THE UNIVERSITY OF TURKISH AERONAUTICAL ASSOCIATION

INSTITUTE OF SCIENCE AND TECHNOLOGY

A Design For Generating MP In A Solar Cell

MASTER THESIS

ALI DAWOOD AWAD

THE DEPARTMENT OF ELECTRICAL & ELECTRONIC ENGINEERING

JANUARY 2017

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Türk Hava Kurumu Üniversitesi Fen Bilimleri Enstitüsü'nün 1403630022 numaralı Yüksek Lisans öğrencisi, Ali Dawood Awad ilgili yönetmeliklerin belirlediği gerekli tüm şartları yerine getirdikten sonra hazırladığı A Design For Generating MP In A Solar Cell: Aşırı koşullarda güneş pillerinin verimliliğini artırmak, aşağıda imzaları olan jüri önünde başarı ile sunmuştur .

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Yüksek Lisans Tezi olarak sunduğum, A Design For Generating MP In A Solar Cell: Aşırı koşullarda güneş pillerinin verimliliğini artırmak, tarafımdan akademik etik ve kurallara aykırı düşecek bir yardıma başvurmaksızın yazıldığını ve yararlandığım kaynakların kaynakçada gösterilenlerden oluştuğunu, bunlara atıf yapılarak yararlanılmış olduğunu belirtir ve bunu onurumla doğrularım.

13.01.2017

ALI DAWOOD AWAD

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13.01.2017 **ALI DAWOOD AWAD**

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LIST OF ABBRIVIATION

A	Diode quality factor
FF	Fill factor
I	Output current of the PV array
Io	Dark generated current
IL	Light generated current
IMPP	Maximum power point Current
ISC	Short circuit current
K	Boltzmann’s constant
np	The number of solar cells connected in parallel
ns	The number of solar cells connected in series
PV	Photovoltaic
q	Charge of an electron
RS	Series resistance of a solar cell
RSH	Shunt resistance of a solar cell
S	Irradiation in W/m^2
T	Absolute temperature
V	The output voltage of the PV cell/array
VMPP	Maximum power point Voltage
VOC	Open circuit voltage
ISC	Short circuit current
Panel 1	Solar panel covered with conductive glass
Panel 2	Solar panel Without conductive glass

ABSTRACT

A Design For Generating MP In A Solar Cell

ALI DAWOOD AWAD

Master, Department of Electrical & Electronic Engineering

Thesis Supervisor: Assist. Prof. Dr. Ibrahim Mahariq

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Due to the fact that the solar cell efficiency is relatively poor, it is important to find methods, reducing power losses, and seeking for techniques leading to extracting solar cell power with maximum efficiency. For this purpose, this thesis applied two techniques in order to reduce power losses. First, self-cleaning technique. Dust accumulating on the surface of the solar cell is one of the challenges that affect on efficiency.

Self-cleaning depends on the concept that dust particles statically charged with a negative charge in nature, hence we applied the idea of cleaning the surfaces of solar collectors in a manner dependent on the generation of negative electrostatic charge on the surface of solar collectors. The target is achieved by generating a repulsive force between the accumulated dust particles and the charged surface.

To apply this idea we used conductive glass that is composed of a thin sheet of glass coated with a thin film of SNO2 as a cover to the solar panel, and supplying this sheet with negative voltage.

Secondly maximum power point tracking is adopted in this work,Finally, important results drawn in the conclusion chapter of this thesis.

ÖZET

Bir Güneş Pili İçinde MP Üretmek İçin Bir Tasarım

ALI DAWOOD AWAD

Yüksek Lisans, Elektrik-Elektronik Mühendisliği Bölümü

Tez Danışmanı: Assist. Prof. Dr. Ibrahim Mahariq

OCAK 2017, 80 sayfa

Güneş pilinin etkinliği nispeten zayıf olduğu için, yöntemleri bulmak,güç kayıplarını azaltmak ve güneş pil gücünü azami verimlilikle elde etmek için teknikler aramak önemlidir. Bu amaçla, bu tez, güç kayıplarını azaltmak için iki teknik uyguladı. İlk olarak, kendini temizleme tekniği. Güneş pilinin yüzeyinde biriken toz, verimliliği etkileyen zorluklardan biridir.

Kendiliğinden temizleme, toz parçacıklarının statik olarak negatif bir yük ile doğadaki konseptine bağlı olduğunu ve bu nedenle güneş kolektörlerinin yüzeylerini, güneş kolektörlerinin yüzeyindeki negatif elektrostatik yük oluşumuna bağlı olarak temizleme fikrini uygulamıştır. Hedef, birikmiş toz partikülleri ile yüklü yüzey arasında itici bir kuvvet üretmek suretiyle elde edilir.

Bu fikri uygulamak için, güneş panelinin bir örtüsü olarak ince bir SNO2 filmi ile kaplanmış ince bir cam levhadan oluşan iletken cam kullandık ve bu levhayı negatif voltajla tedarik ettik.

İkincisi, bu çalışmada maksimum güç noktası izlemesi kabul edilmiştir. Son olarak, bu tezin sonuç bölümünde önemli sonuçlar verilmiştir.

CHAPTER ONE

INTRODUCTION

1.1 Background

The hot topic on the international schedule nowadays is the global warming and energy policies. It is obligated, especially in developed countries,to reduce gas emissions in the greenhouse, an example of that, the European countries promised to reduce greenhouse gas emission to a value below (18%), and generate less than (18%) of its energy needed from these sources by 2020 [1].

In this way, photovoltaic (PV) has a wide important part to do, because it generates clean power.Solar cells were discovered by Bell Telephone scientist in 1954, they found that silicon material is generating charge at the moment when photons exposed it. From that time up to nowadays researchers have been trying to devise new technologies to improve the efficiency of these materials for producing electrical power.

The only emissions produced from PV power generation are those generated from the factories of the panels, also, the PV has flexibility to install in different places like the roofs of the buildings. Also, they can be used as a stand alone in case no electricity were available. There are installation types, called off-grid facilities that are commonly used as an alternative to generate electricity in isolated areas.

However, the common connection of PV power generation is established with power network where the energy is fed, in fact, PV cell is a promising business in many EU countries followed by Japan, USA and Italy [3].PV is on a high cost compared to other resources of energy due to the equipment required, And through running the system, the cost is not rendered as necessary. In fact, the main cost of this system is directed towards equipment and installation.

The key aspect of this technology is to increase the efficiency of PV, as the efficiency increase, reducing consequently the cost of the power generated. According to the International Standardization Organization, dust is defined as: Small, dry, and solid particles projected into the air by natural forces, taken that these particles are below (75μm) in diameter such as wind, volcanic eruptions, and mechanical or man-made processes such as crushing, grinding, milling, drilling, demolition, shoveling, screening, bagging, and sweeping.

Dust particles size varies between(1 to 100 μm) in diameter, and they settle under the influence of gravity, it can be found anywhere, such as homes, offices, and other places, an example of dust particles found in our environment [5]:

1-Mineral dust; such as these with free crystalline silica (e.g, coal, quartz and cement dusts).

2-Metallic dust; like heavy materials, such as lead, cadmium, nickel, and beryllium dusts.

3- Chemicals and pesticide dust.

4- Vegetable and Organic dusts: such as wood, flour, cotton.

5- Biohazards; such as fertile particles, spores.

There are several dust shapes, and the common one is sphericity, which is characterized as the ratio of an area of the surface of a sphere which has the same volume as the particle of the real surface area particle [6] Density (In practical measurements) is a given weight of a dry powder, and its volume can be calculated by the volume of fluid it displaces. [7] Van der Waals (forces between rigid bodies).

When two particles come into contact they become capillary-electrostatic force and van der Waals forces - capillary forces generate from condensed moisture at the surface of the particle. Electrostatic forces mainly depends on the charges present in the particles [8, 9,10].

To remove it from surfaces there are several methods which are:

A: Wind clearing method which is a natural dust removal.

B: Mechanical Dust Removal: through applying automatic equipment to remove and clean the solar panel surfaces by using shaking, brushing, shocking, vibrating and sweeping of solar panels.

C: Using hydrophobic water, the water droplets roll off the solar panel surface and carry the dust away [11]

D: Electrical method which is applied in current thesis.

In this thesis, we suggest a cleaning system which uses a thin film of a SNO2 coated sheet of glass cover to the solar panel, the method revolves around the idea of using an electric curtain developed by F.B. Tatum in 1967, this technique is able to move the charged dust particles away from the surface of the solar panel.

The SNO2 thin film is charged with negative charge and placed on the surface of a solar panel, which is facing the solar light, so the dust particles will be charged with negative charges and this forces the particles to repel one another and then move out of the surface of the panel.

There are three factors affected, mainly to the efficiency of a PV plant:

The efficiency of the PV panel (which is between (8-15%) [3]; the efficiency of the maximum power point tracking (MPPT) algorithm (which is more than 98%) [14] and the efficiency of the inverter (95-98 %) [13].

It is not easy to improve the efficiency of the PV panel and the inverter, as it is dependant on the available technology, it requires better components, which means increasing the cost of the installation; instead, it is easier to apply tracking techniques for the maximum power point (MPP) with new low cost control algorithms, in other words, through improving the software of the inverter to obtain high efficiency algorithm. This way we increase the efficiency of the PV cells with small amounts.

MPPT algorithms are considered very important in applying the PV array, because these arrays have a nonlinear voltage-current characteristic with a single maximum power point [15]. This point depends on the irradiance conditions and temperature of the panels, both parameters change daily and also changes during the seasons of the year, in addition, the change of the irradiation may happen rapidly due to the change in the conditions of the atmosphere such as fogs and clouds.

Hence, applying MPPT is very important with all its conditions to obtain the maximum available power. In fact, MPP is the key upon which the expansion of using this technology depends on. During the last years, many types of MPPT techniques have been established [16], and they differ from one another in many aspects such as cost, efficiency, sensors needed and complexity; however, it is not useful to apply more complicated method or more expensive ones if a lower cost ones, similar and simpler, can be used.

This is the main reason to eliminate some types of MPPT technique that has been proposed, after publishing the European Standard EN 50530 at May, 2010 [17], the measuring of MPPT efficiency became standardized, it states how to measure MPPT efficiency both dynamically and statically.

1.2 Overview:

Due to the ongoing increase in demand for electric power, and the fact that fossil fuels upon which power plants depend on are exhaustible, it is necessary to focus on an alternative sustainable energy such as solar power generating.

1.3 Thesis Topic:

The idea of this project is based on the use of modern methods of increasing the efficiency of solar cells, taking into account the fact that this increament will assist in making it an alternative for fossil fuel electric power plant.

1.4 Literature Review:

Hee et al [39] :

Examined the effect of dust on the solar cell efficiency under the weather of Singapore. The researchers explained that the dust has a noticeable impact on solar cell efficiency and has been calculated in spite of the rain intensity in Singapore.

Sims et al [12] :

Examined the development of a transparent electrodynamic shield to protect panels from dust deposition is described as: the shield contains a solar panel with embedded parallel electrodes connected to a single-phase AC supply to produce an electromagnetic wave, the electromagnetic field produced by the electrodes on the surface of the panel repels dust particles that have already settled on the panel surface.

K. Hussein [26] :

Examined the modeling method of photovoltaic (PV) systems and an implementation of the incremental conductance for maximum power point tracking (MPPT) algorithm, the method is used to study the influence of rapidly changing irradiance level concerning performance of photovoltaic systems.

Ashram et al [16] :

Examined the different techniques used for maximum power point tracking with variations in implementation.

1.5 Contribution of Thesis:

This thesis constitutes a contribution seeking successful methods to improve the efficiency of solar cells, which will have a significant economic and scientific influence.

1.6 Arrangement of Thesis:

Chapter One:

Includes a general idea of the thesis (introduction, overview, thesis topic, literature review, arrangement of the thesis, the contribution of the thesis).

Chapter Two:

Includes the specifications of solar cells and I/V characteristics.

Chapter Three:

Includes discussing the types of self-cleaning used nowadays while focusing on self-cleaning using cover-coated glass with an SNO2 thin film.

Chapter four:

Includes discussing the MPPT and types of this technique and the processes for applying it on solar panel and focuses on Perturb and observing technique.

Chapter Five:

Includes the experimental part and practical test we did on solar panel by applying self-cleaning (glass cover) and Perturb and observing MPPT technique and discussing the results.

Chapter six:

Includes conclusions of discussing the experimental part and recommendations according to these results.

CHAPTER TWO

Solar Cell

2.1 The operating principles:

The basic components of photovoltaic panels are solar cells. It is a tool used to convert part of sunlight to electrical power. Silicon is the basic materials that are used to manufacture solar cell. Generally, most of solar cells are composed of two or more semiconductor layers, unfortunately, part of the sunlight spectrum has been exploited as electrical power, therefor the efficiency of these cells are limited.

Solar cells applies the benefit of the photoelectric phenomenon which is the ability of some semiconductors, like the silicon which convert solar energy to electrical current. The current generated by a single solar cell is small; hence the array of cells are connected together to make the generated power enough for consumption. There are many methods used to collect and connect the arrays of solar cell to make the structure of strings calls for PV panel.

A solar cell is commonly composed of two different layers of silicon, P and N layers which makes the sandwich doped form with low impurity materials, the P-layer is doped to have few eletctrons (positive one; acceptor) while N-layer doped to have a lot of electrons (negative one; donor) when joined together, a barrier is created at the junction place of the two layers. The electrons in N-layer will diffuse through the barrier to the P-layer and the holes (positive charges) will diffuse in the opposite direction.

This movement continues till an equilibrium case happens and no charge moves and then an electric potential are created which causes a current if the layers are connected through a load.

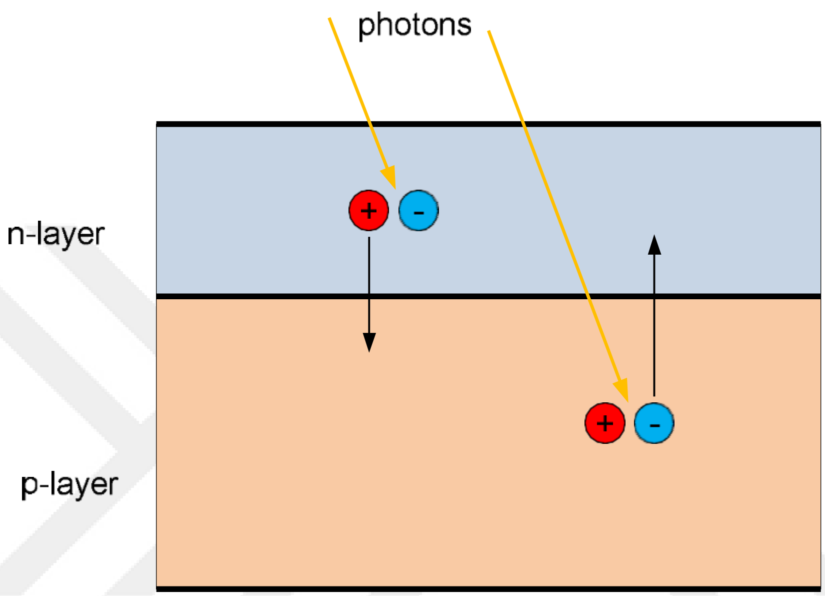

Figure 2.1 The solar cell p-n junction

A diagram of the P-N junction in Figure (2.1) explains the effect of the mentioned electric field, in order to collect the electrons and holes, metallic contacts are added on both sides so the current will follow, the N-layer is facing solar light, so to override the problem of collecting the holes and electrons from that side of metal contacts, there is a metallic strip called fingers that are used.

The operating principle and the structure of the solar cell has been described later on, when the photons of the solar radiation fall on the cell, three different cases could happen. Some of the photons don’t penetrate through the cell and reflect from the face of the cell and metal fingers.

Some of them have low energy and pass without any effect taking place, only photons with enough energy more than the silicon band can generate an electron-hole pair. These pairs of electro-hole will be created on each side of the P-N barrier.

The light-generated current depends directly on the irradiation, if it is higher, then it creates more current generated by the solar cell due to having more energy with enough photons to generate more electron-hole pairs.

2.2 The equivalent circuit of a solar cell:

The solar cell can be symbolized by the electrical model shown in Figure (2.2), its current-voltage relation can be represented by the following equation (2.1):

$$I = I_L - I_0\left[e^{\frac{q(V-IR_S)}{AKT}-1}\right] - \frac{V-IR_S}{R_{SH}} \tag{2.1}$$

Where V and I are the solar cell voltage and current respectively, Q is the charge of an electron, Io is the dark saturation current, K is the Boltzmann constant, A is the diode quality (ideality) factor, RSH and RS are the shunt and series resistances of the solar cell, T is the absolute temperature, RS is the resistance offered by the contacts and the bulk semiconductor material of the solar cell. The shunt resistance RSH is present due to the impurities near the edges of the cell, which causes non-ideal behavior of the P-N junction and causes a short-circuit path around the junction. Ideally, RSH infinite and RS would be zero.

However, this ideal value of RSH and RS is not possible and manufacturers try to improve their products by minimizing the effect of these resistances.

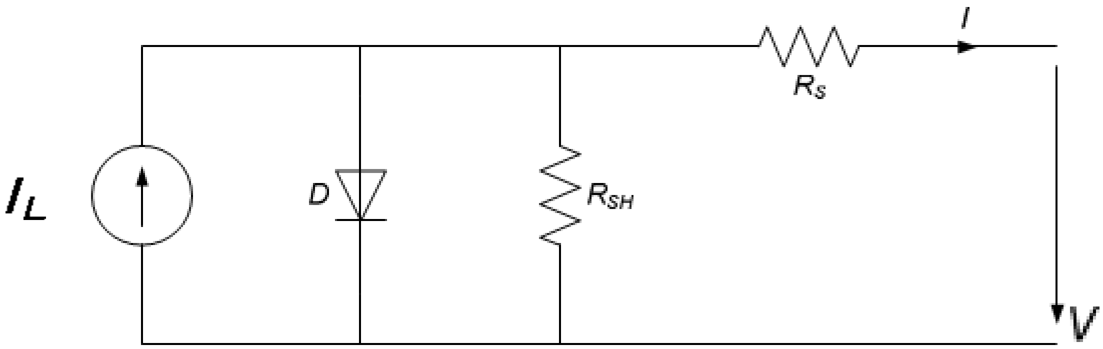

Figure 2.2 The solar cell equivalent circuit

To make the model simpler, consider the value of the shunt resistance being very large (infinite), then the last term in (2.1) will be neglected. The photo voltaic panel is constructed from many arrays of solar cells, joined together and then connected as series and parallel in a way to supply the appropriate capability for the tethered loads.

By neglecting the effect of shunt resistance and simplifying the representation of a solar cell, the PVoutput current-voltage characteristics are explained by the equation (2.2), where NS and NP are the number of solar cells in the series and parallel respectively [19].

$$I \approx n_p I_{L-} n_p I_0 \left[e^{\frac{q(V-IR_S)}{AKTn_s}} - 1 \right] \quad (2.2)$$

2.3 Open circuit voltage, short circuit current and maximum power point:

Two important points of the current-voltage characteristics must be pointed out: The open circuit voltage VOC and the short circuit current ISC. At both points the power generated is zero. VOC can be approximated from (2.1) when the output current of the cell is zero, i.e. I=0 and the shunt resistance RSH is neglected. It is represented by equation (2.3). The short circuit current ISC is the current at V = 0 and is approximately equal to the light-generated current IL as shown in equation (2.4).

$$V_{OC} \approx \frac{AKT}{q} I_n \left(\frac{I_L}{I_0} + 1\right) \tag{2.3}$$

$$I_{SC} \approx I_L \tag{2.4}$$

The maximum power is generated by the solar cell at a point of the current-voltage characteristics where the product VI is maximized, this point is known as the MPP and is unique, as can be seen in Figure (2.3), where the previous points are represented.

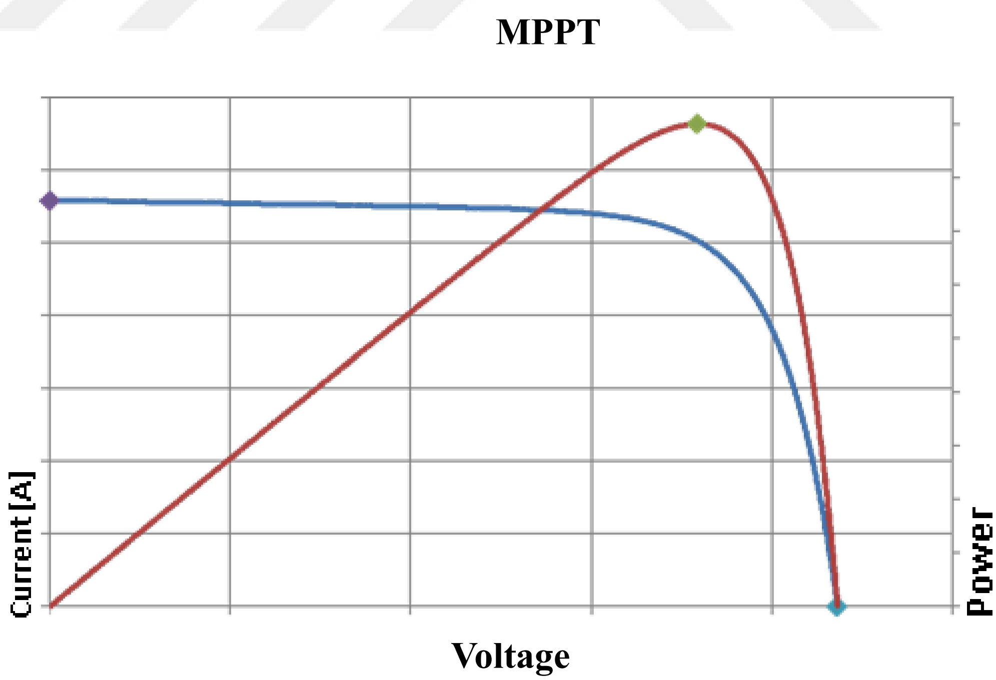

Figure 2.3 Important points on the characteristic curves of a solar panel

2.4 The fill factor:

Using the MPP current and voltage, IMPP and VMPP, the open circuit voltage (VOC) and the short circuit current (ISC), the fill factor (FF) can be defined as shown in equation (2.5):

$$FF = \frac{V_{MPP} I_{MPP}}{V_{OC} I_{SC}} \qquad (2.5)$$

It is a widely used measurement method of the solar cell overall quality. It is the ratio of the actual maximum power (IMPP , VMPP) to the theoretical one (ISC , VOC), and due to the fact that the values of short circuit voltage and short circuit current are always above MPP voltage and current, the diode is depicted and the shunt and series resistances as in Figure (2.2), so this value is not obtainable, the fill factor is typical for commercial solar cells that is usually above 0.70.

2.5 The temperature and irradiance effects:

There are two factors must be taken into account, the temperature and irradiation. They are important and strongly affect the characteristics of solar modules, it means that the MPP for current and voltage will varies during the day.

Figure (2.4) explains the effect of the ordinance on the curves of voltage-current (V-I) and voltage-power (V-P) behavior, the curves, as seen, in (per unit), i.e. the current and voltage curves are straighten using the ISC and VOC respectively, to explain the effects of the ordinance on the curves of V-I and V-P.

In the conditions of no short circuit, and the operation point is not at this point,the photo current will be the main parameter in PV current, equations (2.1) and (2.2) explained that the short circuit current increases directly with increasing the photo current, and then proportionally mainly with the solar irradiance.

The irradiation controls the voltage-current curve. And due to the logarithmic dependence of the light generated current, the open circuit voltage is not highly affected as explained in equation (2.4).

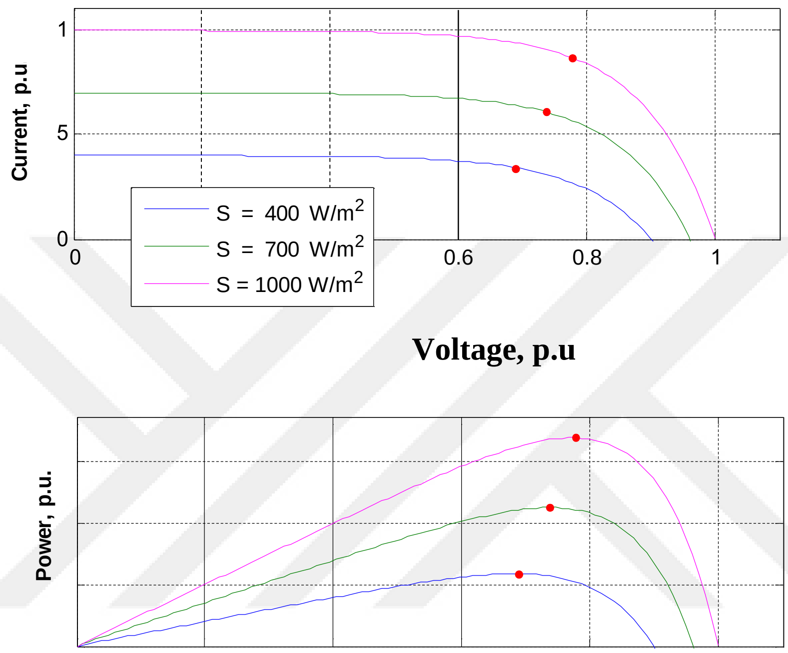

Figure 2.4 The V-I and V-P curves at (25°C)

Figure (2.4) illustrates that the variation happening to the values of the current is more than that in voltage and this confirms that the voltage has little impact by the variation of solar energy.

Both current and voltage increases when the solar energy increases, the effect is positive for both. Also, the power increases positively; more irradiation means more power will be obtained, the influence of temperature is mostly on the voltage, as shown in equation (2.6) the VOC is affected linearly by temperature.

$$V_{OC}(T) = V_{OC}^{STC} + \frac{K_{V\%}}{100}(T - 273.15) \tag{2.6}$$

In regard of the equation (2.6) the effect of the temperature on VOC is negative, due to the negative value of Kv, i.e. the voltage decreases when the temperature rises, the influence of the temperature on I is very little, and it cannot compensate for the shortage at the voltage done by temperature rising effect.But as the effect of the temperature on the current values is really small, it is commonly neglected [18], this explains the reason of decreasing the power. Manufacturers of PV panels provide the temperature coefficients with the data sheets, that explain how the ISC, VOC and Pmax changes when the temperature varies.

Figure (2.5) illustrates how the voltage-power and voltage-current and the characteristics of the curve changes with temperature, as in the previous case, the curves are again in (per unit).

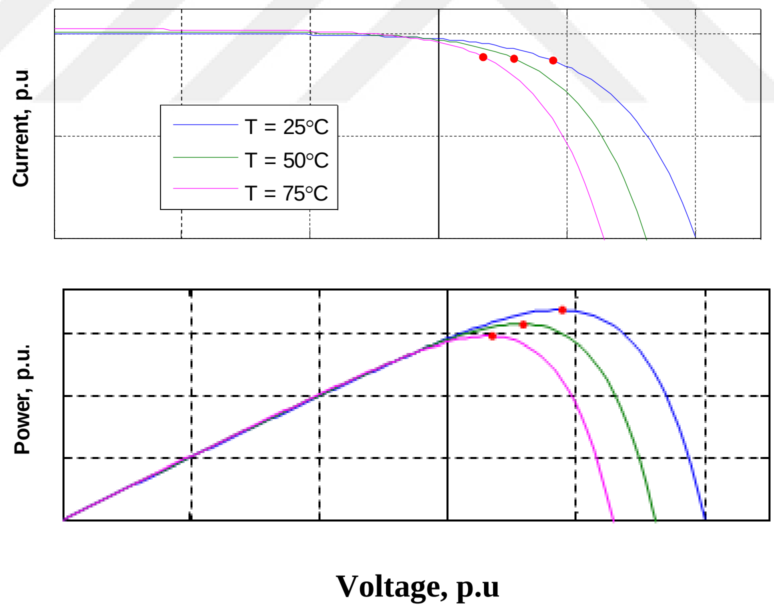

Figure 2.5 The voltage-current and voltage-power curves at (1 kW/m²) standard value and three different temperatures

The irradiation and temperature depend on the environmental and atmospheric conditions as mentioned earlier, they may vary quickly due to fast changing conditions happening, such as clouds.

Hence, depending on the irradiation and temperature conditions, the MPPT moves constantly, great power losses occur at the point of consumption where the operating point is not near to the MPP point, it is important to run MPP in any PV process to obtain Pmax from the PV.

2.6 Solar cell types:

During the last years, almost the only compound used for manufacturing solar cells was silicon, beside new techniques and new compounds that have been developed, silicon is still used widely in the manufacturing of solar cells, and Silicon is a brittle and hard material with symbol Si. It is the most popular material on Earth. It exists as silicon dioxide, besides that it is not toxic, the two major types of silicon solar cells are monocrystalline and polycrystalline silicon solar cells .

Another type of solar cell is amorphous silicon, which is made by depositing the silicon as a thin layer rather than crystal structure. In a thin film, its efficiency is less than the efficiency of last mentioned one and its applications are also lesser. There are another new solar cells, which is composed from cadmium Telluride (CdTe) or Copper indium gallium (DI) selenide (CIGS).

Many developments and research effort have been made to develop new compounds, but still, the above types of solar cells are mainly used in the applications. In the current section, different types of solar cells will be revised, efficiency is an important parameter of PV cells, which is the percentage of solar energy exposed to electricity generated by the cells, normally the efficiency has been calculated under (STC) (Standard Test Conditions), 1000 W/m² solar energy, with A.M 1.5 (air mass coefficient), and 25°C solar cell junction temperature.

The PV panels have limited area, hence the efficiency obtained with small area is important, this is important due to space limitation in some applications, and other costs of the installation depend on the installed PV surface.

2.6.1 The monocrystalline silicon:

The most efficient ones of solar cells are Monocrystalline silicon, it's made from a sliced cell taken from single crystal as a wafer. The slice has a predictable and uniform property as a crystal structure.The manufacturing process done at high temperatures and must done with extreme care, which is expensive, to get 1 kW in STC the surface needed is about 7 m^2 and the efficiency of these cells is around (15-18%) [3].

2.6.2 The polycrystalline silicon:

It is made from pure slushy silicon as wafers, however the structure of crystals is random; when the silicon cools down, it produces an irregular structure and simultaneously crystallize in many different points: crystals of random shapes, sizes, and orientation. The efficiency of this type is lesser because the structures are not ideal as the monocrystalline cells, at around (11-15%) [3], however, the lower efficiency is compensated by low manufacturing process cost, to get 1 kW the surface needs about about 8.5m^2.

2.6.3 The amorphous silicon:

It is made by depositing the silicon as a thin layer in low temperature, the process is easier, simpler, and cheaper with lower cost than in the crystalline photo cells, the lower efficiency is the main problem of this type of photocell, which is about 6-8% [3],this low efficiency is measured under standard test condition, under weaker irradiation, the performance of these cells will be high, such as cloudy days, and more than crystalline cell type, with a small temperature coefficient [4]; also, it is a better light absorber than crystalline, so in spite of having low efficiency, the cell is a promising and competitive technology.

Since the 1980s they have been used in the electronics industry, for example; calculators. Nowadays, it is starting to be used in many applications; for example, power applications. Recently it is commonly used for cladding buildings, in frontispiece, as it offers the advantage of electricity generating and the price is low compared with other cladding materials with high quality.

Easy manufacturing at low temperature is the main advantages of thin film technologies, by using production methods with low cost substrates and continuous production with no need to mount individual wafers and flexibility with light weight. The advantages mentioned above are available for most of the thin-layer cells, not for amorphous cells only, nowadays another recent type established of silicon, microcrystalline type silicon, this type of thin–layer wafer made by deposit silicon as thin–layer, improving the efficiency of amorphous and minimizing the quantities of crystalline needed.

Also light absorption of amorphous silicon is higher than microcrystalline silicon, it needs to use a light trapping system to force the incident light to penetrate the film, this type of cell is not used for commercial application and needs more development.

2.6.4 The other cells and materials:

Other materials can be applied in manufacturing solar cells, it is not confined only by silicon material, the alternative materials are also made from thin-layer deposited, and have good efficiency with the advantages of the other types, among these materials there are two types used already in commercial applications, which are CdTe and CIGS. Their efficiency is about (9-12%) [3] and promise to keep on rising in the future by using advanced development technologies.The thin layer technology is the power generating tool where the expenses of generating electrical power are near or less than the expenses of the power network, the toxicity is the main problem of this type of cells, for example, indium; which is used in CIGS.

This compound is not commonly available as silicon and it is needed for other electronics applications such as component and equipment, CIGS is interfaced with cadmium sulfide (CDs) when creating the P-N junction, cadmium is cumulatively poisonous because it is a heavy metal which means another problem.

In the case of CdTe, which is used in the technology of thin film solar cell production, it is not as toxic as other used components, but some precautions must be taken during the process of manufacturing. Gallium Arsenide (GaAs) has been commonly used in space applications, due to it being less liable to suffer damage from radiation of space than silicon, and to its direct band gap of (1.42 eV), it can employ the important spectrum part of the solar light.

Nowadays, in order to apply this material with low cost, a light condenser must be used to focus the light on small cells to reduce the materials used, triple junction GaAs cells have 40% efficiency, but need to focus the light on the cells [4], the problem nowadays for this type is that it needs to focus the light exposed to the cells which are not cheap and also needs a sun tracking system.

One other technology for solar cell which is actively developed is dye-sensitized (DSSC) technology, this type is considered as the second generation of PV cell technology. It is made through the depositing thin film on substrate like metal or glass, the efficiency of this type is more than amorphous cell type, the main advantage is that their temperature coefficients are lower and their performance is well under diffuse and low light. The materials used are abundant, their manufacturing processes are relatively simple and non-toxic.

Flexible cells created in MIT (USA) can be made by using the PV vapor depositing methods on plastic or paper substrates. This technology is not for commercial use nowadays, the thin film silicon cells, which have been explained above, currently applied in commercial solar cell, all the types of solar cells mentioned earlier have non-linear voltage-current curves and the temperature beside irradiation affected against their behavior.

2.7 The Photovoltaic modules:

For the voltage and current levels of PVE to be more specific, the cells are joined together and connected in parallel series, solar cell connections are robust and corrosion free and encapsulated as they have to be waterproofed, PV typical construction can be seen in Figure (2.6). Airtight layer of ethylene vinyl acetate has been used to encapsulate the modules due to the frailty of the cells. The cells are cushioned and protected this way. They are covered with a treated tempered glass and using an anti- reflection coating to obtain maximum light penetration through the cell. And uses a polyvinyl known as the underneath to prevent the module from moisture.

Also an aluminum structure is fixed around it to make the handling simpler, the construction mentioned earlier is the typical one used for PV, because the module is applied for outdoor applications and can survive for about 25-30 years with different outdoor conditions, guarantee of no less than 20 years the PV panel manufacturers provide.

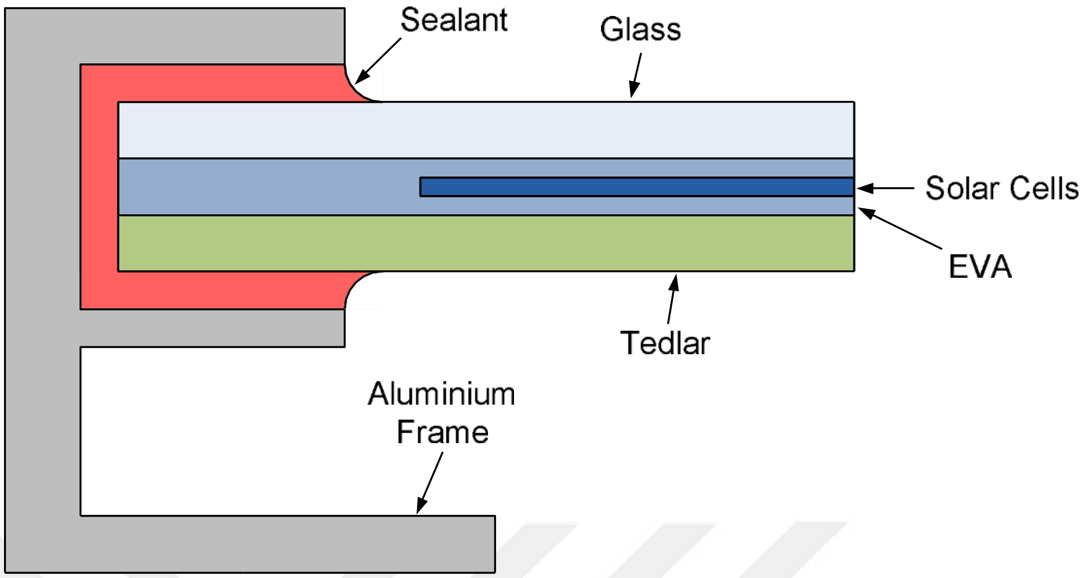

Figure 2.6 The typical construction of PV Module

2.8 System Configuration of PV:

PV systems create DC voltage and current. To feed the electrical energy to the network, this DC power must be converted to AC power, inverters are the suitable equipment which can be applied to convert DC to AC, beside, the PV operating point can keep at the MPP (maximum power point), this is normally done by applying MPP tracking algorithms, nowadays there are different types of inverter depending on the ways of connecting PV module to the inverter system [4].

For every case the decision whether to apply this configuration or not will be selected depending on the financial requirements and environment. If the PV modules and not identical, the MPP are different at each module and getting many maximum points, in this case, not all the possible power is being fed to the grid if the operating point is not the MPP, for these reasons, we must study each case carefully to find the optimum configuration and then obtain maximum performance.

In this chapter, the different types of configurations have been described briefly in there is a chapter assigned for MPPT techniques.

2.8.1 The central inverter:

It uses a single power inverter with symmetrical PV arrays that have the same operation points connected in parallel with it. These PV arrays are operated with the same voltage which means that the MPPT is the same for all the arrays, Figure (2.7) explain this configuration, the main issue of this connection is the possibility of mismatches for the PV arrays, if they received different light energy, the operating at single and actual MPP won't be easy to determine.

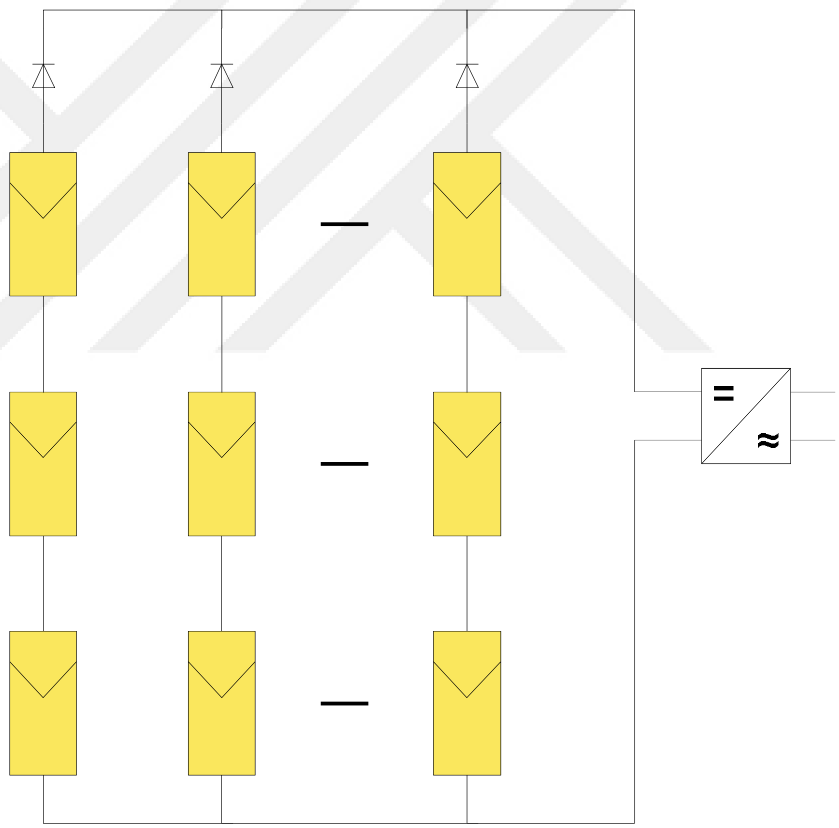

Figure 2.7 The central inverter configuration

2.8.2 The string inverter:

There is a different inverter connected to every PV string, as can be seen in Figure (2.8), the effect of mismatching or shading in this technique is less because each string will be operating at a different value of MPP, and each string may have different MPP points. By this connection the inverters obtain the maximum available power from each string.

On the other hand, the installation cost increases as well as the number of components of the system.

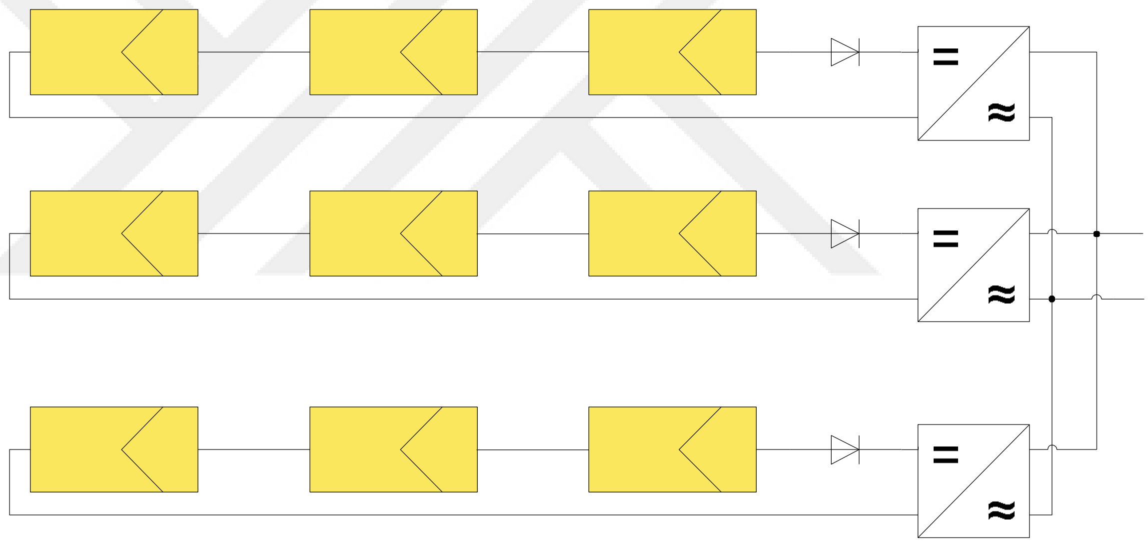

Figure 2.8 The string inverter configuration

2.8.3 Inverter with multi-string:

There is an DC-DC inverter connected to each PV working at MPP of this string, and then all inverters connected to single inverter, as in Figure (2.9), the advantages of this are obtaining maximum output power from each string individually, and the final inverter will opearate on single MPPT which may not match with each string.

The disadvantages are, increasing in cost compared to the central inverter configuration.

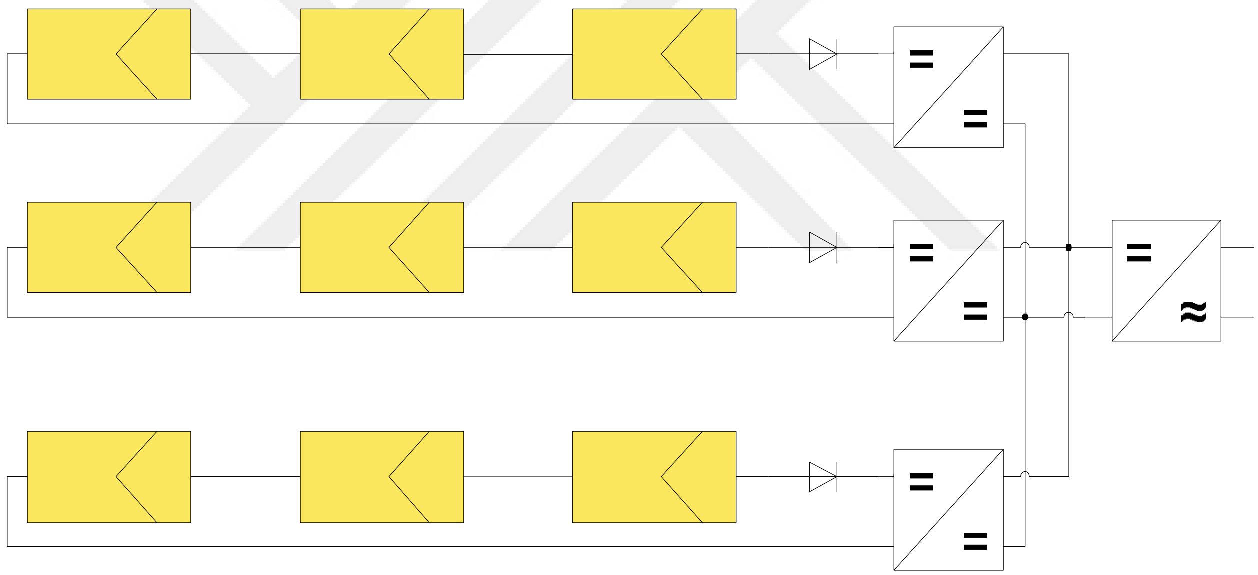

Figure 2.9 The multi-string configuration

2.8.4 Module integrated inverter:

A different inverter is connected to each PV module and the maximum output power is gained from each PV panel and individual MPP tracking by each inverter.

This configuration is recommended when there is a big difference in operating points of each module, however, it is of a high cost due to the existence of an inverter for each panel. Figure (2.10) illustrates this connection.

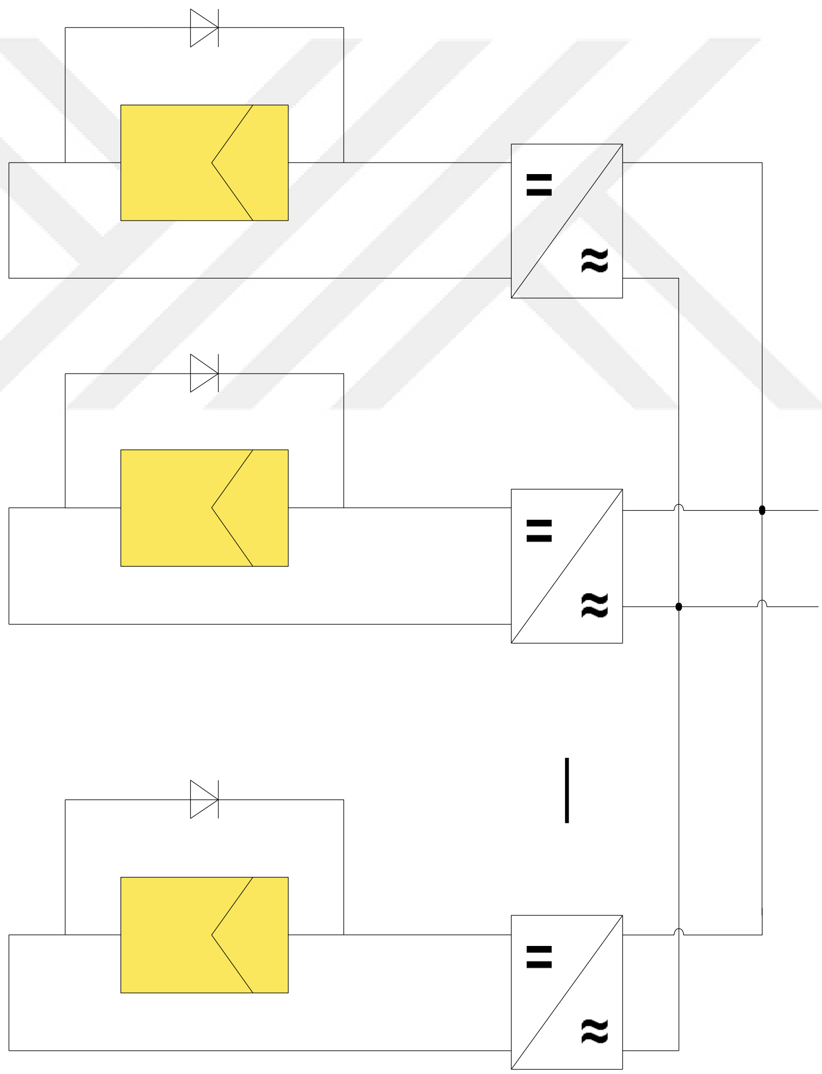

Figure 2.10 The Individual inverter configuration

CHAPTER THREE

Self-cleaning Technic

3.1 Divination of dust:

Definition of dust is: a small solid particles projected into the air by natural forces, taken as those particles below 100μm in diameter such as wind, volcanic eruptions, and by mechanical or man-made processes such as crushing, grinding, milling, drilling, demolition, shoveling, screening, bagging, and sweeping.

Dust particle size is usually about (1 to 100 μm) in diameter, and they settle under the influence of gravity, it is found in houses, offices, and other human environments. Particles found in our environment are:

1- Metallic dust; such as cadmium, lead, beryllium and nickel dusts.

2- Mineral dust; such as silica and free crystalline.

3- Other chemical dusts; like bulk chemicals and pesticides.

4- Organic and vegetable dusts; such as, wood and flour cotton.

5- Biohazards; such as spores.

The first step to control hazards of dust is their reorganization, this requires a clear understanding of the nature, origin, mechanisms of generation, release, and sources of particles, as well as knowledge of the conditions of exposure and possible associated effects in our life.

3.2 Dust removal technique:

3.2.1 Natural removal of dusts:

The natural forces are employed to remove the dust, such as wind, gravitation and the scour of the rain water, the effect of this method is limited. Gaier J, Davis P and Marabito M, reported that they had studied the validity of this method, it is viable that the solar cell array can be turned to vertical or oblique position to remove the dusts easily in the morning, late evening, night and on a rainy day. However, the rotation of the large solar cell array is very difficult.

3.2.2 Mechanical removal of dusts:

The mechanical methods remove the dusts by brushing, blowing, vibrating and ultrasonic driving.The brushing methods clean the solar cell with something like the broom or brush that are driven by the machine that was designed just like windscreen-wiper.

However, first, because of the small size and the strong adhesivity of the dust, the cleaning method is inefficient. Second, the abominable working environment of the solar cell makes the maintenance of the machine difficult.

Also, due to the large area of the solar cell array, the cleaning machine must be powerful, lastly, the surface of the solar cell may be damaged by the brush when wiping. The blowing method cleans the solar cell using wind power which is an effective cleaning method except its low efficiency, high energy-consumption and the unsatisfactory maintainability of the blower.

Removing the dust with vibrating and ultrasonics are also a valid mechanical cleaning method. The key aspect of this strategy consists of the driving method, the frequency and the amplitude of the solar cell. Williams, R. Brett and his team have studied the vibration characteristics of the self-cleaning solar panels with piezoceramic actuation, their research work is at its initial stage of exploration.

3.2.3 Self-cleaning Nano-film:

If the surface of the solar cell array was covered with a pellucid self-cleaning Nano-film, it will remain clean.The self-cleaning Nano-film is made of super-hydrophilicity material or super-hydrophobic material that means the self-cleaning mechanism of the Nano-film involves two strategies.

3.2.3.1 Super-hydrophilicity film:

The popular super hydrophilicity film is $TiO2$, which has hydrophilicity and photocatalytic activity, the self-cleaning method consists of two stages, the first one is a photocatalytic process which $TiO2$ film reacts under the ultraviolet light, and splits the organic dirt, then, because of the hydrophilicity, the rainwater will diffuse on the whole surface instead of merging and rinse the dust.

Now, most researchers focused on the preparation, doping and modification of this material.This self-cleaning method cannot be used in a solar cell array because they work mostly in desert regions with seldom rain.

3.2.3.2 Super-hydrophobic film:

Super hydrophobic surfaces such as the leaves of the lotus plant show high hydrophobicity and extremely low wettability, various studies have been conducted to realize super hydrophobic surfaces by forming microstructures or nanostructures.The nanostructures of this surface can enhance the contact of angle (CA) to higher than 150.

Hence, the water droplets that hit the surface would quickly roll off, carrying dust and other particles with it, nevertheless, most studies regarding super hydrophobic surfaces have focused mostly on enhancing the non-wetting property itself, it is still a question of whether such a super hydrophobic surface can be practically applied in areas such as self-cleaning surfaces of solar cells, further studies are needed to verify the feasibility of super hydrophobic surfaces in real world application.

3.2.4 Electrostatic removal:

Electrostatic technique, depends on the idea of charging the dust particles by negative voltage and then the particles repulse one another, to apply this technique we used conductive class sheet (thin glass sheet coated with a thin film of SNO2) as a cover for testing solar panel, supplying it with negative voltage in the range of (1-6 Volt) throwing two electrodes fixed on each side of conductive glass, Figure (3.1) explain conductive glass sheet.

In order to apply SNO2 thin film to self-cleaning technique, we must make sure that the optical spectrum of solar panel operating must be in the range of the optical spectrum allowed by SNO2 thin film, Figure (3.2) illustrates that the thin film used to prevent dust is highly transparent in the range of the spectral response of the solar cells (400-800nm).

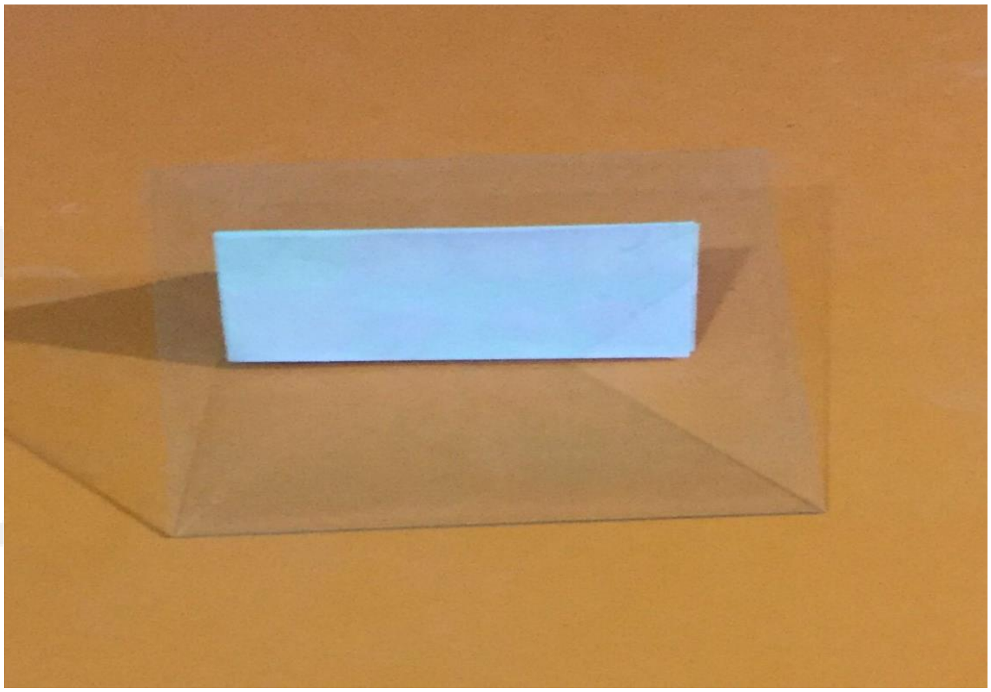

Figure 3.1 Glass sheet coated with thin film SNO2

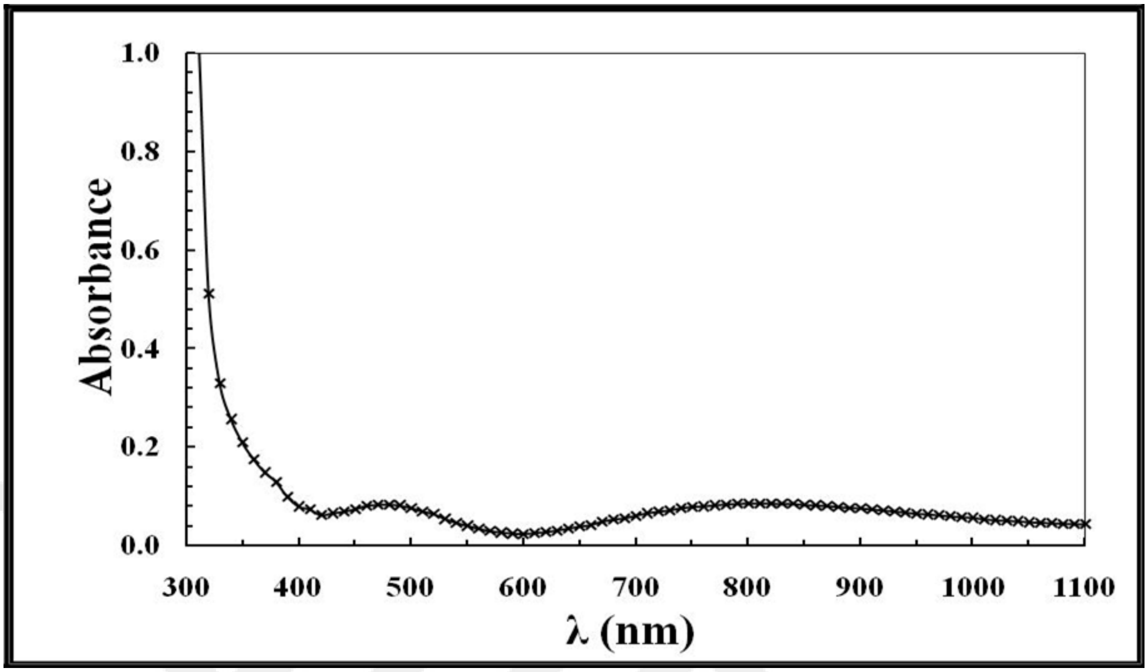

Figure 3.2 The normalized optical absorption spectrum of the conductive glass

CHAPTER FOUR

Maximum Power Point Tracking Algorithms

Due to non-linearity of V/I specification of solar cell, it is very important to seek an ideal way of extracting maximum solar cell power. MPPT is the best solution to this problem.During the last decades, many methods have been developed and published to find the MPP. Each technique differs from others in many aspects such as cost, range of effectiveness,required sensors, complexity, whether tracking is required when irradiation or temperature varies or not, convergence speed, the hardware needed to add to the implementation,in [16] you can find a review of the different types of MPPT algorithms.

In these techniques, the perturb and observed P&O and the In Cond algorithms are the most common. These techniques are easy to implement, but they have hurdles, as will be noted later.The V-P curve at normal conditions of these methods has only a single maximum point.

However, there are multiple maximum power points if the PV array is shaded partially, in order to eliminate this problem, some MPP algorithms have been established as in [22]. In current section the most common MPPT techniques will be discussed.

4.1 The Hill-climbing techniques:

Both of perturb and the observation together with On Cond algorithms depends on the same concept and principle of “hill-climbing” which relies on moving the operating point of the PV in the way of the power increases [22] and [23], due to their good performance and ease of implementation when the irradiation is constant, Hill-climbing is the most used MPPT technique [23].

The advantages of both methods are their simplicity, power they require and low computation, the weaknesses are mainly during fast changes in atmospheric conditions.They can scan the MPP in a wrong way and also the oscillation may happen around the MPP [7] [23] [28], these problems will be illustrated later.

This method depends on picking the value of dp/dv (changes of rate of the power with respect to the changes of the rate of voltage) and evaluating this value through the feedback loop to make it zero; it means, the point when the change in voltage is not followed by a sudden change in power, this is called MPP, where the power at maximum value and must stop the sweep for new value of PV array voltage, but still monitoring this value of power, instead of using dp/pv parameter, the system uses dp/di, because the output is connected to a battery with fixed voltage.

The method is simple and can be applied to analog or digital controller for tuning the parameters, but there is a big problem with this method, if the switching intervals for sweeping the system is dD, then the aim of this technique is to force the value of dp/Dd to zero;however, if the sweep moves from the left part of the curve of power with respect to D where dp/Dd is larger than zero, it will be reach MPPT, but if the operation point at the right part of this curve where dp/Dd lesser than zero, the sweep will fail.

4.2 The P&O:

In This algorithm, the controller adjusts the voltage of the cell array by small increments and then monitor the power output, if a change took place on the power, the controller will make additional adjustment in voltage by continuing in the same direction of increment, or change the direction of the controller to decrement way. At the point where power at maximum value, and any increment or decrement in the voltage will not increase the output power, the controller then will stop at this point of voltage and continue to monitor the power.

In Hill-climbing method, the sign of last disturbance and last power increment in the Powe are used to decide what the next disturbance should be, as has been seen in Figure (4.1), on the up side of the MPP, incrementing the voltage increases the power, while on the down side, increasing the voltage decreases the power.

If there is an increment in the power, the perturbation should be kept in the same direction, and if the power decreases, then the next perturbation should be in the opposite direction. Based on these facts, the algorithm is implemented [16], the process is repeated until the MPP is reached, then the operating point oscillates around the MPP.This problem is common also to the In Cond method, as was mentioned earlier, a scheme of the algorithm is shown in Figure (4.2).

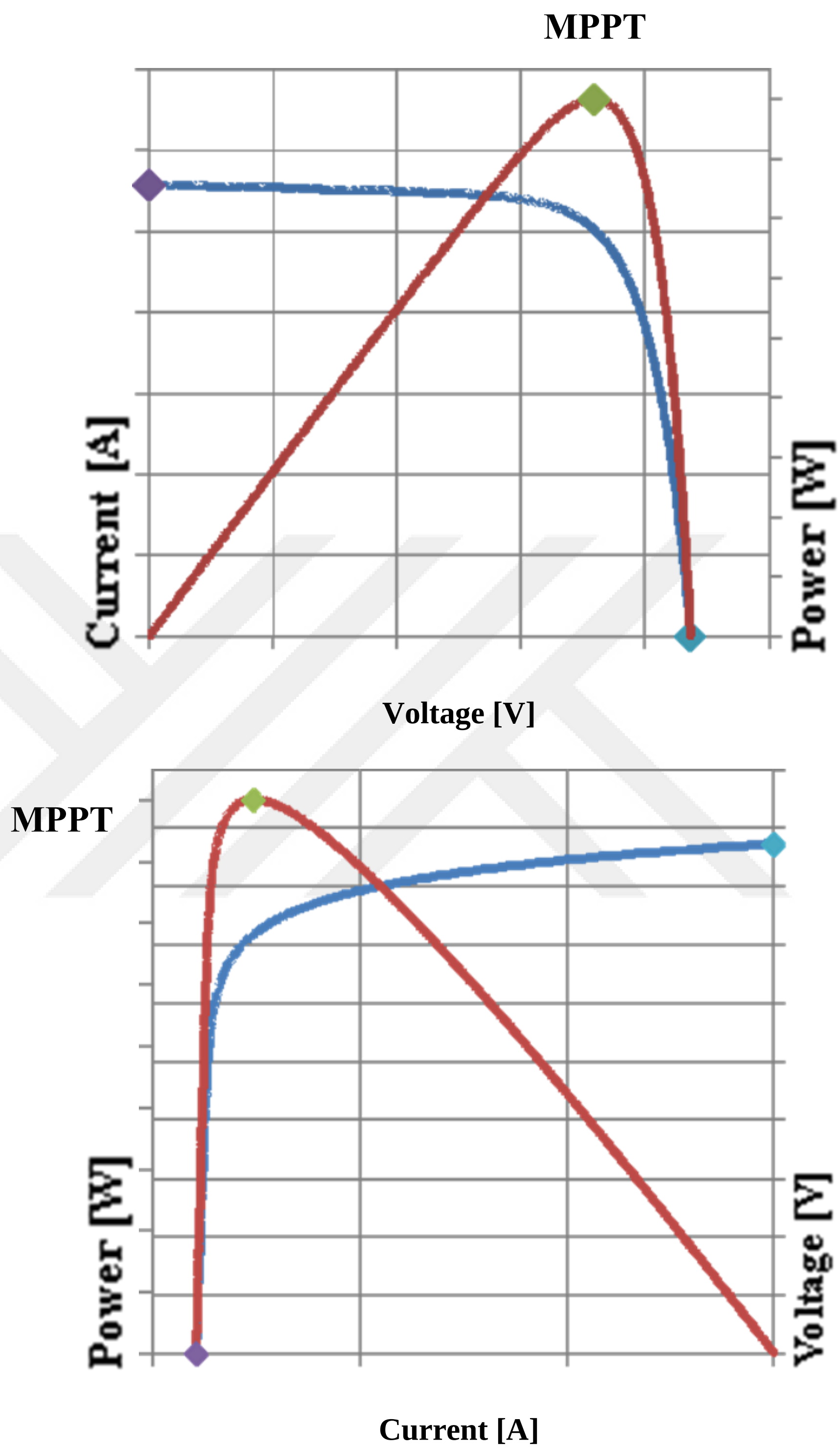

Figure 4.1 PV panel characteristic curves

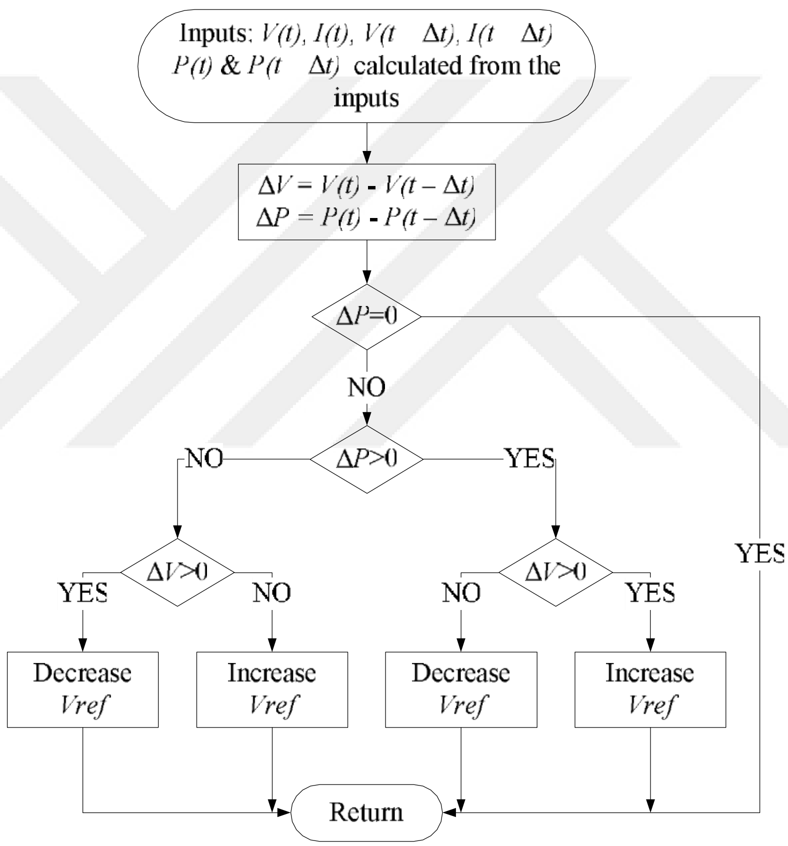

Figure 4.2 The P&O Algorithm

4.3 The Incremental conductance:

This method depends on monitoring the changes in the current and voltage of PV output. To realize the variation effect of the voltage on power, there is a lot of computation work need for this method. This method gets the MPPT by evaluating the incremental conductance with respect to the PV array conductance.

●$\Delta V/\Delta P = 0$ ($\Delta I/\Delta P = 0$) at the MPP

●$\Delta V/\Delta P > 0$ ($\Delta I/\Delta P < 0$) on the left

●$\Delta V/\Delta P < 0$ ($\Delta I/\Delta P > 0$) on the right

By comparing the increment of the power vs. the increment of the voltage (current) between two consecutive samples, the change in the MPP voltage can then be determined. A scheme of the algorithm is shown in Figure (4.3), how fast the MPP is reached in both P&O and In Cond schemes, depending on reference voltage increment size.

The main hurdles of these techniques are two, the first one is that they can easily lose track of the MPP if the irradiation changes rapidly [15], [23] -[26], the curve in which the algorithms are based changes continuously with the irradiation. When the irradiation changes following a slope, as seen in Figure (4.4), the changes in the voltage and current are not only due to the perturbation of the voltage, as a result, it is not prospective for the algorithms to determine whether the change in the power is due to its own voltage increment or due to the change in the irradiation.

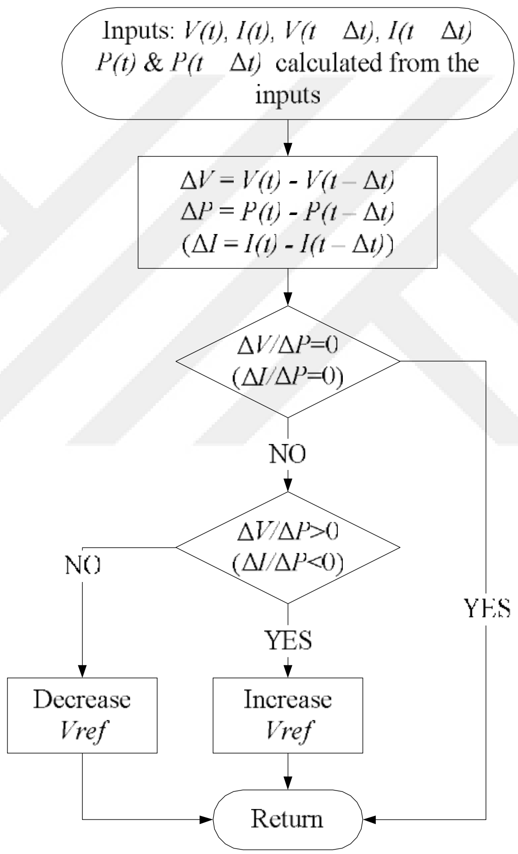

Figure 4.3 The flow chart of the In Cond Algorithm

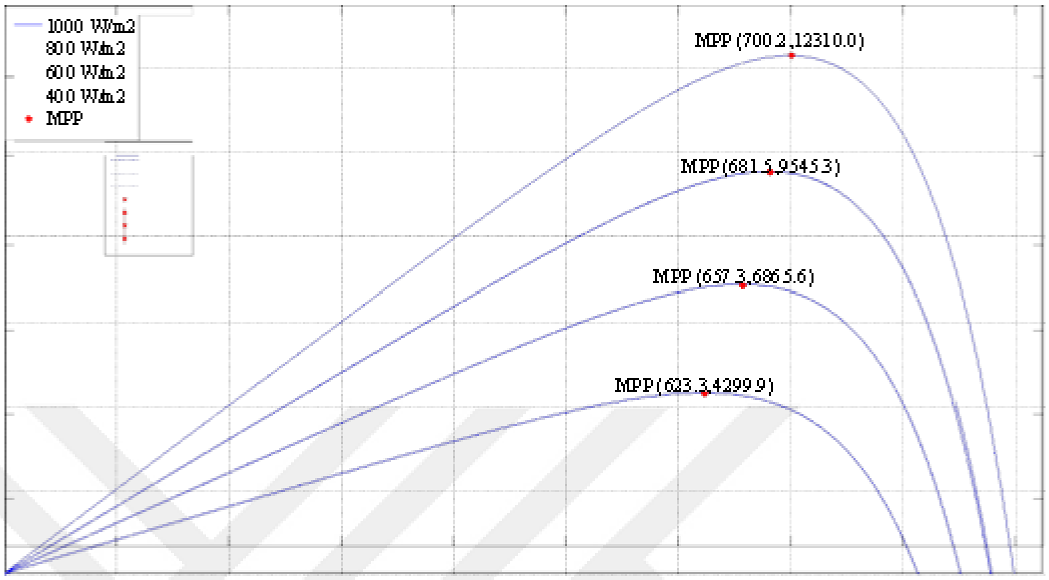

Figure 4.4 P-V curve and irradiation relation

The oscillations of the current and voltage around the MPP are the other impediment of both methods in the steady state [15], [25], [27] and [28], this happened due to the fact that the voltage and current are not at the actual MPPT and still oscillates at this point, the rate of change of the reference voltage determines the value of the oscillations, a higher amplitude value of the oscillation means a higher rate of change of the reference voltage.To eliminate these problems, some solutions have been established nowadays.

Concerning the fast changes of the irradiation condition, Sera et al. Published in [23] and [24] an improved method of P&O, called "DP-P&O", in which an additional measurement is performed without disturbance in the voltage and current, in this method, each three consecutive samples affect the disturbance in the current, voltage and the effect of the change in the conditions of the atmosphere can be analyzed. The effect caused by the MPPT algorithm, only involved in the increment of power used in the algorithm, so the correct decision about the direction of the next disturbance can be taken. The efficiency of the tracking is improved.

4.4 Modified hill climbing method:

This method is the balance between the dynamic and steady state method through a quick change in switching intervals to cover the fast change that might happen under the weather conditions, MHCM is based on the same concept of standard hill climbing method to improve the dynamic and steady state conditions.

There are other three revised techniques in [16] that uses the same concepts of HCM, they are:

a-dP/di feedback technique: join the tracking of dp/di with dp/dt to move dp/di to zero which is the point of maximum power, regarding to [30] di/dt· dp/dt, or dp/dt·dv/dt are negative at the right of the dp/dt curve and positive at the left of this curve, and zero at the point of MPP. The system calculates the slope of the curve and move dp/di to zero.

b-Slide control: this technique is divided into two steps, the first step is for built voltage reference generator to compute the Vref at the point of maximum power, and the second step is forcing the system to operate on this referenced voltage.

In this method, many algorithms have been used such as Mattlab fitting, Fourier analysis and polynomial function.

4.5 The fuzzy logic control:

All the classic proportional-integral controllers have a fixed error-gain, which is specified at the feedback loop, so in case of fast change in process conditions, it can't cover it. For this reason Fuzzy controller has two inputs, error signal and the rate of change of this error signal. This controller is robust and simple to design.

Over the last decade, the fuzzy controller has become commonly used because it does not need an accurate mathematical model, and can handle nonlinearity. And it can deal with imprecise inputs, with the popularization of fuzzy logic control, microcontrollers have also helped [16]. There are three stages in the fuzzy logic: inference system; falsification; and defuzzification.

In Figure (4.5) there are seven fuzzy levels used: NM (Negative, Medium), (NB) (Negative Big), (PM) (Positive Medium), (NS) (Negative Small), (ZE) (Zero), (PS) (Positive Small), and (PB) (Positive Big).

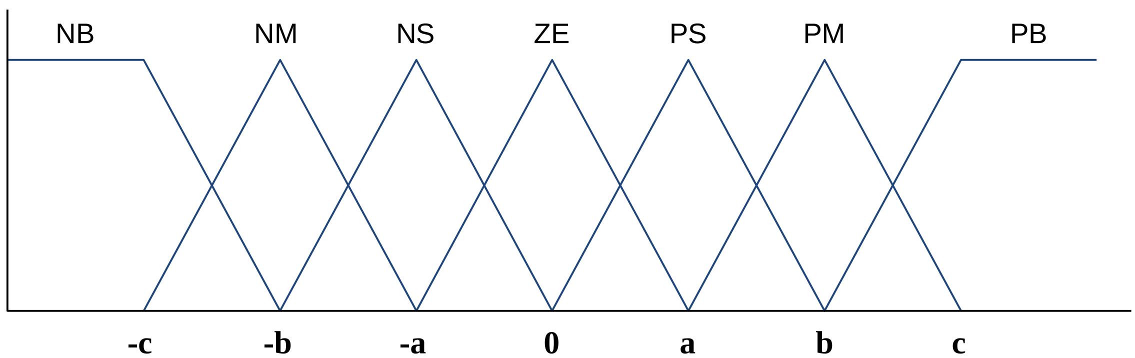

Figure 4.5 The membership functions

As mentioned earlier, the fuzzy controller has two input signals, an error E, and ΔE. The errors are normally selected as ΔP/ΔV which will be zero at the MPPT, then E and ΔE are acquainted:

$$E = \frac{P(K)-P(K-1)}{V(K)-V(K-1)} \tag{4.1}$$

$$\Delta E = E(K) - E(K-1) \tag{4.2}$$

In other cases, ΔP/ΔI have been used as an error [31], where ΔU and ΔP are used, the fuzzy logic converter outputs usually a change in the duty ratio of the power converter, ΔD, or a change in the reference voltage of the DC-link, ΔV.

The rule base, also defined as fuzzy rule algorithm or rule base lookup table, associates the fuzzy output to the fuzzy inputs based on the power converter selected and on the knowledge of the user, the rules for a three phase inverter based on fuzzy logic has been shown in the table (4.1), where the inputs are E and variance in the input is ΔE, as selected in (4.1) and (4.2), when the operating point (OP) at the right place of the MPPT, ΔE is zero and E is (nb), and in order the reference voltage reaches the MPP, it should decrease, so to force of the OP at the front of the MPP ΔV should be (nb) (Negative).

Table 4.1 The rule Base for three phase converter

E\dE	**NB**	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

The defuzzification is the last step of the fuzzy logic control, through this step, the output is changed from a lingual variable to a numeric part, again, by applying memberships as in Figure (4.5). To convert lingual variables into numerical values, there are different methods, the center of gravity method is considered the most popular among all other methods.

4.6 The neural networks:

Neural Networks [16] is another MPPT method that is well adapted into microcontrollers and neural system is helpful to use with complex and non-linear system, it is part of the computing control as Fuzzy controller.

There are many architectures used with this technique, but the simple one composes of three layers named the hidden layer, it is an input which receives external signals, hidden which composes of different hidden neurons, it is an interface layer between first and third one, receiving data from the first layer and pass it to the third. The third layer is the output layer. Figure (4.6) explain this structure, the input parameters are the values of ISC, VOC, temperature and irradiation, while the output is the reference voltage, the quantity of nodes in each layer and the number of layers depends on the skill of the user.

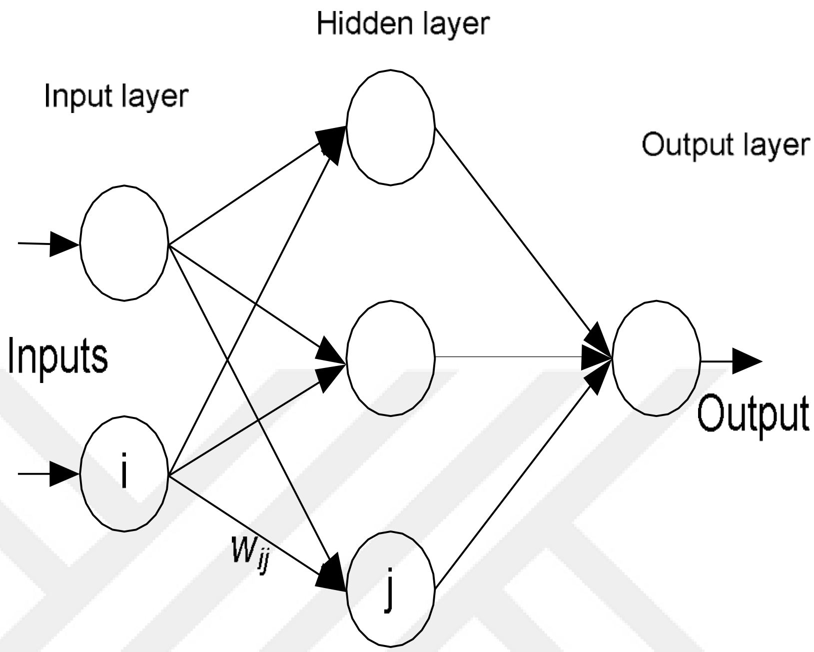

Figure 4.6 The neural network

Effectiveness of the system is based on how well the neural network has been trained and the functions used by the hidden layer. The links between the nodes are all weighted, Figure (4.6) shows that the scales between the nodes i and j is tagged as wig, the scales are tuned during the preparation process.

4.7 The fractional open circuit voltage:

FOCV technique applies the linearity approximation relation between the open circuit voltage (VOC) which varies with temperature and irradiance [16] as shown in equation (4.3):

$$V_{MPP} \approx K_1 V_{OC} \tag{4.3}$$

Where k1 is a constant which depends on the characteristics of the PV array and has to be determined beforehand by determining the VMPP and VOC for different levels of irradiation and different temperatures, according to [16] the constant k1 has been reported to be between (0.71) and (0.78),

Once the constant of proportionality, k1, is known, the MPP voltage VMPP can be determined periodically by measuring VOC, to measure VOC the power converter has to be shut down momentarily so in each measurement process a loss of power occurs. Another problem of this method is that it is incapable of tracking the MPP under irradiation slopes, because the determination of VMPP is not continuous.

One more disadvantage is that the MPP reached is not the real one because the relationship is only an approximation, to overcome these drawbacks, some solutions have been proposed, as is reported in [16], For example, pilot cells can be used to obtain VOC. They are solar cells that represent the PV array’s cells and which are not used to produce electricity, but to obtain characteristic parameters such as VOC without interfering with the power converters.

These pilot cells have to be chosen with extreme caution and placed to represent the PV array characteristics and the irradiation conditions, one drawback of using these pilot cells is that the cost of the system is increased, depending on the application, this technique can be used because it is very easy to implement and it is cheap- it does not require DSP or microcontroller control and just one voltage sensor is required [16].

However, according to [16] this method is not valid under partial shading of the PV array because then the constant k1 changes, to update k1 a voltage sweep is proposed, though this increases the complexity of the system, the cost, and there are more power losses during the sweep.

4.8 The fractional short circuit current:

Just like in the fractional open circuit voltage method, there is a relationship, under varying atmospheric conditions, between the short circuit current ISC and the MPP current, IMPP, as shown in equation (4.4):

$$I_{MPP} \approx K_2 I_{SC} \tag{4.4}$$

According to each PV array, the coefficiency of proportionality k2 has to be determined, as in the previous method dealing with k1, the constant k2 has been reported to be between (0.78) and (0.92) according to [16], if measuring the short circuit current when the system is operating causes a problem, it usually requires adding to the power converter an additional switch to periodically short the PV array and measure ISC, in [34] measuring ISC by shorting the PV array with an additional field-effect transistor (FET) added between the PV array and the DC link capacitor, another option is shown in [35]: applies a boost converter and the switch of the converter is applied to short the PV array, short circuiting the PV array also leads to loss of power.

One last problem is that the real MPP can't be reached due to the fact that the proportional relationship is an approximation. Beside, k2 changes if the PV array is partially shaded, which happens because of the shades or surface contamination, to eliminate this problem, [34] suggest an online tuning of k2 and [36] a periodical scan of the PV voltage from open circuit to short circuit to update k2 and make sure that the real MPP is reached in the presence of multiple maxima which clearly increases the complexity of the system, most of the literature using this MPPT technique uses a DSP as controller [16].

4.9 The current sweep:

This method uses a solar scanner to sweep the current of the PV with different intervals and with different loads, the scanner calculates VI curve at each interval (each scan) and then computes at which value of voltage (Vref) the power is at maximum value, after that the controlling forces the inverter to operate at this value.

4.10 The maximum power point voltage and current computation:

VMPP & IMPP computation methods are described as methods in which the maximum power point is obtained in accordance to calculating the temperature and the solar energy using a PV module [16], the problem is the a lot of extra work is required for measurements the variables which is not easy, even under conditions of changing atmospheric parameters, the MPP is correctly tracked. It can be applied to large plants with high investment.

4.11 The states based MPPT technique:

SBMPP technique depends on the plant and a nonlinear time-varying dynamic feedback controller in addition to a state-space representation of the plant,SB is regarded as solid and tracks the MPP under the conditions of fast changes in atmospheric conditions.

CHAPTER FIVE

Experimental Results & Discussion

5.1 Self-cleaning:

For experiment part, we have been cooperating with two scientific centers, one of them was the collage of science (Baghdad university), which provided us the conductive sheet of glass, the other was meteorological center in the ministry of science to provide daily readings of solar power and ambient temperature, the aim of the experiment is to test the efficiency of solar panel under the conditions of using conductive glass.

The experiment is divided (5) steps:

a- calculating the voltage; the current specification of the two solar panels before using conductive glass, by using the solar analyzer model: PROVA 200 as explain in figure (5.3) to be sure they are identical, table (5.1) explains the conductive glass specifications.

We used two identical solar panels to be explained in figure (5.1), Specifications of these solar panels are explained in table (5.2).

Table 5.1 Conductive glass specifications

Active Area	10x19 cm
VO.C	7 V
ISC	500 ma.

Table 5.2 Solar panel specifications with 1000w/m²

Coating material	Sno2
Substrate thickness	6um
Average resistance of sno2 thin film	700 ohms

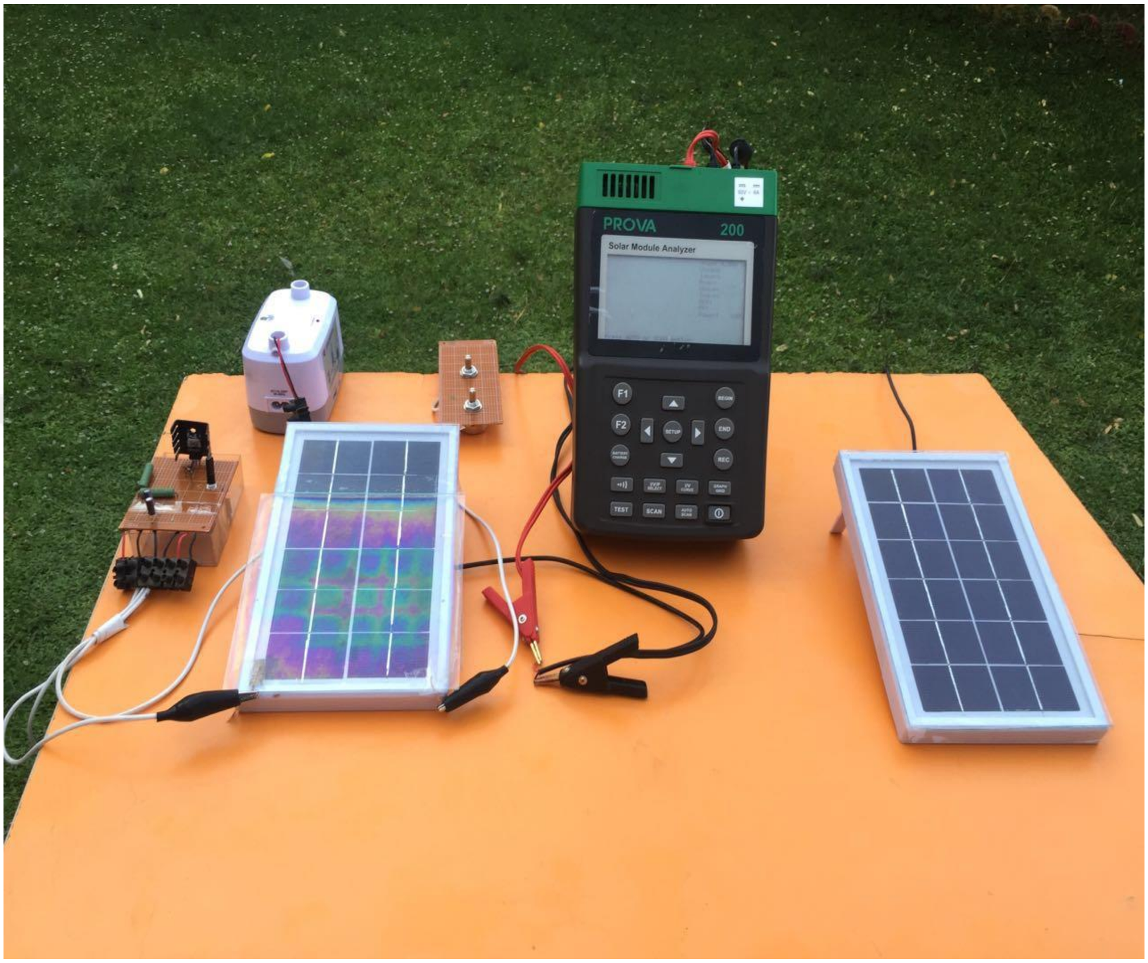

Figure 5.1 Test bench

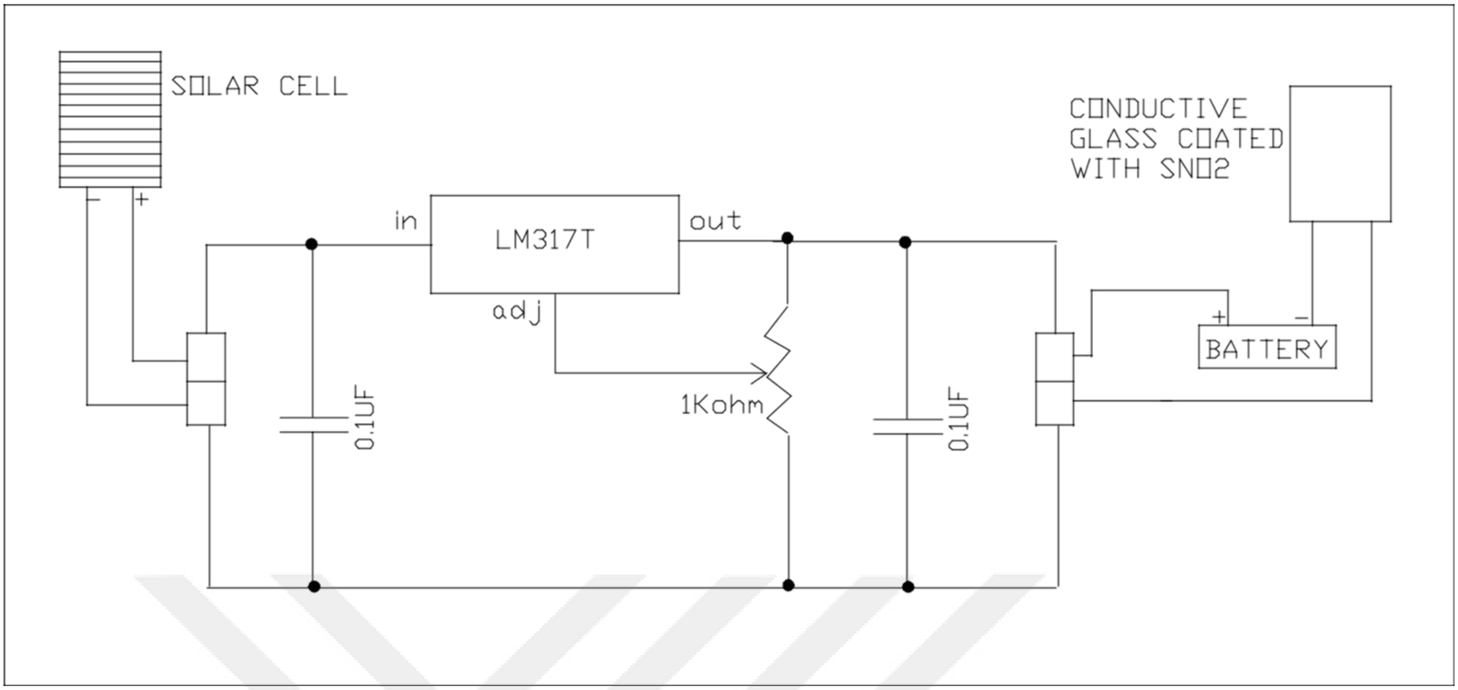

Figure 5.2 Selective voltage generator

We designed electronic circuit to generate a selective voltage in the range of (1-6 v), this circuit uses a variable output voltage regulator LM317. Figure (5.2) circuit diagram of this selective voltage generator, through experimental part, we used different values of negative voltage (1, 2 and 3V) and found that (4V) is the best value for less time to remove the dust, which is about (70 minute) .

The solar analyzer, in fact, is a variable load, starts from opening the circuit to short circuit ,and during this scan the analyzer determines V and I, Figure (5.4) explain the V/I and P/I curve, which is taken from the solar analyzer at single scan of solar panel at solar energy=900w/m².

Figure 5.3 Solar analyzer

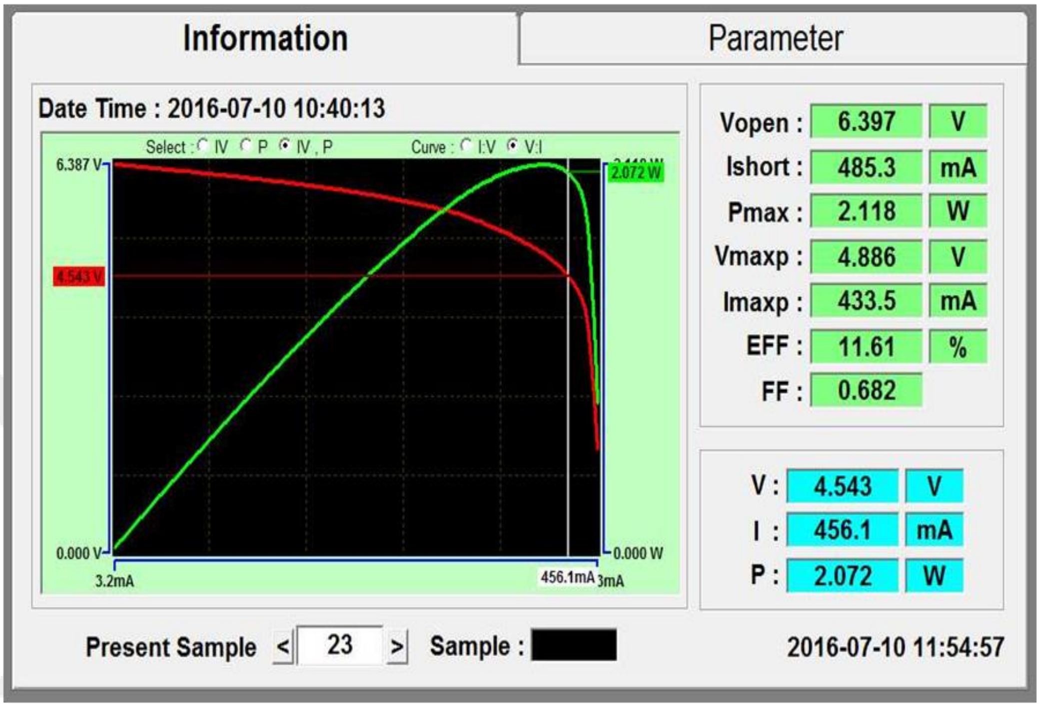

Figure 5.4 V/I and P/I curve from solar analyzer for single scan of the solar panel

b- covering one of the solar panels with conductive glass and the other panel with non-coated glass with the same type of class, but without the coating, in order to keep the same conditions of the two panels.

c- Spread 3grams of dust on each panel. In order to be sure that the two panels gets the same amount of dust, repeat measuring voltage and current values and changing the amount of the dust till the readings of voltage and current become equal.

d- using an electronic circuit in figure (5.2) to generate adjustable negative voltage applied to the conductive glass, with this circuit, we used different output voltage supplied to the conductive glass (2V, 3V &4V) and found that 4V is the value which the lowest time in removing dust (70 minutes), after 70 minutes, we found that most of the dust at coated solar panel is moved at the bottom of the solar panel (about 90%).

e- After the dust had shifted, we made a scan on the two solar panels using a solar analyzer at different solar energy to find relative efficiency. Figures (5.5) to figure (5.7) explains the P/I curves which will be used to find relative efficiency.

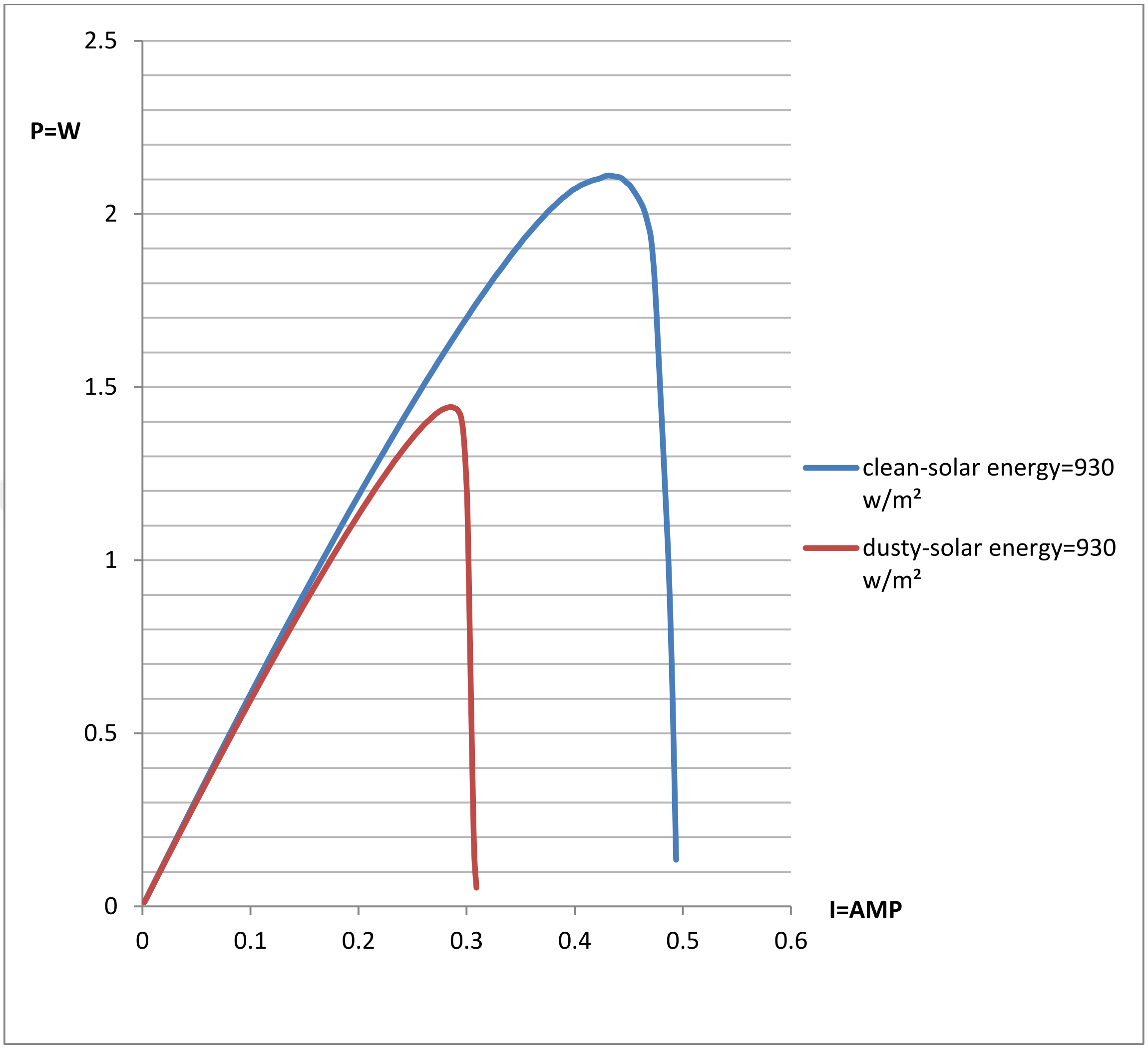

Figure 5.5 P/I curves at 930w/m² solar energy

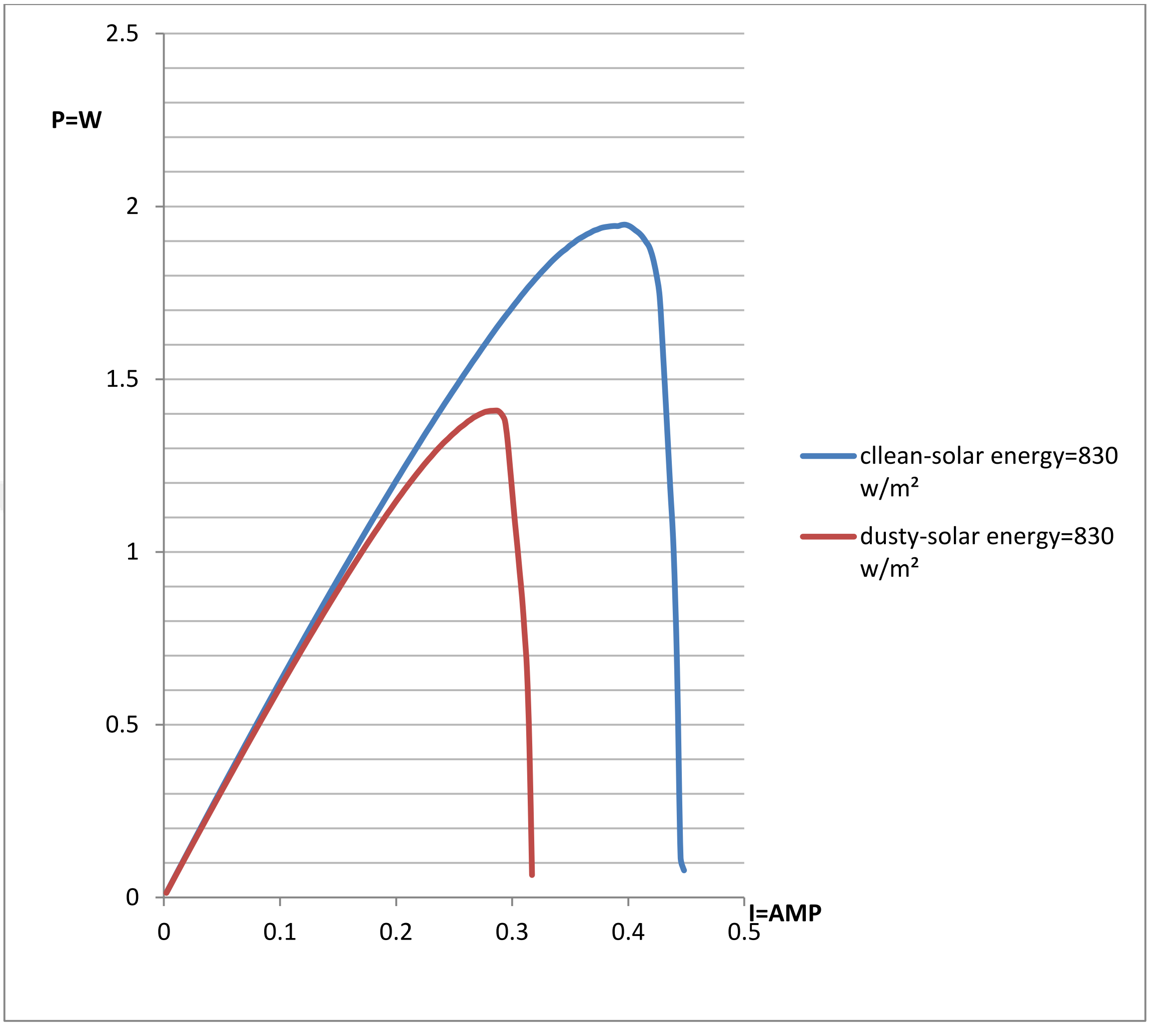

Figure 5.6 P/I curves at 830w/m² solar energy

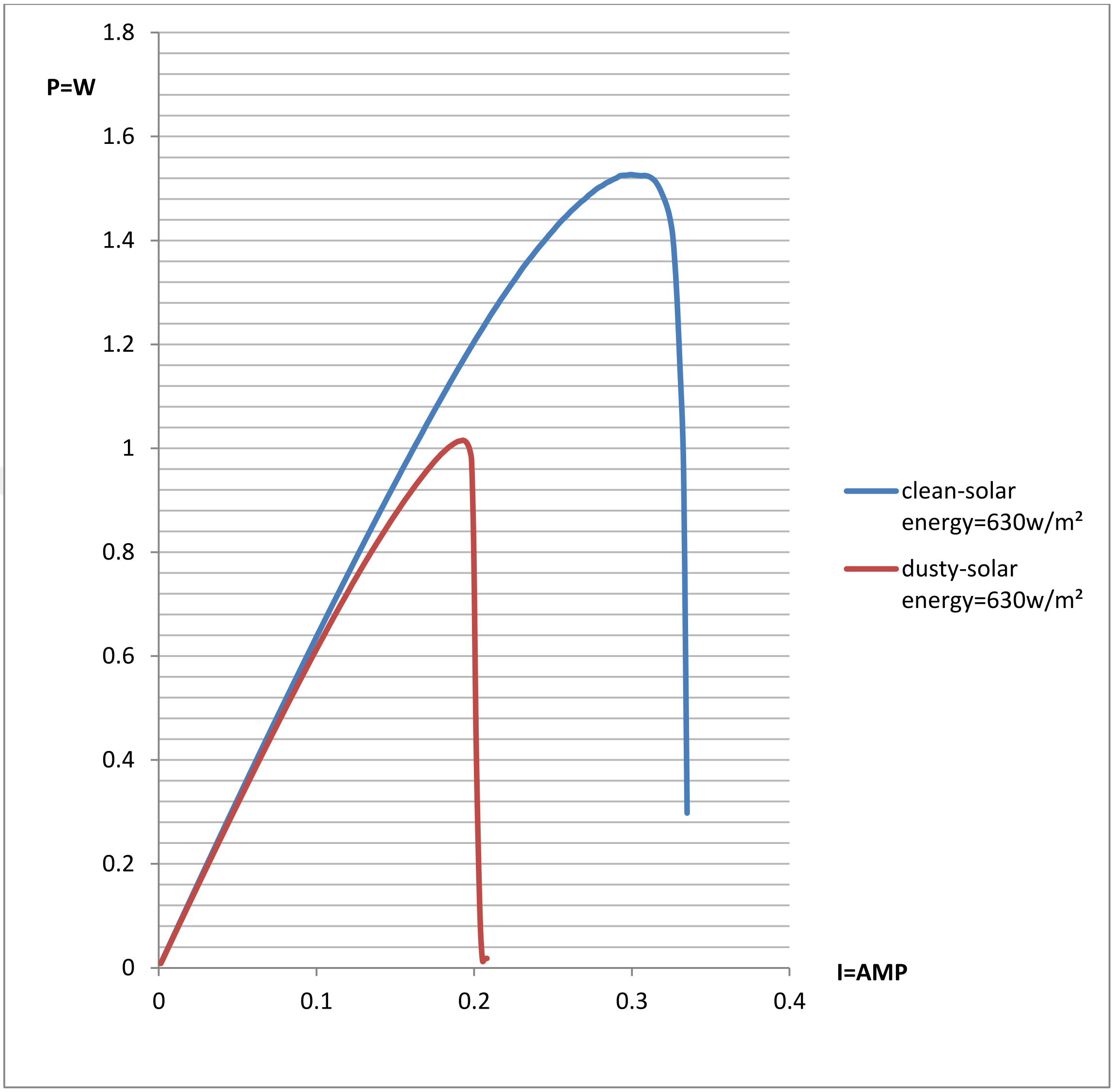

Figure 5.7 P/I curves at 630w/m² solar energy

5.1.1 Loss in relative efficiency calculations:

Calculating the power output of the conductive glass; solar panel (panel 1), and comparing this value to the power output of the other panel (panel 2, which is covered with non–coated glass). It's very important to observe the effect of using conductive glass, the power output of the two panels was measured after 70 minutes from spreading the dust on the surface of the panels. Table (5.3) explains the loss in relative efficiency when using conductive glass (panel 1) and panel without cover (panel 2).

The output power of each panel= I*V watt

$$\text{Loss in relative efficiency} = \frac{\text{pmax of panel 1} - \text{pmax of panel 2}}{\text{pmax of panel 1}} \times 100\% \quad (5.1)$$

Table 5.3 Explains the loss in the relative efficiency of different solar energy

Panel1 Pmax (w)	**Panel2 Pmax (w)**	**Loss in relative efficiency**	**Solar energy (w/m^2)**
2.111	1.442	31.6%	930
1.982	1.397	29.5%	885
1.947	1.409	27.6%	830
1.937	1.414	27%	757
1.526	1.117	26.8%	630
1.437	1.031	28.2%	601
1.065	0.733	31.1%	490
0.906	0.607	33%	318

To explain the effect of coated glass cover (without dust) on the efficiency of solar panel, compared with the same solar panel without any cover, we have taken the readings in table (5.4), using equation (5.2) to calculate the loss in efficiency; the result= (6.9%) When comparing this value with the loss in efficiency with dusty solar panel as in table (5.4) at the same solar energy, we found that the loss in dusty solar panel=31.6%.

Table 5.4 The effect of using a glass cover on efficiency of solar panel at 931 w/m²

Pmax(w)	**Vmax(v)**	**Imax(ma)**		
2.593	5.386	481.5	Solar panel without any cover	Loss in relative efficiency=6.9%
2.441	5.285	461.9	Solar panel with coated glass	

Loss in relative efficiency with using glass cover

$$=\frac{\text{pmax without glass cover} - \text{pmax with glass cover}}{\text{pmax without glass cover}} \times 100 \qquad (5.2)$$

5.1.2 Effect of temperature on efficiency of solar panel:

To investigate the effect of temperature on the efficiency of solar panel, we tested the panel under the same amount of solar energy with different time and ambient temperature, table (5.5) using equation (5.3) to calculate these values.

Table 5.5 Explains the effect of temperature on efficiency of solar panel

Pmax (w)	time	T (ċ)	Pmax (w)	time	T (ċ)	Loss in relative efficiency	Solar energy (w/m^2)
2.167	10:00	38.21	1.947	14:00	41	10%	839
2.124	11:00	39.7	1.951	13:00	41.2	8%	930
1.99	9:20	35.7	1.83	15:00	42.3	8%	720

Loss in relative efficiency with increasing ambient temperature

$$= \frac{\text{pmax at low tempreature} - \text{pmax at high tempreature}}{\text{pmax at low tempreature}} \times 100\% \quad (5.3)$$

5.2 Maximum Power Point Tracking:

The experimental part is divided into 4 steps:

a- scanning the panel1 with a solar scanner to find a V/I curve at specific solar energy, in this step, we made (33) scan readings at (33) solar energy values starting from 8:48 AM to 5:11PM; table (5.6) represents a reading of V, I and P for single scan by using a solar scanner at (896w/m²) of solar energy; Figure (5.8) shows the flow chart of the P&O algorithm.

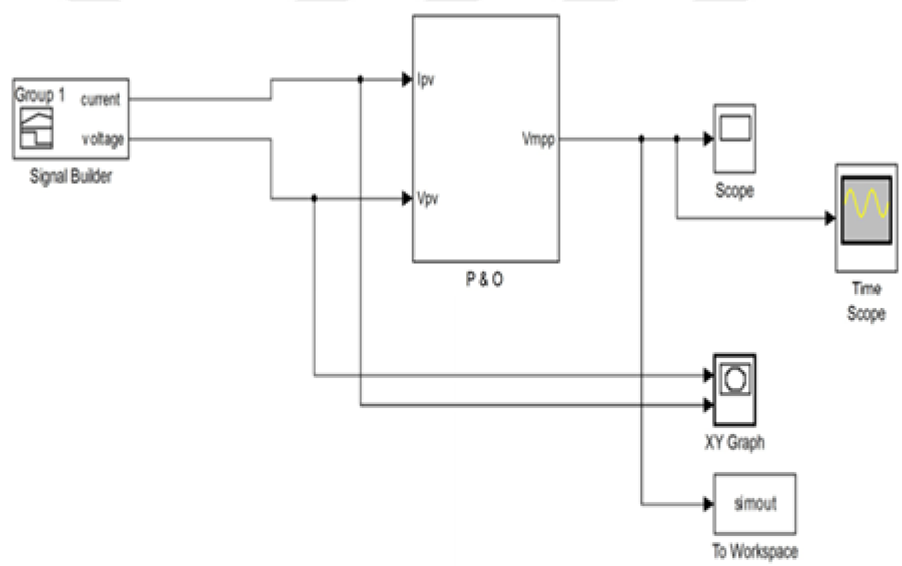

Figure 5.8 The flow chart of the P&O Algorithm

Table 5.6 V/I curve of solar panel scan at (896w.m²) solar energy

V(V)	I (A)	P(W)
6.375	0.0031	0.019763
6.37	0.0062	0.039494
6.365	0.0093	0.059195
6.359	0.0124	0.078852
6.355	0.0156	0.099138
6.35	0.0187	0.118745
6.346	0.0218	0.138343
6.34	0.0249	0.157866
6.336	0.028	0.177408
6.332	0.0312	0.197558
6.327	0.0343	0.217016
6.319	0.0374	0.236331
6.316	0.0405	0.255798
6.31	0.0436	0.275116
6.304	0.0468	0.295027
6.299	0.0499	0.31432
6.295	0.053	0.333635
6.29	0.0561	0.352869
6.285	0.0592	0.372072
6.279	0.0624	0.39181
6.274	0.0655	0.410947
6.27	0.0686	0.430122
6.265	0.0717	0.449201
6.259	0.0748	0.468173
6.252	0.078	0.487656
6.249	0.0811	0.506794
6.243	0.0842	0.525661
6.236	0.0873	0.544403
6.231	0.0904	0.563282
6.226	0.0936	0.582754
6.22	0.0967	0.601474
6.216	0.0998	0.620357
6.211	0.1029	0.639112
6.205	0.1061	0.658351
6.199	0.1092	0.676931
6.191	0.1123	0.695249
6.186	0.1154	0.713864
6.18	0.1185	0.73233

6.174	0.1217	0.751376
6.169	0.1248	0.769891
6.161	0.1279	0.787992
6.157	0.131	0.806567
6.15	0.1341	0.824715
6.145	0.1373	0.843709
6.137	0.1404	0.861635
6.13	0.1435	0.879655
6.124	0.1466	0.897778
6.117	0.1497	0.915715
6.11	0.1529	0.934219
6.104	0.156	0.952224
6.098	0.1591	0.970192
6.093	0.1622	0.988285
6.086	0.1653	1.006016
6.079	0.1685	1.024312
6.072	0.1716	1.041955
6.064	0.1747	1.059381
6.058	0.1778	1.077112
6.05	0.1809	1.094445
6.044	0.1841	1.1127
6.037	0.1872	1.130126
6.031	0.1903	1.147699
6.023	0.1934	1.164848
6.016	0.1966	1.182746
6.009	0.1997	1.199997
6	0.2028	1.2168
5.993	0.2059	1.233959
5.986	0.209	1.251074
5.979	0.2122	1.268744
5.972	0.2153	1.285772
5.962	0.2184	1.302101
5.955	0.2215	1.319033
5.946	0.2246	1.335472
5.937	0.2278	1.352449
5.93	0.2309	1.369237
5.922	0.234	1.385748
5.914	0.2371	1.402209
5.905	0.2402	1.418381
5.897	0.2434	1.43533

5.888	0.2465	1.451392
5.879	0.2496	1.467398
5.869	0.2527	1.483096
5.861	0.2558	1.499244
5.849	0.259	1.514891
5.842	0.2621	1.531188
5.832	0.2652	1.546646
5.821	0.2683	1.561774
5.812	0.2714	1.577377
5.801	0.2746	1.592955
5.791	0.2777	1.608161
5.781	0.2808	1.623305
5.771	0.2839	1.638387
5.76	0.2871	1.653696
5.751	0.2902	1.66894
5.74	0.2933	1.683542
5.728	0.2964	1.697779
5.718	0.2995	1.712541
5.704	0.3027	1.726601
5.692	0.3058	1.740614
5.679	0.3089	1.754243
5.667	0.312	1.768104
5.655	0.3151	1.781891
5.644	0.3183	1.796485
5.629	0.3214	1.809161
5.615	0.3245	1.822068
5.601	0.3276	1.834888
5.588	0.3307	1.847952
5.575	0.3339	1.861493
5.558	0.337	1.873046
5.541	0.3401	1.884494
5.525	0.3432	1.89618
5.509	0.3463	1.907767
5.49	0.3495	1.918755
5.472	0.3526	1.929427
5.453	0.3557	1.939632
5.433	0.3588	1.94936
5.411	0.3619	1.958241
5.391	0.3651	1.968254
5.369	0.3682	1.976866

5.346	0.3713	1.98497
5.322	0.3744	1.992557
5.295	0.3776	1.999392
5.27	0.3807	2.006289
5.241	0.3838	2.011496
5.216	0.3869	2.01807
5.185	0.39	2.02215
5.153	0.3932	2.02616
5.122	0.3963	2.029849
5.096	0.3994	2.035342
5.059	0.4025	2.036248
5.021	0.4056	2.036518
4.983	0.4088	2.03705
4.95	0.4119	2.038905
4.92	0.415	2.0418
4.883	0.4181	2.041582
4.836	0.4212	2.036923
4.785	0.4244	2.030754
4.731	0.4275	2.022503
4.673	0.4306	2.012194
4.617	0.4337	2.002393
4.542	0.4368	1.983946
4.459	0.44	1.96196
4.369	0.4431	1.935904
4.251	0.4462	1.896796
4.036	0.4493	1.813375
3.655	0.4524	1.653522
3.172	0.4556	1.445163
2.781	0.4587	1.275645
2.283	0.4618	1.054289
1.646	0.4649	0.765225
0.429	0.4681	0.200815

b- feeding the values of V and I from table (5.6) as inputs to matt lab perturb algorithms as in the figure (4.2) seeking Vmax, which satisfies Imax and then Pmax at each of (33) scan readings; table (5.7) explains Pmax extraction by perturb MPPT algorithm.

Table 5.7 Vmax and I max extracting by MPPT technique

solar energy (w/m²)	time	Imax (mA)	Vmax (V)	Pmax (W)
643.6	8:48	365.8	5.318	1.945
679.2	9:01	380.2	5.254	1.997
729.3	9:20	393.7	5.074	1.997
781.5	9:41	415	4.92	2.041
823	10:00	432	4.934	2.131
839	10:04	414.4	4.911	2.167
870	10:20	440.5	4.94	2.176
896	10:40	433.5	4.886	2.118
928	11:00	434.9	4.885	2.124
931	11:04	431.2	4.896	2.111
952	11:20	426.8	4.869	2.078
941	11:40	427.6	4.869	2.081
962	12:00	414.7	4.915	2.038
969	12:20	414.1	4.889	2.024
939	12:40	414.9	4.897	2.031
946	13:00	412.2	4.91	2.023
930	13:03	398.5	4.897	1.951
910	13:20	404.2	4.867	1.967
885	13:40	404.7	4.899	1.982
845	14:00	401.8	4.884	1.962

827	14:11	397.3	4.901	1.947
823	14:12	285.3	4.939	1.409
810	14:20	401	4.919	1.972
757.3	14:40	392.7	4.934	1.937
713.4	15:00	375.7	4.886	1.835
631	15:31	299.2	5.103	1.526
624.7	15:32	192.8	5.266	1.015
601.6	15:40	293.4	4.899	1.437
547.5	16:02	257.3	4.934	1.269
490	16:20	220.1	4.84	1.065
436.9	16:42	256.8	5.044	1.295
377.4	17:00	225	4.862	1.093
318.1	17:11	184.5	4.911	0.906

c- referring to table (5.7) we have all Pmax for all values of solar energy and timings, hence, at the current step, we can draw Pmax with the timing as in figure (5.9) and Pmax with solar energies as in figure (5.10), these values of Pmax represents the optimum values of power that can be consumed from solar panel with optimum efficiency by using MPPT technique.

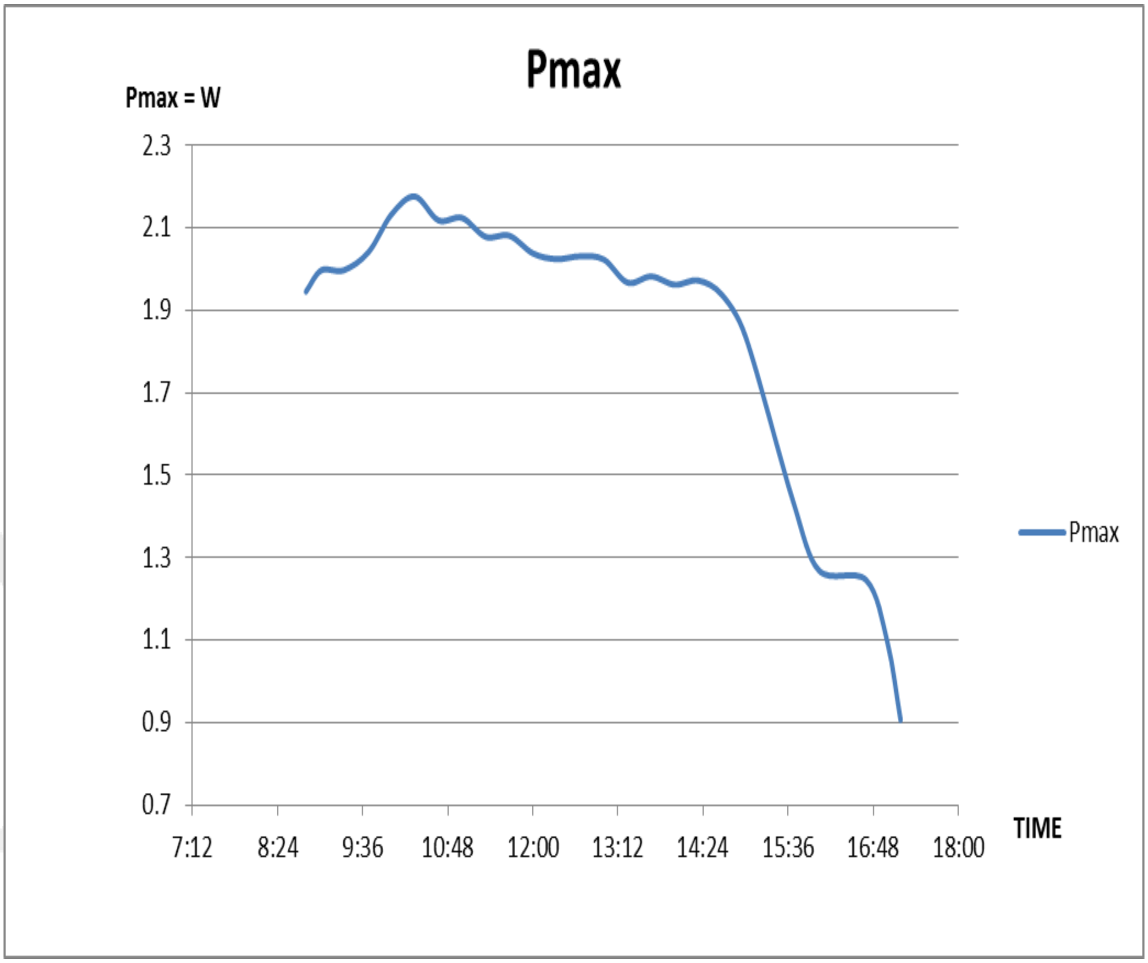

Figure5.9 Pmax with time

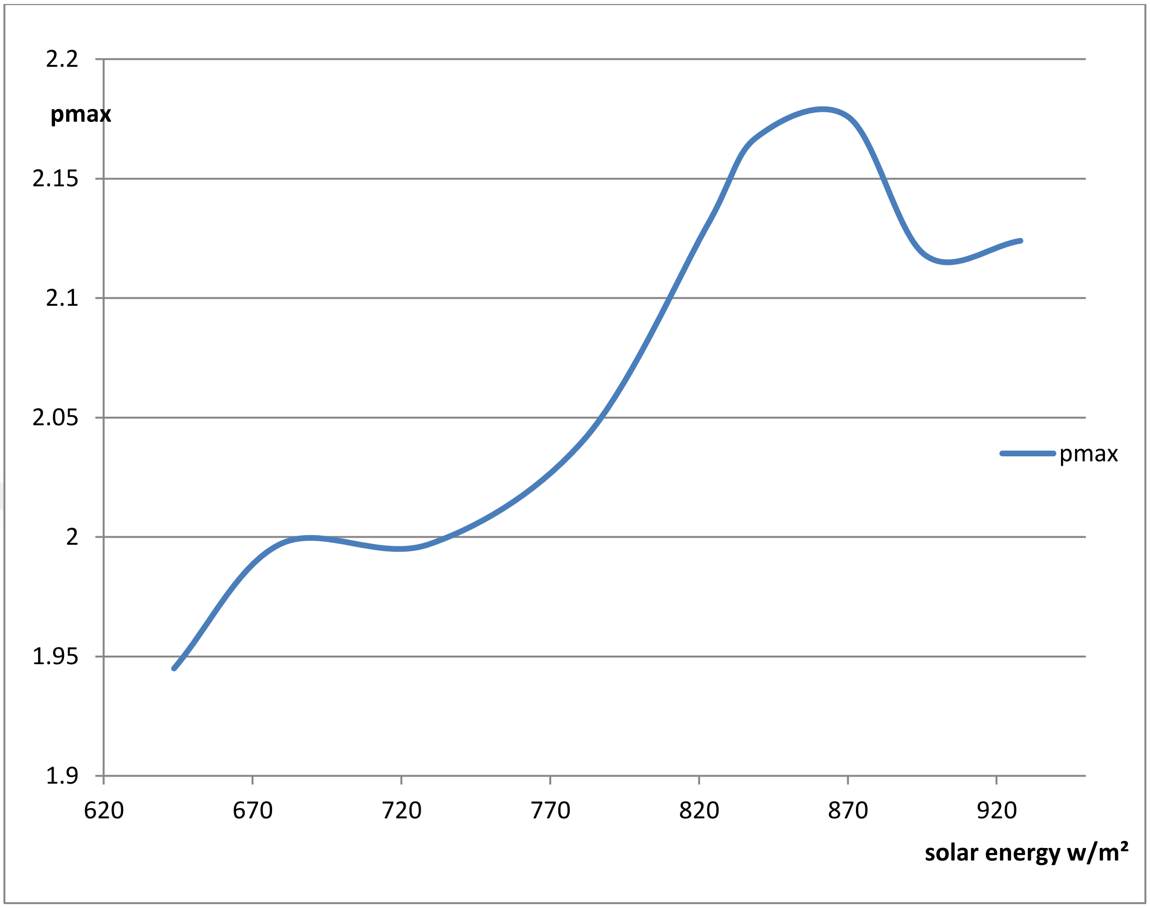

Figure 5.10 Pmax with solar energies

d- To recognize the benefits of using MPPT, we made a test on solar panel by using a fixed load of (170 ohm) and read P output and then comparing these values with the extracted power as a result of the MPPT technique at the same solar cell; as in table (5.8).

To find the relative efficiency in this table, we used the following equation:

$$\text{Relative efficiency} = \frac{\text{maxmum power with fixed load}}{\text{pmax with MPPT}} \times 100 \quad (5.4)$$

Table 5.8 Explains V, I and P by using (170) ohm load

V(v) with load (170ohm)	I(ma) with load (170 ohm)	Solar energy with load (170ohm) (w/m²)	P(w) by using MPPT technic	P(w)with load (170ohm)	Relative efficiency
5.1	30	643	1.945	0.098	5%
5.6	32	962	2.038	0.107	5.2%
5.2	30.5	910	1.967	0.088	4.4%
4.1	24	436	1.95	0.043	2.2%

CHAPTER SIX

Conclusions & Recommendations

6.1 Self-cleaning technique:

Through the experimental part, we focused on the feasibility of using a glass shield coated with SNO2 thin film (conductive glass) as a cover of solar panel to increase the power efficiency by preventing the dust from accumulating and then the absorbing part of solar energy. Also checking if applying this technique is economical in solar energy plants. It's important to check that the optical properties of SNO2 thin film are suitable to use as a cover with solar panel.

Figure (3.2) illustrates the absorption spectrum of SNO2 thin film. In reference to this figure, we can investigate that the thin film is highly transparent in the range of the spectrum response of a solar cell (400-800nm).

•Self-cleaning technique depends on the idea of charging the dust particles and panel cover with negative voltage and produce a repulsion force between these particles itself and also the particles with panel cover, to move it – the dust- away from the panel and forcing it to accumulate at the bottom.

•We found that increasing the negative supplying voltage to conductive glass, increases the efficiency of removing dust in lesser time, at the moment of supplying negative voltage to conductive glass up to removing (90%) of covering dust, which took (70) minutes, while through using (1) and (2) volt taken about (2) hours.

The negative voltage supplied to conductive glass energized from the solar panel itself as in figure (5.2), so supplying limited voltage with an output voltage of the solar panel means that the negative voltage cannot go above the value of solar panel output voltage, in addition to that, the selective voltage regulator (LM317) needs an input voltage more than its output voltage by no less than (2) volt.

• In reference to table (5.3), we conclude many points:

a- Using conductive glass sheet as a cover with solar panels gives importance and clearer results at the point of increasing efficiency of solar panel. The table illustrates that the dust causes loss in relative efficiency at a margin of (27%) to (33.6%) .

b- In reference to the readings of table (5.3) we noted that the effect of dust on efficiency of solar panel increases on the conditions of low solar energy. From table (5.3) conclude that at the low solar energy (318 w/m^2) the loss in relative efficiency increased and reached to (33%).

c- The effect of glass sheet in absorpting the solar energy and partially preventing solar light from reaching the solar panel is simple, and the loss in relative efficiency doesn't exceed (6.9%) as in table (5.4), while the loss in relative efficiency in dusty solar panel reached (33%) which means no need to worry about its effect.

• Effect of temperature on the efficiency of solar panel:

Table (5.5) illustrates that increasing the ambient temperature reduces the efficiency of solar panel, the loss in relative efficiency reached up to (10%) during effective daily margin. This reduction of efficiency cannot be avoided, but it can be compensated by using the self-cleaning technique.

• The power consumed by SNO2 thin film is very low compared to solar panel output power, due to the high resistance of the thin film layer (700ohm). If we calculate the current consumption at (4) volt supplied to this thin film, it will result in a (5.7ma), meaning a (0.123) watt, which is too low compared with normal output current of solar panel which is about (400ma).

6.2 Maximum Power Point Tracking Algorithms:

MPPT is a DC to DC converter, always seeking Vmax at the point where the current is at maximum value. Continuing scan output voltage by going to the next higher value of Vmax and monitoring the current, at the point where the current goes down, the algorithm stops the scan and operates on this value as the Pmax.

In reference to the experimental part, we can investigate the following points:

• The output power extracted from solar panel on specific solar energy is always at maximum values with maximum efficiency.

• The power extracted by MPPT technique is too high compared to the method of connecting the solar panel directly to the load or charger. Table (5.8) explains this difference, we select a load (170 ohm) because this load is an average value between open circuit and short circuit load.

In reference to this table, we notice that the difference in power between the two methods is too high and the ratio of power output at a fixed load (170ohm) reached a value in the range (2.2% to 5 %) of power output at MPPT technique with the same solar energy.

• In reference to figure (5.10) which explain the Pmax at daily time with different values of solar energy, we concluded that Pmax start increasing in the morning from 10AM up to 2PM, the Pmax is almost fixed with small change due to the stable rate of solar energy in the region, after the Pmax goes down due to dropping in solar energy with time.

• In reference to figure (5.9) which explain Pmax with solar energy, we concluded that Pmax is increased when increasing the solar energy, but nearing the midday there is a decay happens due to an increasing in ambient temperature which affect the efficiency of solar panel.

6.3 Recommendations :

For Self-Cleaning, we found, experimentally, that the self-cleaning technique by using glass cover coated with thin film will save about (33%) of solar panel efficiency, beside, the equipment used in this technique (glass cover, electronic circuit) is not expensive; hence, we recommend using this technique in all applications of solar panel.

For MPPT technique, we found, experimentally, that there is a big difference in power consumption from solar panel if using MPPT technique compared to power output when using fixed load. We can say that using solar panel without MPPT technique is useless and uneconomical in any application of solar panel, and it must apply the MPPT technique.

Self-cleaning and MPPT technique together are recommended to use in any application of solar panels.

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