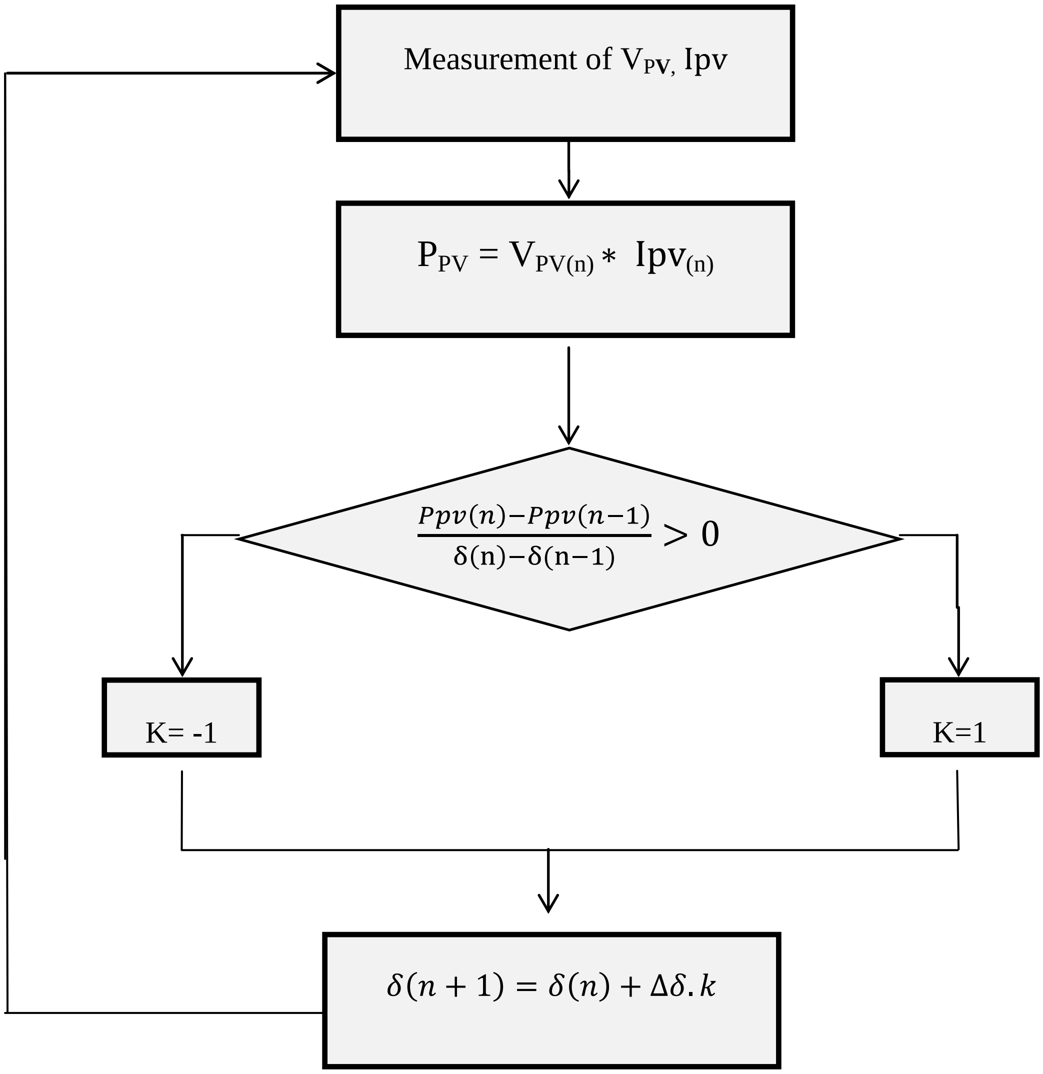

Figure 6.4: Classic P&O method

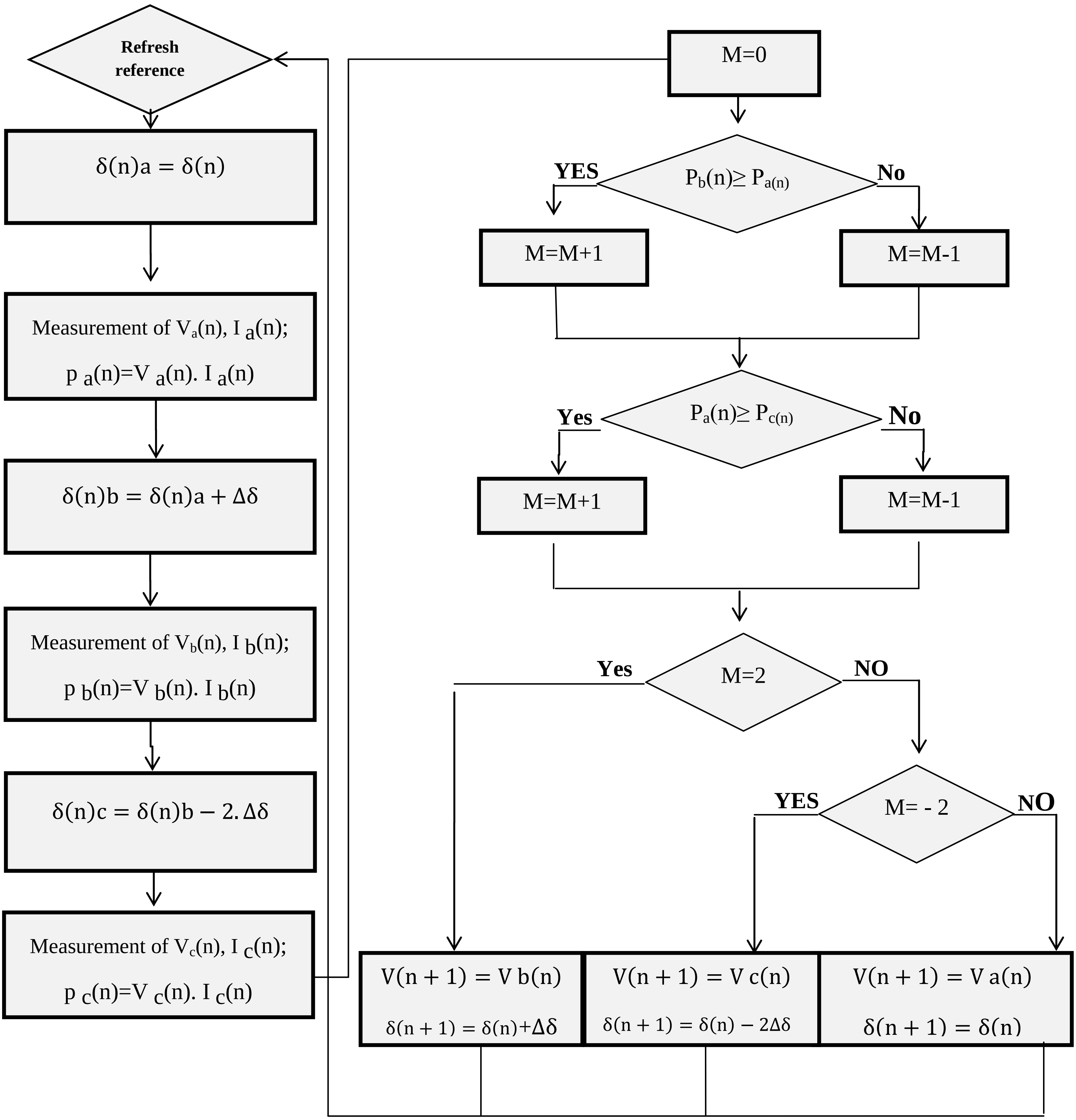

Figure 6.5: Three point P&O method

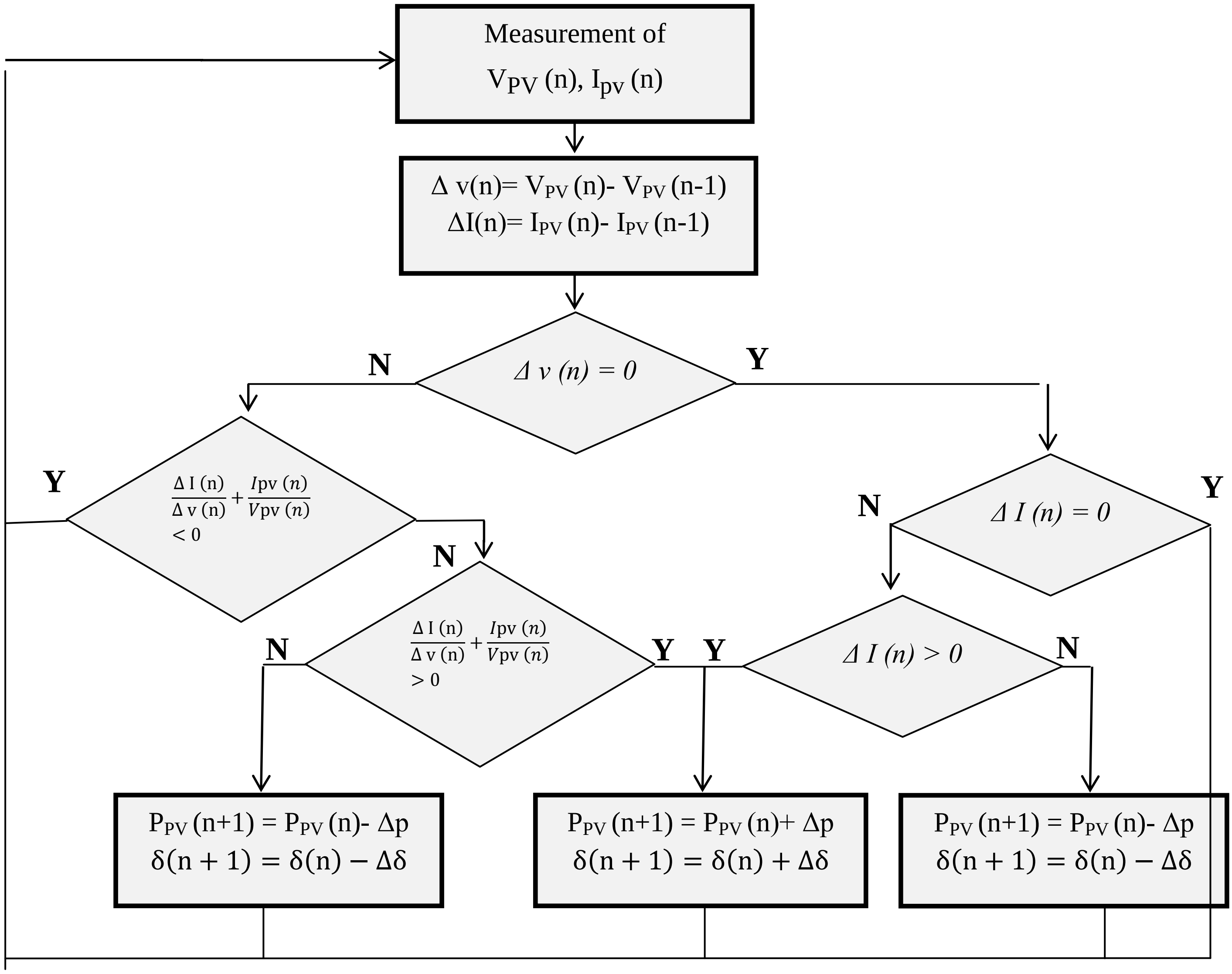

Figure 6.6: Incremental conductance method

6.2 Some Notes Regarding the Operation of PV Typically as Stated in the Flow Charts

- Applying sampling time of defined milliseconds value for measuring current and voltage for CV, OV, SC, P&O(a) and IC techniques while P&O(b) technique requires 3 measurements instead of only one.
- Regarding the duty cycle variation ($\Delta\delta$), it can be maintained at a certain value for all methods. It is important to know that low values of duty cycle ($\Delta\delta$) decreases the speed of the system to reach maximum power but in converse, it increases the accuracy to reach maximum power.
- The P&O(b) technique works by comparing 3 points on power curve. In this case, the value of the duty cycle ($\Delta\delta$) is constant and the irritation is repeated every 10 milliseconds for one complete cycle (T.Noguchi, 2002).
- The constant voltage technique (CV) is appropriate with a constant irradiance value which is practically very difficult to satisfy.
- Nevertheless, the CV technique is suitable to state an initial set point for voltage.
- The OV and SC techniques require further measurements for open circuit voltage and short circuit current respectively.
- Regarding the OV technique, every 3 seconds the current should be temporarily interrupted to measure the open circuit voltage and to refresh the voltage reference.
- It is noticed that the ratio of MPP voltage and the OV is not usually constant with temperature, i.e. it is suitable with one temperature value.
- The OV technique is better than the CV technique despite still being not as good as P&O and incremental techniques. That is because of the repeated measurements and the voltage drop that is near by 1.5v that affects the output power and the efficiency of the converter (Dehbonei, 2002).
- As well as the OV technique, the SC technique has a voltage drop equals to 0.6v. The SC technique also has to refresh the current value every 3 seconds. In this case, the measured current is approximately equal to real short circuit current (S.Togashi, 2002).

6.3 Analysis and Discussions

Depending on the results of the stated above algorithms, it is concluded that P&O (a) technique provide the highest efficiency despite having relatively low response time at low irradiance levels. While the incremental technique provide lower efficiency than P&O techniques but with better response time and it is noticed that the efficiency increases when irradiance increases so the incremental technique can be preferred in some applications characterized by continuous and high irradiance variations like transportation. Both P&O and incremental techniques have nearly the same complexity of software and expenses. Both techniques require microcontroller of high performance unlike the other techniques. Regarding the cost and the performance, P&O (a) technique can be considered a good alternative to incremental techniques. Although it provides lower output power, it is less complex and has lower cost. While P&O (b) technique may not be a perfect alternative due to high complexity structure without a significant benefit in performance. In these tests, we use a solar simulator configuration that gives nearly half the real irradiance provided by the sun. This condition can affect the performance of the incremental technique such that the efficiency of the incremental technique increases in case of higher irradiance levels. The rest techniques (CV,OV,SC) are considered the worst alternatives due to low performance. In addition, for real practical applications, they can even give worse results. Even the OV and the SC that are modified than the CV technique, they require further measurements that decrease the efficiency of the converter. Nevertheless, the CV technique can be used in case of necessity of low cost system which gives a good efficiency at irradiance levels near to 700w/ sqrm (Faranda, 2009).

As deduced from the summarized discussions and comparisons in the previous section, it was found that among the widely most used maximum power point of tracking techniques including constant voltage, short circuit current, open circuit voltage, perturb and observe and incremental conductance, the perturb and observe classic method recorded the best performance with smooth output voltage near the maximum point and relatively normal requirements with simple algorithm that is not very complex for microcontroller implementation. As a result, the choice was to work on and make further modifications on the classic P&O technique. However, the P&O classic technique has fixed step values that may cause slow response time especially at medium and high irradiance levels. Another common problem in the classic perturb and observe method is that every Mppt cycle, the terminal voltage is perturbed, therefore on reaching Mpp the output oscillates around the maximum value so this reduces the PV system generated power. It is also observed that at lower irradiance levels, oscillations are more effective while in case of fast irradiance wrong choice of search direction may happen.

6.4 The New Technique as a New Modification on P&O Classic Technique

These problems that are recorded within the classic perturb and observe method may be overcome or even reduced by making a modification on the perturb and observe technique by using a smart feature. Simply the idea is introducing a new variable step value rather than the old constant one. Whereas mentioned previously, choosing large steps may result in oscillation while too small steps may result in slow response. So by making this step value small near the maximum point while making it large at far values from the maximum point, accuracy at maximum value with less oscillations can be achieved and response time in case of far values from maximum point can be improved. A function should be developed for the step value so that this new modified technique could be implemented. If we notice the P-V curve characteristics of the output of PV system as below in Figure 6.7

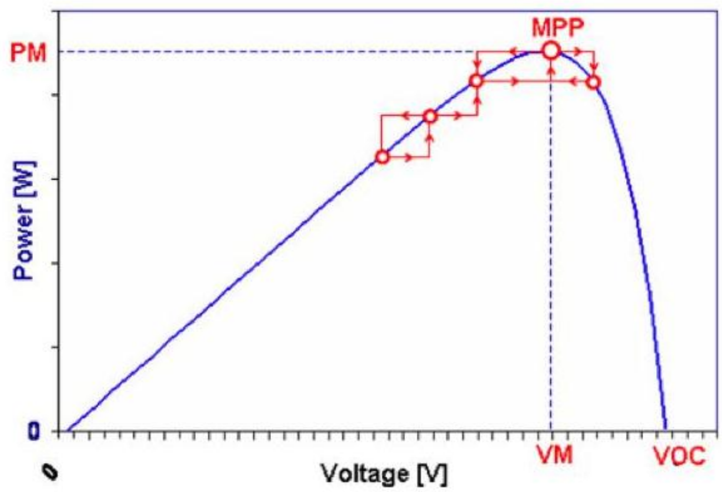

Figure 6.7: P-V output

When we go away from the maximum point, left or right, the absolute value of the slope of the curve $\frac{dP}{dV}$ increases. If a new value for step named alpha **(α)** is introduced, then it will be equal to the absolute of $\frac{dP}{dV}$ multiplied by constant M

$$\boldsymbol{\alpha} = M * \left[\left|\frac{dP}{dV}\right|\right] \tag{6.1}$$

And then the output step value will be equal to the old value plus K multiplied by the new step as shown in Equation 6.2

$$\delta(n+1) = \delta(n) + k.\alpha(n).\Delta\delta \tag{6.2}$$

From the previous Equation, when slope increase i.e. going far from M_{pp}, [|dp/dv|] increases so α increases then the total step value $\delta(n+1)$ increases, this means the perturbation process become faster and that is what exactly we need when we are still far from reaching M_{pp} so the response time is improved. While if the slope decreases i.e. going near M_{pp}, [|dp/dv|] decrease so α decreases then the total step value $\delta(n+1)$ decreases, this means the perturbation process become slower and that is exactly we need when we are near to M_{pp} so that the accuracy at getting real Mpp increases with less oscillation.

6.5 Flow Chart and Simulation for the New Modified Technique

The proposed new algorithm can be understood from the flow chart in Figure 6.8.

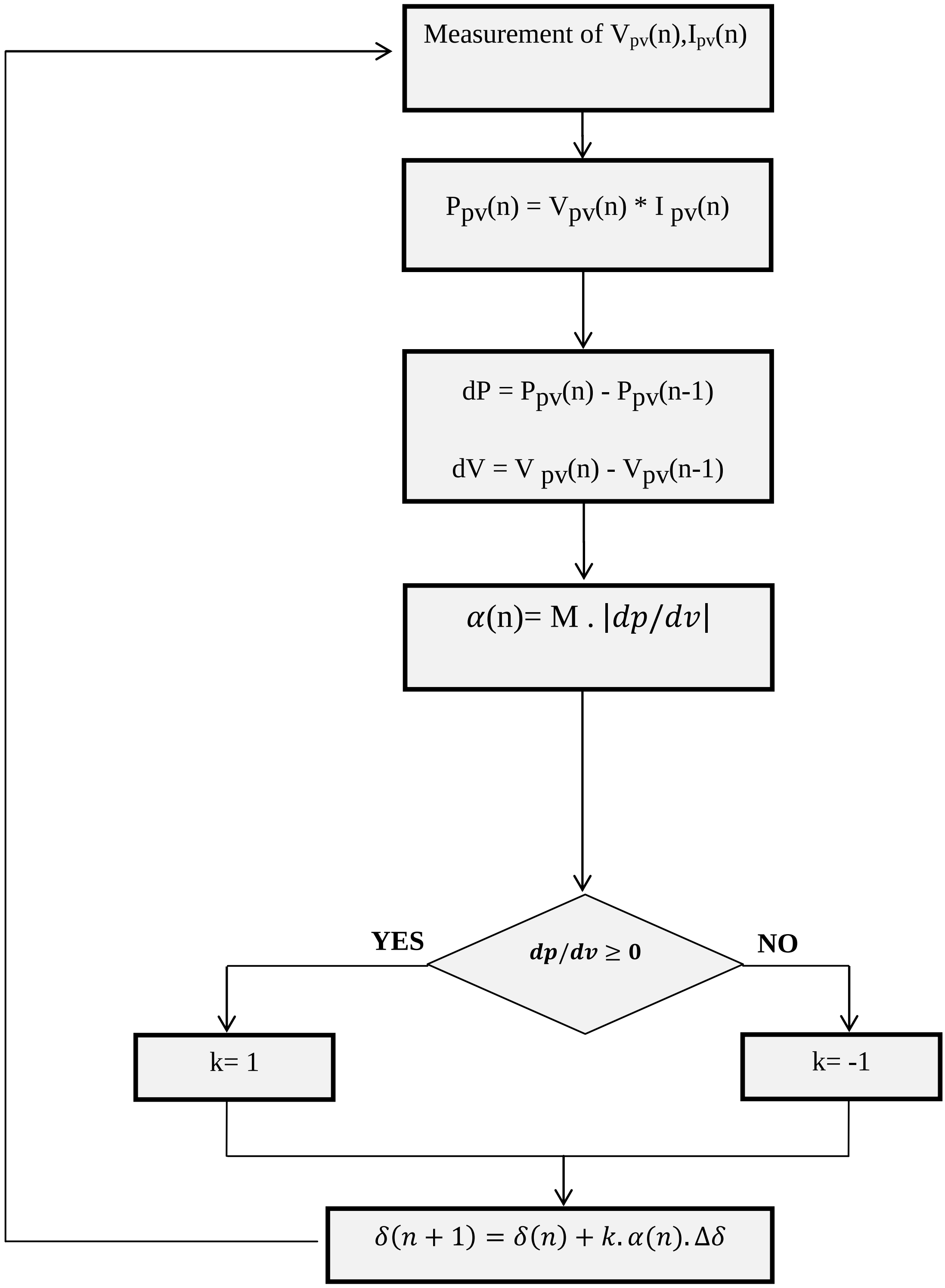

Figure 6.8: Proposed flow chart for new P&O technique

Attached in Figure 6.9 screen shoot from the mat lab simulink for the new optimized perturb and observe method.

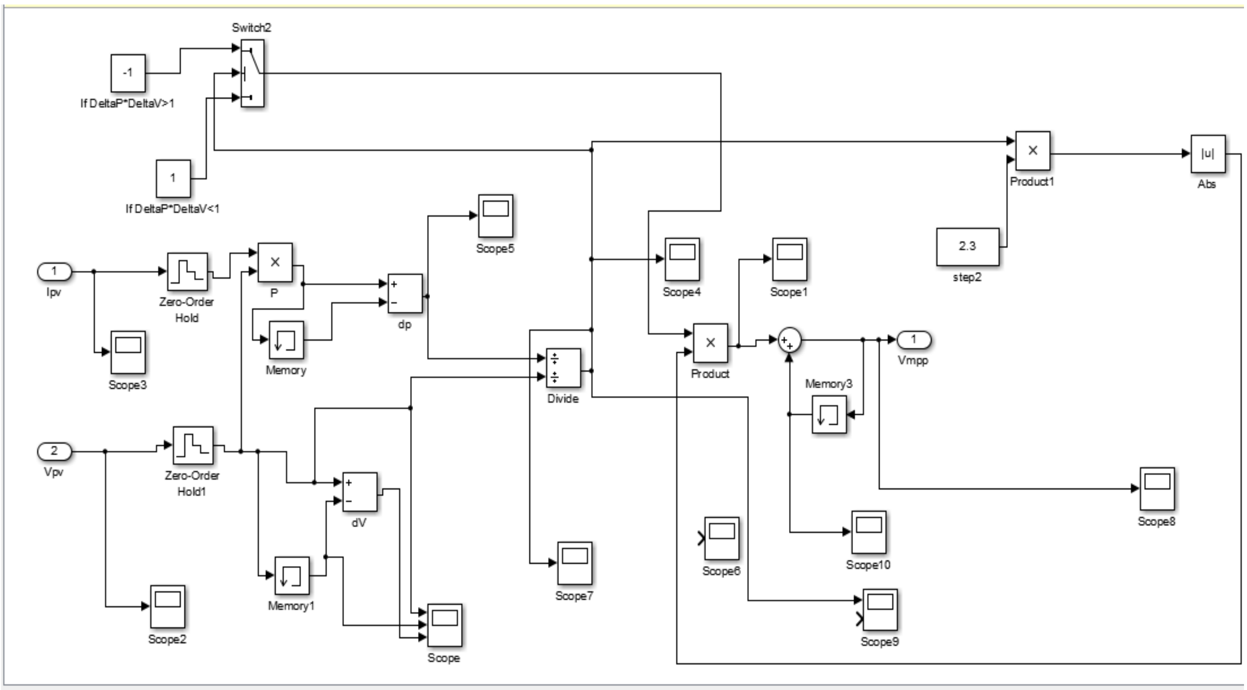

Figure 6.9: Matlab simulation for new P&O technique

6.6 Explanations of the Program Algorithm

The two inputs are the current and voltage that are obtained from the PV simulator. Both inputs are passed by a The Zero-Order Hold block that holds its input for the sample period specified. The present voltage is measured and the previous voltage is obtained by a memory block then the dV is calculated as shown. Also the present power is measured and the previous power is obtained by a memory block then the dP is calculated as shown. By dividing $\frac{dP}{dV}$, we can obtain a positive or negative value. This value is entered to a switch block so that if $\frac{dP}{dV} > 0$, an output value equals to 1 is the output of the switch while if $\frac{dP}{dV}<0$, an output value equals to -1 is the output of the switch, where this value is the K. After that, M *[l$\frac{dP}{dV}$l] is obtained, where M is a constant assumed to be equal 1.The value of M *[l$\frac{dP}{dV}$l] is the value of α(n) which is then multiplied by the K value and by Δδ (which is assumed to be equal to 2.3). The obtained value now is $k.\alpha(n).\Delta\delta$ is added to the previous voltage value obtained from last cycle. The output now is the new voltage value. $\delta(n+1) = \delta(n) + k.\alpha(n).\Delta\delta$. This algorithm is repeated till reaching the maximum power point voltage that guarantee a maximum power achievement. When the irradiance varies, the current varies and the power varies so the power curve varies as well forming a new curve with different maximum power point that should be tracked again automatically by using this algorithm.

CHAPTER 7
RESULTS AND CONCLUSION

7.1 Results Discussion

- The output obtained from our simulation of the new optimized P&O technique is the V_{mpp} as shown from scope 8 in Figure 7.1 which is observed that it saturates at 60 volt.
- During the transient time before reaching steady state, it is noticed that the damping oscillations are few. While after reaching steady state, the oscillations are eliminated completely.
- The value of the open circuit voltage for the present input is 80 volt as deduced from scope 2 as shown in Figure 7.2.
- While the V_{mpp} obtained saturates at 60 volt as shown in Figure 7.1 although the input voltage is varying as shown in Figure 7.2. The V_{mpp} value is then found to be equal to $0.75 \cdot V_{o.c.}$ as recommended and estimated before in previous researches and papers to guarantee maximum power.
- The response time hasn't been affected badly when oscillations are reduced which is a modified feature that mostly does not happen as normally the value of oscillations are related inversely to the response time.

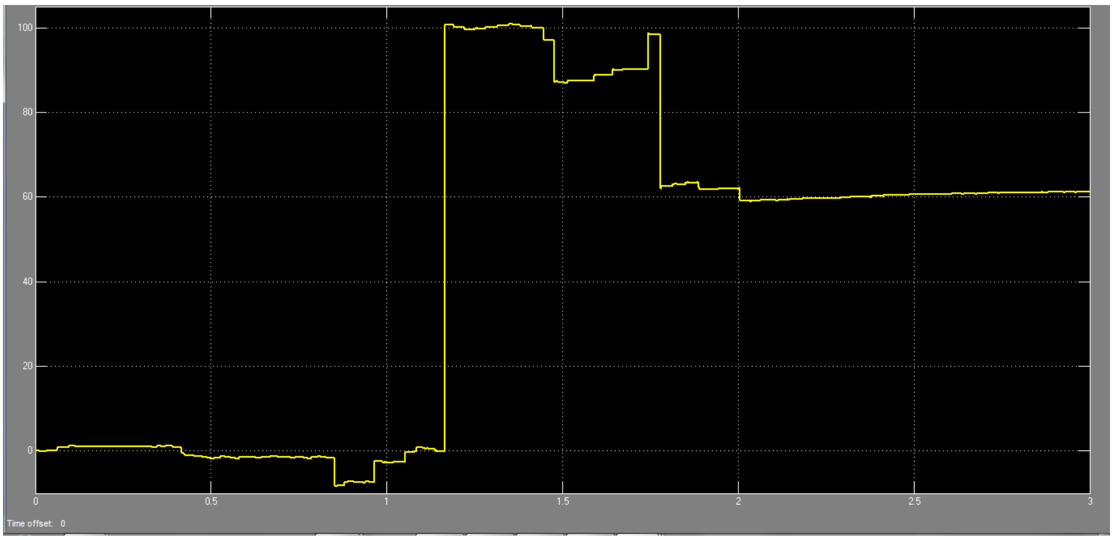

Figure 7.1: V_{mpp} output for new P&O technique

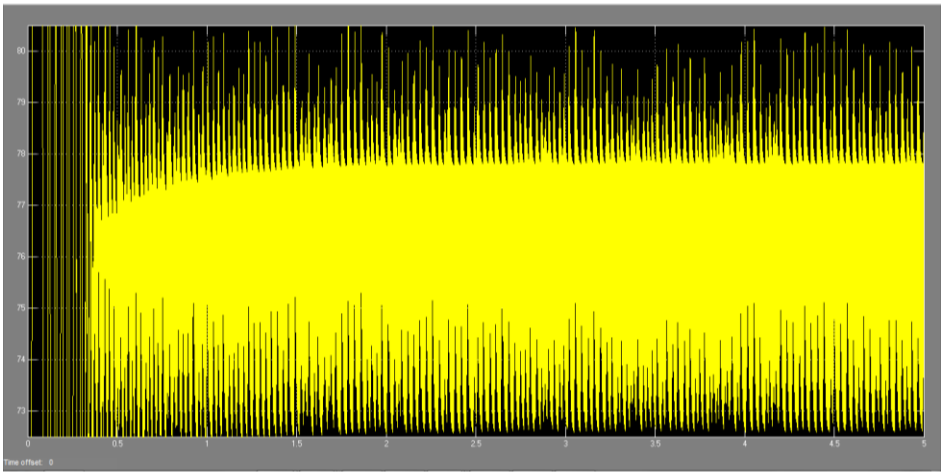

Figure 7.2: Input voltage from sun simulator

7.2 Comparison between the New and Old Techniques

By comparing my work to the classic P&O method which is simulated also by matlab simulink with the same inputs V, I values obtained from the sun simulator where the step value is constant and does not depend on dP/dV. The matlab simulation of P&O classic technique which is developed by me is shown in Figure 7.3

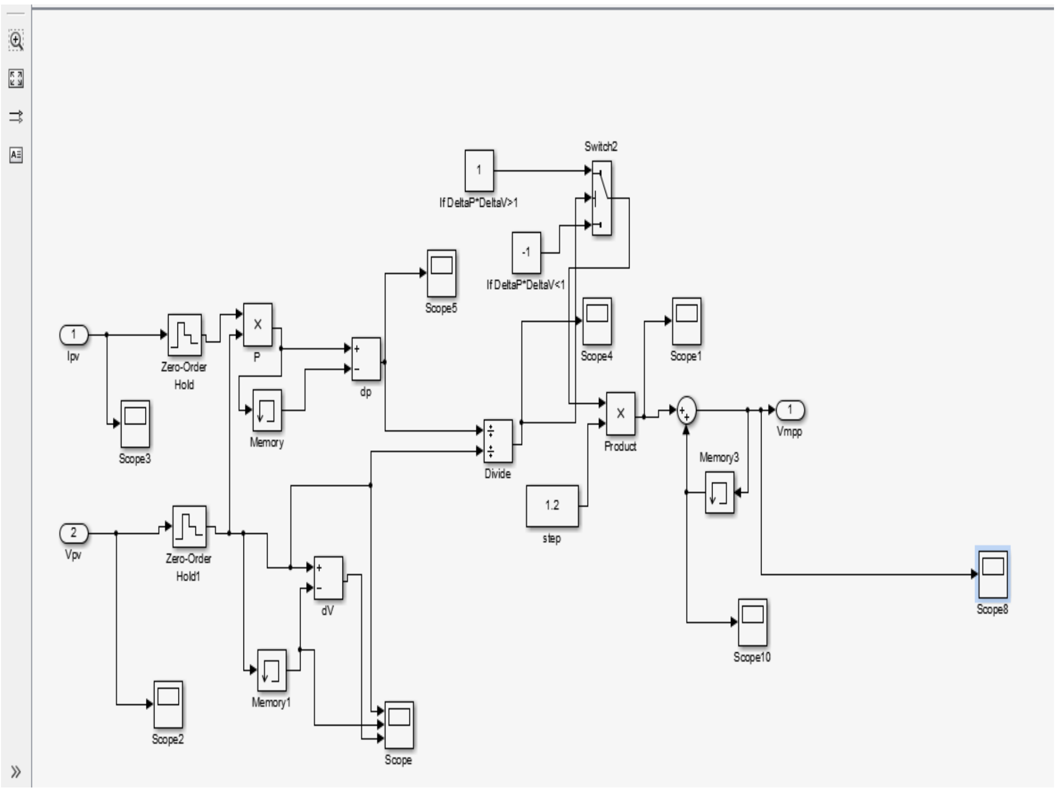

Figure 7.3: Matlab simulation of classic P&O technique

While the output of V_{mpp} is obtained from scope 8 as shown below in Figure 7.4

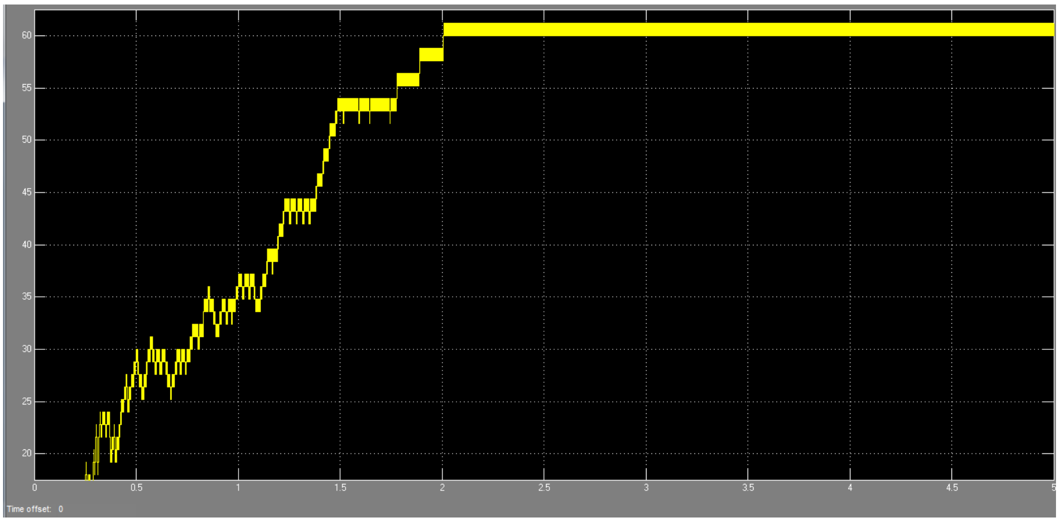

Figure 7.4: V_{mpp} output of classic P&O technique

By comparing the obtained results, it is found that in the classic P&O technique there are more oscillations occur in the values of V_{mpp} than the modified new technique until reaching steady state. Even on reaching steady state value, by zooming in, it is noticed that there are continuous oscillations around the Mpp as shown in Figure 7.5 in contrast with the value obtained from the modified new P&O technique. These oscillations, for sure, increase the power losses among the PV array so the power produced is decreased and the efficiency of the system become lower. As a result, it can be said that our new modified P&O technique decreased the oscillations before reaching and after reaching V_{mpp} value than the classic method and so increased the power output that can be achieved as well as the efficiency without affecting the response time negatively.

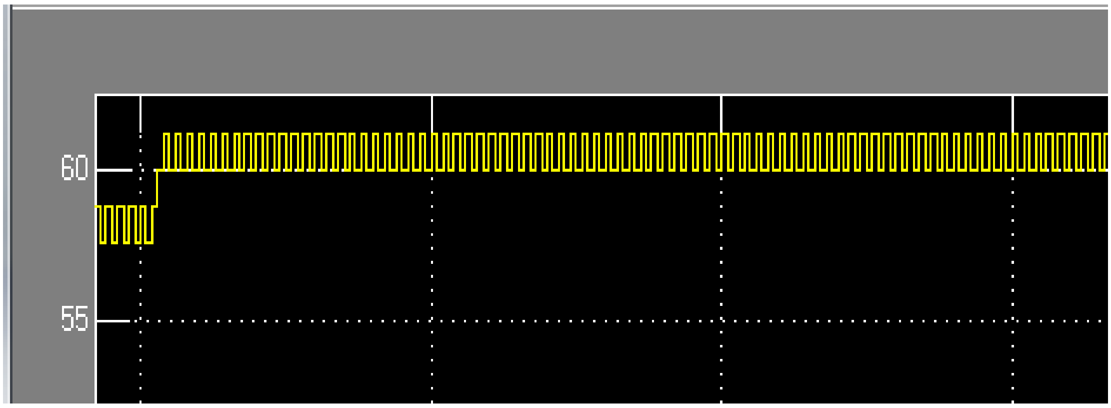

Figure 7.5: V_{mpp} output of classic P&O technique at steady state

7.3 New Conclusion

The new modified P&O technique successfully tracked the MPP and analyzed the problems by improving the response time, decreasing the oscillations, increasing the stability at steady state condition resulting in increasing the efficiency.

7.4 Recommendation and Future Work

The new modified perturb and observe technique that is developed with the stated above algorithm and the obtained results could be literaturely archieved as a good reference and offers reasonable knowledge as well as considerable support to related researchers and manufacturers to the PV industry and maximum power point of tracking techniques. By using appropriate micro-controller of normal complexity with medium configurations, this new modified P&O technique could be successfully applied in various PV applications that require high efficient system with relatively low power losses.

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