

# Simulation the Design of Solar Cell Circuit with Dc Converter

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## **Abstract:**

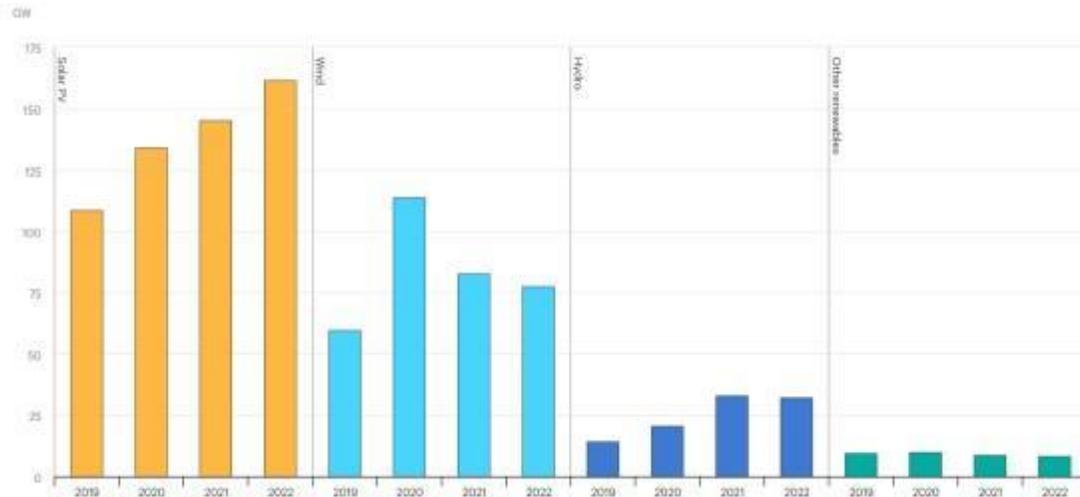
The increasing demand for sustainable energy solutions has driven research in photovoltaic (PV) systems and their integration with power electronics for efficient energy conversion. Despite advancements, challenges remain in optimizing PV system efficiency, particularly in maximum power point tracking (MPPT) and DC-DC converter design. This study presents a simulation model of a solar cell circuit integrated with a DC-DC boost converter, implemented using MATLAB/Simulink. The proposed system enhances energy conversion efficiency by employing the Perturb and Observe (P&O) MPPT algorithm, ensuring optimal power extraction under varying environmental conditions. Findings indicate a significant improvement in voltage regulation and power output stability, contributing to the feasibility of large-scale solar energy integration. These results highlight the importance of advanced MPPT techniques and efficient converter design for maximizing solar energy utilization in grid-connected and standalone applications.

**Keywords:** Photovoltaic system, maximum power point tracking, DC-DC converter, solar energy, MATLAB simulation, renewable energy.

## **1.1 Introduction**

The increasing pollution due to traditional generating units operated by the fossil fuel and nuclear energy becomes a serious concern for the ecosystem. Many countries changed their policies for the production of electricity by reducing the number of traditional methods of generating units to new methods of generating electricity such as Renewable Energy Source (RES) such as Photovoltaic (PV), wind turbine and biomass, which are considered sustainable and environmentally friendly with no fuel costs and easy accessibility.

The global has become very interested in clean energy, especially with the PV energy source; Figure (1-1) shows how the PV has become increase for the period from (2020 to 2022) as compared with other RES.

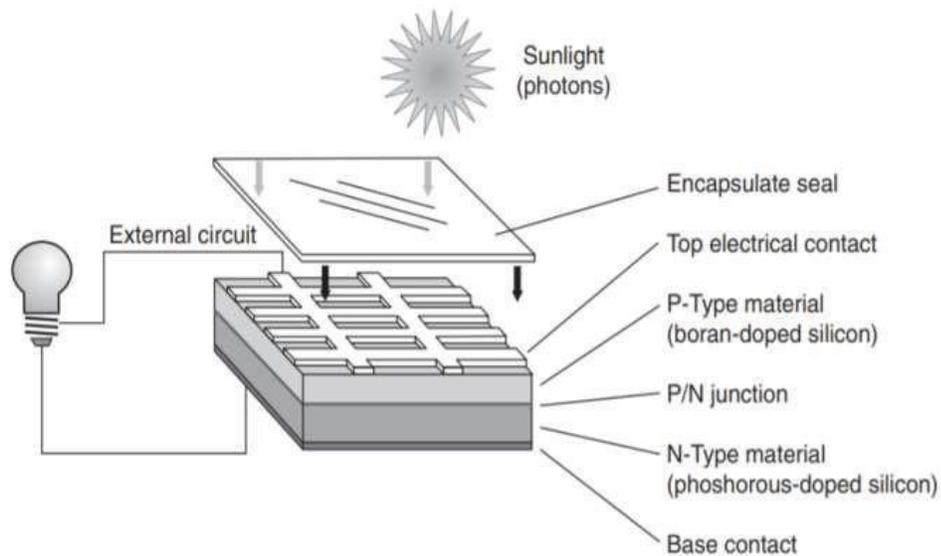


**Figure (1- 1): Net renewable capacity additions by technology, 20202021**

The RES systems are designed to operate within certain operating limits in normal cases, but they may be subjected to disturbances that will change their operating performance and behavior, these disturbances can vary in effect, duration and intensity. Solar cell converts sunlight into electrical energy using photoelectric effect. Sun's radiation is converted directly into usable electricity by the photovoltaic systems. Photovoltaic (PV) systems are made of photovoltaic modules which are semiconductor devices that convert the incident solar radiation directly into electrical energy. PV power depends greatly on solar irradiation and temperature. As a result the powers generated by solar systems are not constant. Apart from this clean conversion of solar energy into electrical energy, one thing which is holding back the photovoltaic systems is their lack of reliability. Depending on different solar irradiation levels and temperatures, their production rate varies. Therefore by adding a supplemental source of power, Solar Power's reliability can be greatly increased where this supplement energy source will work as a backup energy source. Whenever the load demand will not be fully met by the primary solar energy source it will be supported by the backup energy source. And on the other hand when the demand will be less than the generation, the primary solar source will energize the backup source. The main aim of this work is to model and analyze a photovoltaic system coupled with battery energy storage systems using bidirectional DC-DC converters

## 1.2 Work Principles of PV Cells

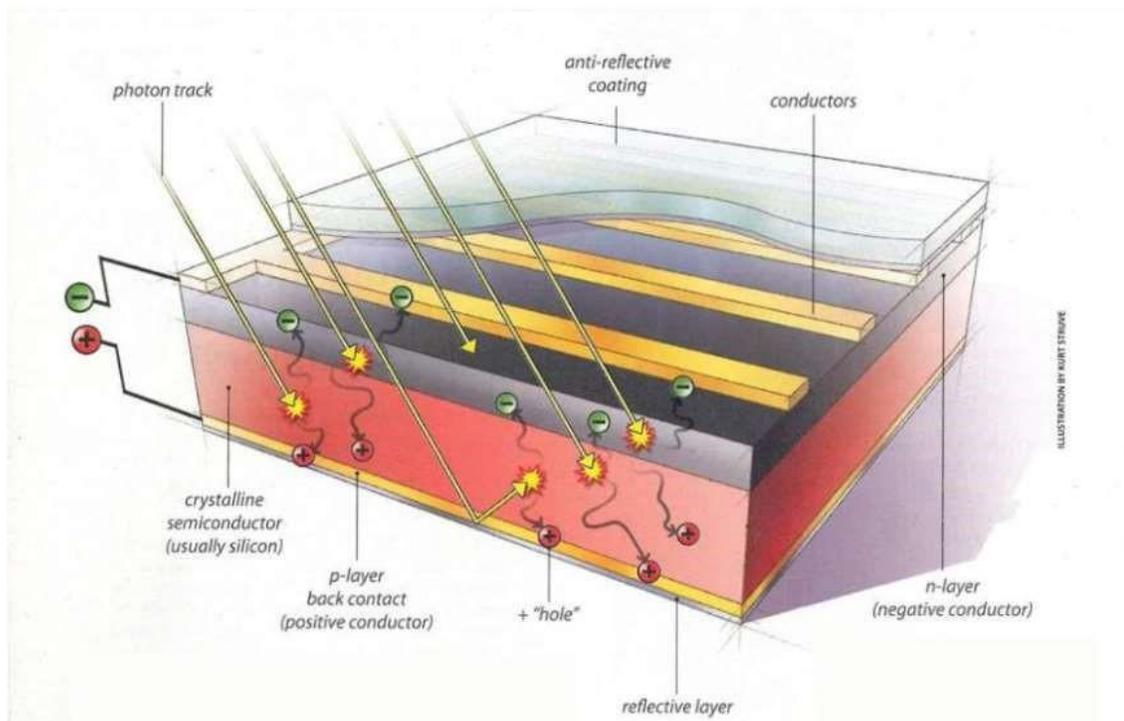
PV cells convert sunlight directly into electricity without creating any air or water pollution. PV cells are made of at least two layers of semiconductor material. One layer has a positive charge, the other negative. When light enters the cell, some of the photons from the light are absorbed by the semiconductor atoms, freeing electrons from the cell's negative layer to flow through an external circuit and back into the positive layer. This flow of electrons produces electric current. To increase their utility, dozens of individual PV cells are interconnected together in a sealed, weatherproof package called a module. When two modules are wired together in series, their voltage is doubled while the current stays constant. When two modules are wired in parallel, their current is doubled while the voltage stays constant; Figure (1-2) shows the basic construction of PV cells.



**Figure (1- 2): Basic solar cell construction**

To achieve the desired voltage and current, modules are wired in series and parallel into what is called a PV array. The flexibility of the modular PV system allows designers to create solar power systems that can meet a wide variety of electrical needs, no matter how large or small.

Photons strike and ionize semiconductor material on the solar panel, causing outer electrons to break free of their atomic bonds. Due to the semiconductor structure, the electrons are forced in one direction creating a flow of electrical current. Solar cells are not 100% efficient in crystalline silicon solar cells, in part because only certain light within the spectrum can be absorbed. Some of the light spectrum is reflected, some is too weak to create electricity (infrared) and some (ultraviolet) creates heat energy instead of electricity.

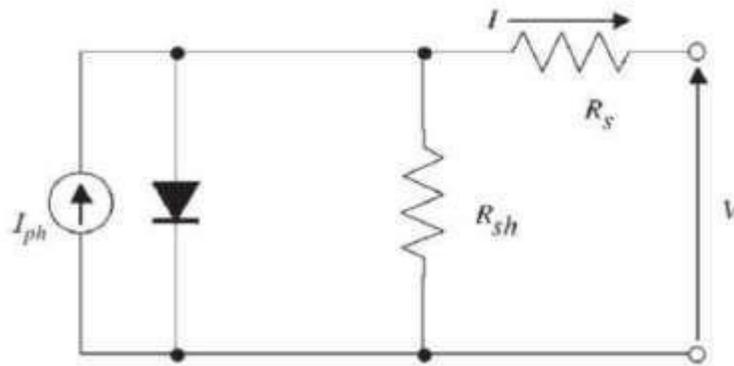


**Figure (1- 3): Diagram of a typical crystalline silicon solar cell**

### 1.3 Current-Voltage Characteristic of Solar Cells

To understand the performance of photovoltaic cells, it is important to find the current-voltage characteristic, otherwise known as an I-V curve. The current-voltage characteristic is a graphical representation of the solar cell's output current as a function of voltage. This characterization is achieved by approximating the solar cell (or module) with an equivalent circuit consisting of a current source in parallel with a single diode, as shown in Figure (1-4). Using a diode to model the cells gives a nonlinear current-voltage characteristic, which does not obey Ohm's Law. With zero irradiance, the solar cell will behave like a diode without a current source.

This will give an I-V curve that begins at a value of 0 amps. As the voltage increases, the current drops into the fourth quadrant of an x-y graph, in the complex plane (real voltage value, imaginary current value). As light intensity is increased, the values needed to characterize the system are in the first quadrant.

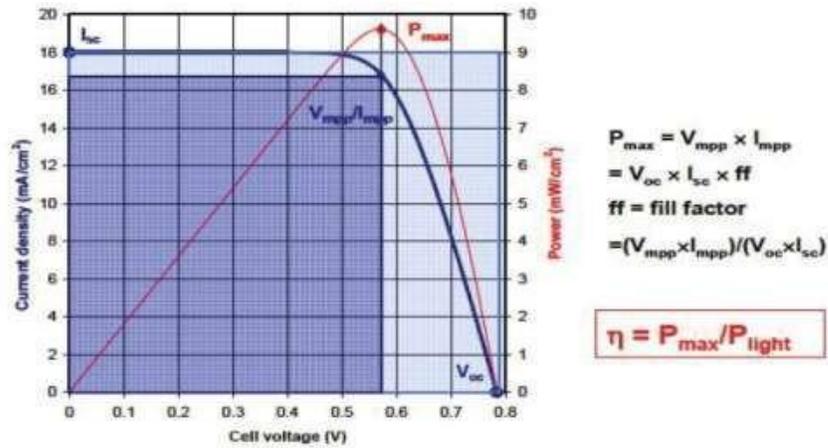


**Figure (1- 4) Equivalent Circuit of a Solar Cell**

When the I-V curve is shown on a graph (as in Figure (1-5)), it can be seen that the short circuit current ( $I_{sc}$ ) can be read where the curve intersects the y-axis (voltage equals zero). Similarly, the open circuit voltage ( $V_{oc}$ ) is shown where the I-V curve intersects the x-axis (where the current equals zero). Using Joule's law, the voltage can be multiplied by the corresponding current at that point in order to find the power generated by the solar cell.

The power can be calculated along the entire curve in order to find the maximum power. The voltage at this point is known as  $V_{mpp}$ , and the current known as  $I_{mpp}$ . This is the most important point in the current-voltage characteristic, as it is used to find the efficiency of the solar cell. The curve can be seen to decrease with a small slope. Upon reaching maximum power, the power decrease is achieved faster as the negative slope increases to a larger number before reaching the open circuit voltage. The maximum power is often compared to the power found from the product of open circuit voltage and short circuit current (known as the theoretical power). The ratio between the two, respectively, is called the fill factor ( $ff$ ). Ideally, the fill factor would be as close to 1 as possible in order to take advantage of the full potential of the solar cells. However, the fill factor in practice will always be less than unity. Once the fill factor is known for each level of irradiation, the maximum power can be calculated by multiplying the fill factor by the theoretical power. The power-voltage curve (P-V curve) is often shown on the same graph as the I-V curve. This shows the power generated by the solar cell as a function of voltage, with the power on a secondary y-axis. The peak of this curve shows the maximum power generated. The P-V curve will cross through the origin at power of zero. After the peak at maximum power, the curve will decrease before crossing the x-axis at the open circuit voltage. A graph showing the

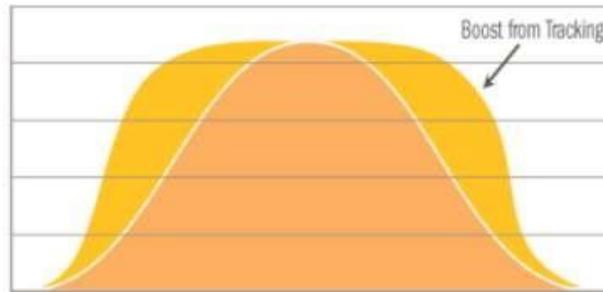
I-V curve, P-V curve, fill factor, open circuit voltage, short circuit current and maximum power generated is shown in Figure (1-5).



**Figure (1- 5): I-V and P-V Curves**

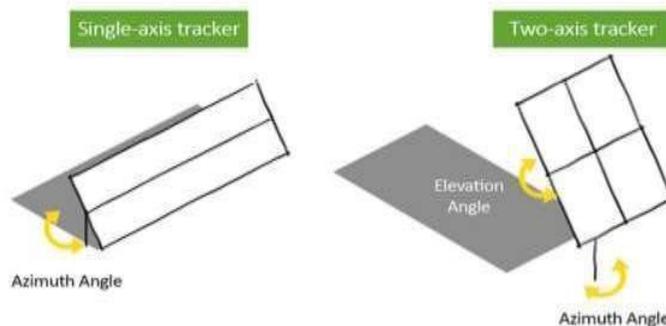
### 1.4 Efficiency of Solar Panels

The solar cells are used for converting the solar energy into electrical energy; the maximum efficiency can be achieved when solar panels are laid perpendicular to the sun's light. Trackers are used to rearrange the direction of the PV panels to be in a direct manner with the sun light from the sun to get the maximum energy. The benefit of tracking is to increase the maximum power delivered from the PV panel, Figure (1-6) shows how the duration of maximum power increases when the tracking system is used.



**Figure (1- 6): Daily power production compared to fix mount**

Many types of trackers can be used in PV systems, two common types of trackers are used in PV systems, they are single axis trackers and dual axis trackers, and the single axis is used to track the azimuth angle, while the dual axis is used to track the elevation and azimuth axis as shown in Figure (1-7).



**Figure (1- 7): Single and dual axis trackers**

## 1.5 Maximum Power Point Tracking

The maximum power point tracking (MPPT) is an algorithm that is usually used with the DC/DC converter to produce the maximum output power of PV arrays panels. The MPPT algorithm used to optimize the output power of a PV array panels for various environmental operating conditions and array configurations. Perturb and Observe (P&O) method is one of the MPPT algorithms that commonly used in PV systems, which can show in Figure (1-8) that shows the nonlinear output power with voltage, this curve is also called the (P-V) curve of a PV array, that shows the maximum power point (MPP). In the P&O perturbs method, the operating voltage of an array is pointed in a certain direction and observes changes in its output power. It can be seen from Figure (1-8) when the change in the power is in the same direction of voltage ( $dP/dV > 0$ ), then the operation point is on the left of the MPP. The MPP can be reached by increasing the operating voltage. Otherwise, when the change of power is in the opposite direction of voltage perturbation ( $dP/dV < 0$ ) then the operation point is on the right of the MPP, and the operating voltage should be decreasing to approach the MPP. This P&O algorithm is processed iteratively until the MPP is reached, and then, the PV array will oscillate around its present

MPP in steady-state operation +.

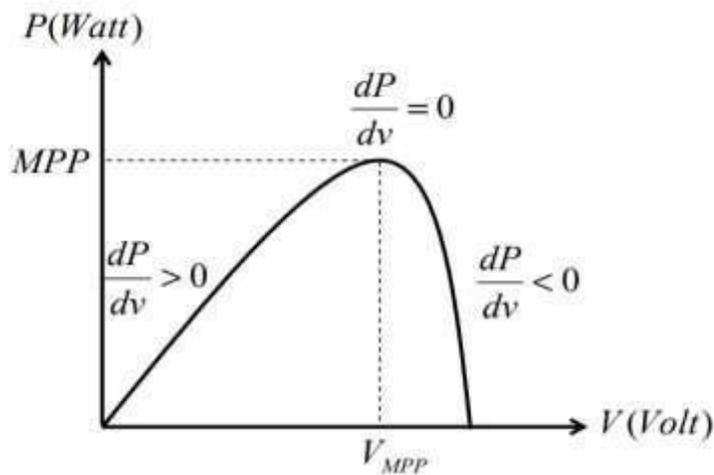
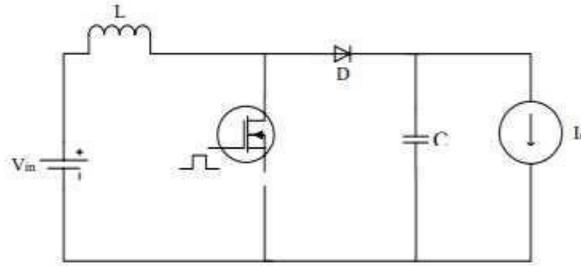


Figure (1- 8): Variations of the operating point based on MPPT

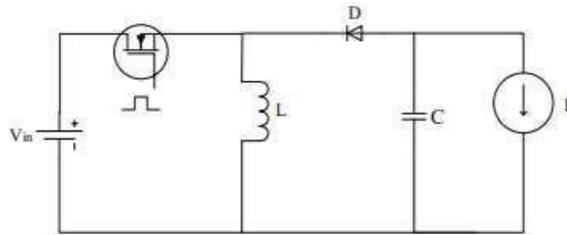
## 1.6 DC –DC Converter

Generally, Power Electronics converters are labelled into classes that's isolated and non-isolated power converters. Boost, Buck-Boost, CUK, SEPIC converter are non-isolated converters which is easy in shape and excessive performance for small voltage conversions. These converters don't provide safety towards excessive enter voltage and transient's voltage. Boost converter is kind of DC to DC energy converter that step-up implemented enter voltages to required output voltage. Boost converter shown in figure (1-9). The operation of the circuit is primarily based totally upon the conduction time of the MOSFET transfer. To function the boost converter in continuous conduction mode, high switching frequency is used. MOSFET has excessive conduction loss and to less conduction loss, switching frequency need to boom and voltage pressure throughout the transfer to be reduced. The output voltage has received has DC ripples, output capacitor is inserted to make ripple loose output voltage.

The buck boost converter is a DC to DC converter which generates output voltage less than or greater than applied voltage magnitude. Figure (1-10) shows circuit diagram of buck boost converter. Buck-boost converter generates range of output voltage, from much greater than applied voltage and down to nearly zero.

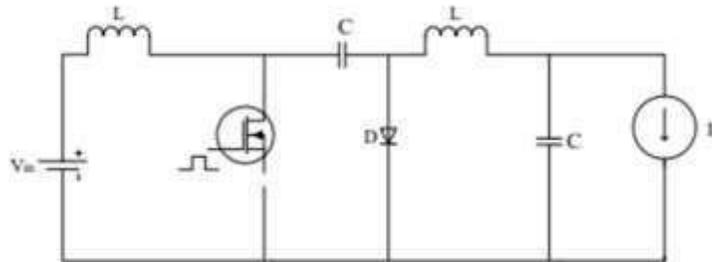


**Figure (1- 9) Boost Converter**



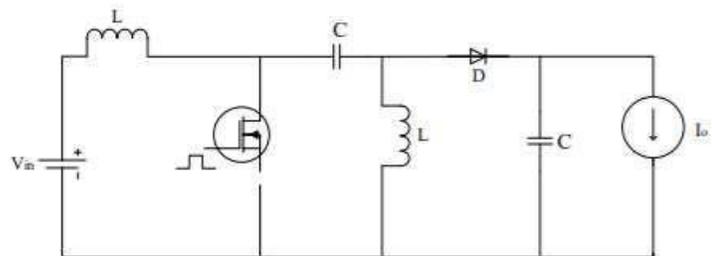
**Figure (1- 10) Buck-Boost Converter**

CUK converter is combination of boost converter which is in input part followed by output part has buck converter circuit with capacitor is connected in between to couple the energy. CUK is similar one like buck– boost converter circuit with inverting topologies. Cuk converter is shown in figure (1-11).



**Figure (1- 11) Cuk converter**

The SEPIC converter is one of the DC-DC converter which step up/step down the input voltage based on the duty cycle which is applied to power converter switch. Figure (1-12) shows the circuit diagram of SEPIC converter.



**Figure (1- 12): SEPIC Converter**

## 1.7 Project Outline

This work is organized in five chapters and five appendices. In addition to the already presented **chapter (1)**, chapters (2-5) are briefly outlined here as:-

**Chapter two** in this chapter we will discuss theoretically the component of the solar cell system and DC converter.

**Chapter three** here in this chapter we will modeling the proposed system by using MATLAB Simulink program, all the component that discussed in chapter two will modeled in this chapter.

**Chapter four** in this chapter we will discuss and analysis the results of simulation of solar cell circuit with DC converter system.

**Chapter five** summarizes the main conclusions drawn throughout this work and offers some suggestions for future work extension.

## 2. Theoretical and Mathematical Model

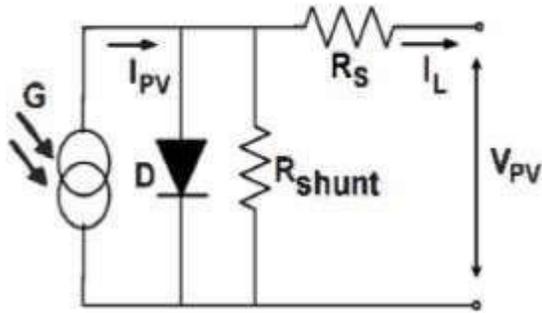
Renewable energy systems offer economic and environmental benefits in providing clean and sustainable energy rather than conventional fossil fuels. Renewable energy sources such as solar energy have received tremendous demands since it is pollution-free from any poisonous byproducts that can pollute the environment. DC-DC converters are widely used in renewable energy generation systems such as solar photovoltaic (PV) system, wind power system and fuel cell for correct energy conversions. The solar photovoltaic (PV) power generation system is extensively used in grid-connected and off-grid applications.

The combination of PV cells will form a PV module and a combination of PV modules will form a PV array to supply the specified loads. Normally, these solar PV modules will be connected in series to increase the PV output voltage due to the nature of solar PV energy that can only generate low DC output voltage in the range between 12V to 75V. Thus, the power electronic interfaces or power converter such as DC-DC converter is a compulsory interface to convert the low DC output voltage from solar PV system to the required voltage rating needed by the utility grid or any suitable utilization voltage.

In this chapter the theoretical of the solar cell system and DC-DC converter in detailed are explained. The mathematical model is also discussed in this chapter, all the type of the DC- DC converter is explained and we will focus of the DC-DC step-up converter type (Boost converter), because it widely used with solar cell system, when the boost converter increase the output voltage, the current will be reduced and the loss is also reduced and the efficiency increased.

### 2.1 Solar System

A photovoltaic cell is a diode which is designed to promote the photovoltaic effect. The term PV denotes the unbiased operating mode of a photodiode in which current through the device is entirely due to the transduced light energy. The photovoltaic systems convert solar energy into electrical energy. It is a nonpolluting source of electricity and is highly reliable, which is suited for many applications. The solar cell is represented by a current source, a Shockley diode and a resistor as shown in Figure (2-1). The current source generates a current proportional to the irradiation  $G$  [ $\text{W}/\text{m}^2$ ]. The photo current,  $I_L$  is in turn directly proportional to the radiation level. The characteristic between voltage and current of a solar cell can be obtained from an equivalent model of a solar cell. The output PV module current is given by:



**Figure (2 - 1) Equivalent Circuit of solar Cell**

$$I_l = I_l(T_1)(1 + K_0 (T - T_1)) \dots (1)$$

In which,

$$I_l(T_1) = S * I_{sc}(T_{1,nom}) / S_{nom} \dots (2)$$

$$K_0 = (I_{sc}(T_2) - I_{sc}(T_1)) / (T_2 - T_1) \dots (3)$$

Where

$$K_0 = (I_{sc}(T_2) - I_{sc}(T_1)) / (T_2 - T_1) \dots (4)$$

And

$$I_0 = I_{0(T_1)} * \left(\frac{T}{T_1}\right)^{\frac{3}{n}} * \left[\exp\left(\frac{-q(Vg)}{N_s K}\right) * \left(\frac{1}{T} - \frac{1}{T_1}\right)\right] \dots (5)$$

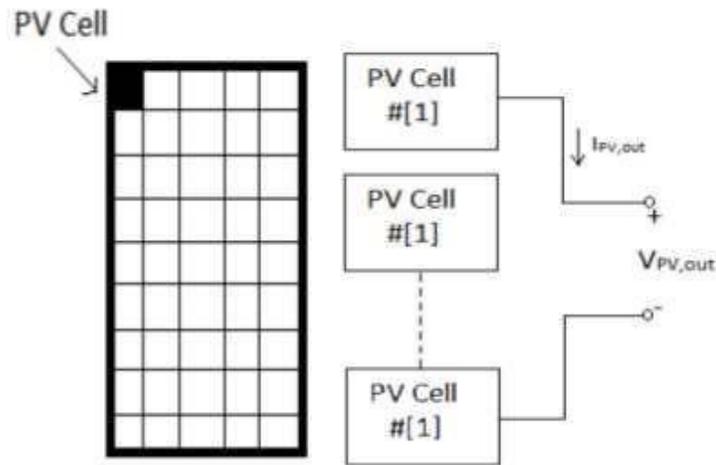
$$I_{0(T_1)} = I_{sc(T_1)} / \exp\left(\frac{-q(Voc_{T_1})}{N_s K T_1} - 1\right) \dots (6)$$

$$R_s = -dV / dI_{voc} - 1 / X_v \dots (7)$$

$$X_v = I_{0(T_1)} * \frac{-q(Vg)}{N_s K} * \exp\left(\frac{-q(Voc_{T_1})}{N_s K T_1}\right) \dots (8)$$

Where  $q$  is electron charge,  $K$  is the Boltzmann Constant,  $T$  is the PV module temperature,  $I_0$  is the reverse saturation current of the diode,  $A$  is the diode ideality constant,  $I_{ph}$  is the light generated current of PV cell,  $R_{sh}$  is the shunt resistance of PV cell,  $R_s$  is the series resistance of the PV cell,  $N_s$  is the number of the PV module connected in series and  $I_{pv}$  is the output current and  $T_1$  and  $T_2$  are temperatures.

For obtaining higher power output the solar PV modules are connected in series and parallel combinations forming solar PV arrays. It is preferred that solar cell used in series connections are identical as far as possible. In series connected PV cells, the PV modules receiving the same level of solar irradiation. These series-connected subassemblies, with a different level of irradiance, form a series assembly. The model of a PV module is developed for simulating an entire PV array. A PV module, which is made of many series-connected PV cells are shown in Figure (2-2). The voltage across each cell is the total output voltage of the PV module ( $V_{pv,out}$ ) divided by the number of series-connected cells, and the current ( $I_{pv,out}$ ) through each PV cell is the same as the output current of the PV module.

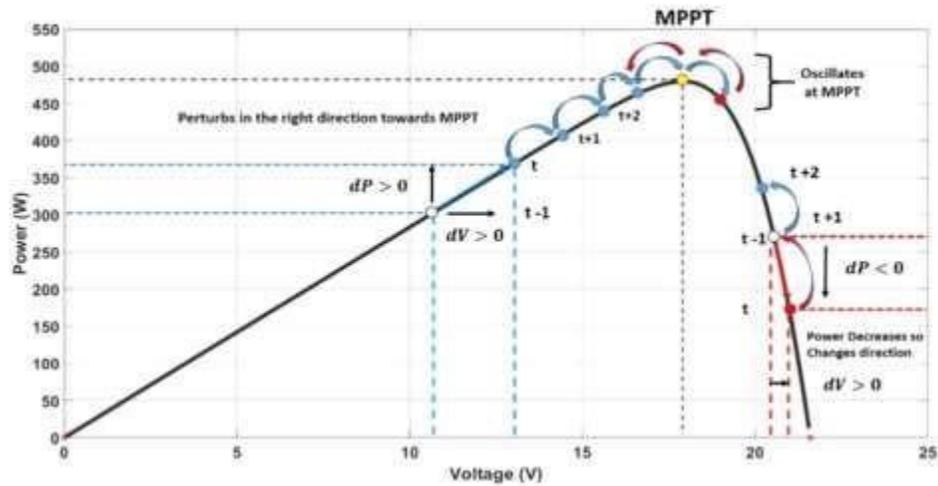


**Figure (2- 2) (a) PV Module (b) A PV Module consists of series connected PV Cell**

## 2.2 Maximum Power Point Tracking (MPPT):

Due to the non-linear characteristics of the PV panel it is required a maximum power point tracking (MPPT) algorithm. Another drawback is the unequal power produced between the PV panels due to various factors, such as dissimilarities of panel production, different temperatures and irradiances due to the orientation of the panels, aging and shading. To design a PV system, solar cells are packaged in PV modules and then connected to electronic converters. These modules are electrically connected in multiples as PV panel. The PV module exhibits a nonlinear voltage - current characteristic. Its maximum power point depends on irradiance and temperature. At a particular solar irradiation, there is a unique operating point of the PV generator at which its power output is maximum. When sunshine is not consistent voltage and current output of a PV module is also affected and hence reduces the efficiency. To get maximum utilization efficiency of a PV module, the matching of the PV module to the load is required. This matching requires finding an equilibrium operating point coincides with the maximum power point of the PV module. The role of dc-dc converter is matching of load to PV source, which continuously adjusts the voltage, current levels and moves the operating point.

On the other hand, Maximum Power Point Tracking (MPPT) can be defined as a controller technique that used to track the position of PV systems to get the maximum output power. There are many control techniques or strategies that produce the maximum output power; here in this project we will use Perturb-and-Observe (P&O) algorithm techniques. The P&O algorithm techniques depend on the comparison between the previous and present values of voltage and power, that can be represent by  $\Delta P$  and  $\Delta V$ , when the ratio of  $\Delta P/\Delta V$  is negative then the operating point is at the right side of MPP and vice versa, when the ratio of  $\Delta P/\Delta V$  is negative or positive the tracking system change their position until get zero changes in power and voltage, the MPP present when  $\Delta P$  and  $\Delta V$  are zeros. The Figure (2-3) shows the P-V (power-voltage) curve and how the MPPT can get by using P&O method.



Figure(2- 3) PV P-V characteristic at 1 kW/m2 irradiance P&O operation The Figure (2-4) below shows the flow chart of the P&O algorithm.

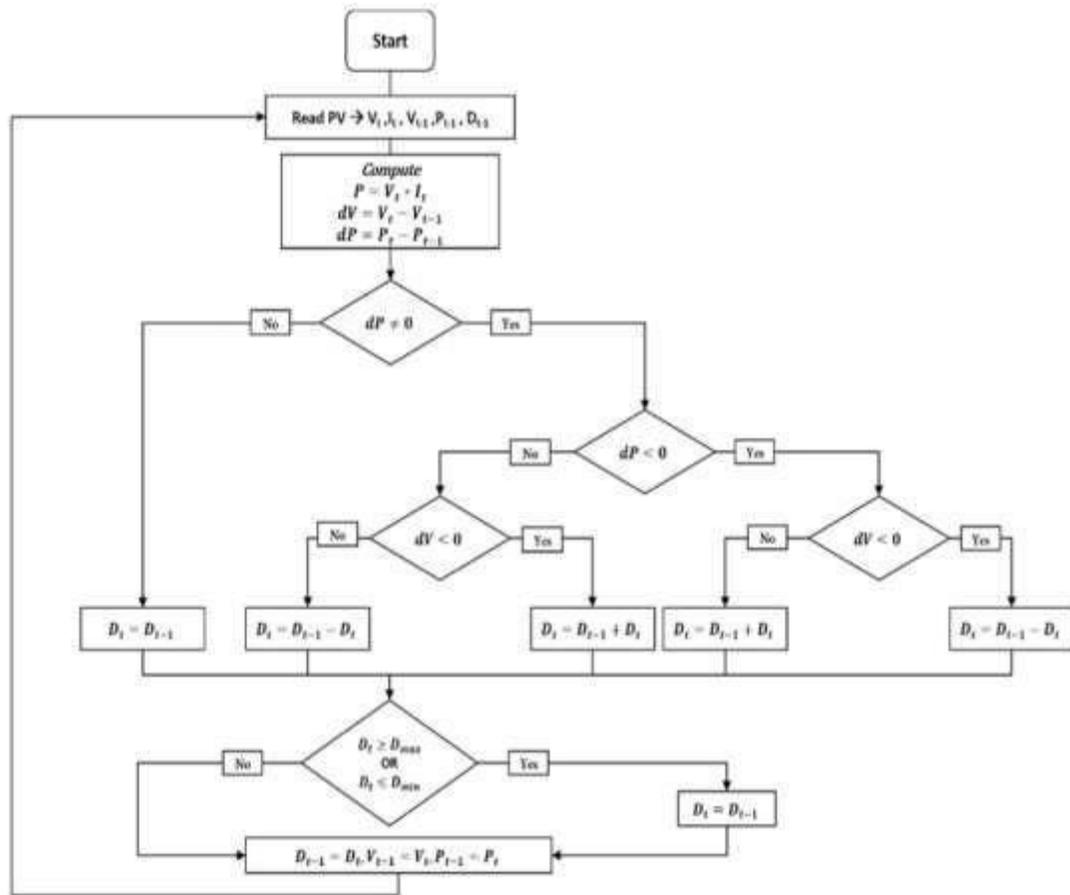


Figure (2- 4) P&O Flow Chart Algorithm

### 2.3 DC – DC Converter:

The **DC-to-DC converters** convert one level of DC voltage to another level. The operating voltage of different electronic devices such as **ICs**, **MOSFET** can vary over a wide range, making it necessary to provide a voltage for each device. A **Buck Converter** outputs a lower voltage than the original voltage, while a **Boost Converter** supplies a higher voltage.

With the application of **DC-to-DC Converters**, the circuit's **efficiency, ripple, and load-transient response** can be changed. Optimal external parts and components are generally dependent on operating conditions such as input and output specifications. So, while designing the products, the **standard circuits** must be varied or changed according to and as per the need to their individual specification requirements. Designing the circuit that satisfies the specification and all the requirements needs a great deal of expertise and experience in that field.

The step-up or step-down DC-to-DC Converters are useful in applications where the battery voltage can be above or below the regulator output voltage. The DC to DC converter must be able to operate as a step up or down voltage supplier to provide constant load voltage over the entire battery voltage range through the operation.

## 2.4 Types of DC-DC Converters

Below the main types of the DC-DC converters that used in power electronic applications:

### 1: Magnetic Converters

In these DC-to-DC Converters, energy is periodically stored and released from a magnetic field in an **inductor** or a transformer. The frequency ranges from 300 kHz to 10MHz. By maintaining the duty cycle of the charging voltage the amount of power that needs to be transferred continuously to a load can be more easily controlled.

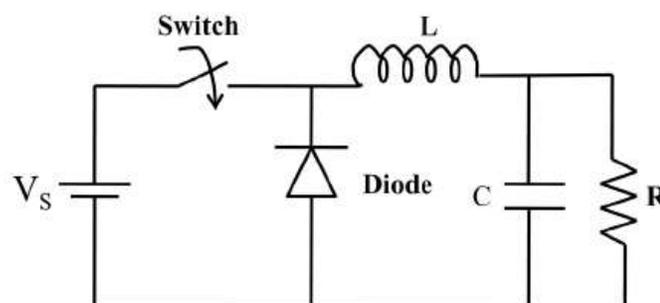
Moreover, the control can also be applied to the input current, the output current or to maintain constant power through the circuit. The transformer-based converter can easily provide the isolation between input and output.

### 2: Non-Isolated Converters

Non-isolated converters are mostly used when the change in the voltage is comparatively small. It possesses the input and output terminal to a common ground. The major disadvantage is that it cannot provide protection from high electrical voltages and it poses more noise.

### 3: Step-down/Buck Converters

In a typical non-isolated step-down or buck converter the output voltage  $V_{OUT}$  depends on the input voltage  $V_{IN}$  and the switching duty cycle  $D$  of the power switch, the output voltage always less than the input voltage, the buck converter is shown in Figure (2-5).



**Figure (2- 5) buck converter**

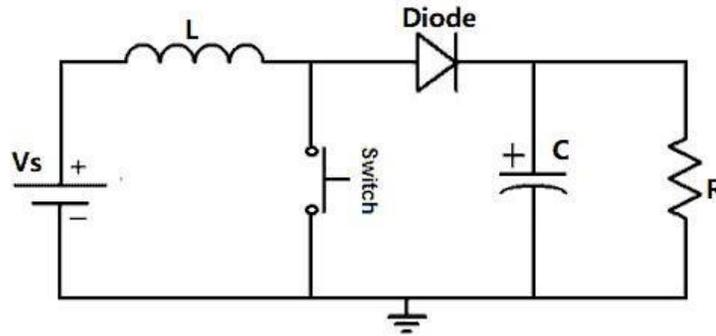
The output voltage can be given by:

$$V_{out} = D * V_{in} \dots (9)$$

Where  $D$  is the duty cycle (less than one and more than zero)

#### 4: Step-up/Boost Converters

It is used to boost DC to DC converter voltage and it uses the same number of passive components but arranged to step up the input voltage so that the output is higher than that of the input, the boost converter is shown in Figure (2-6).

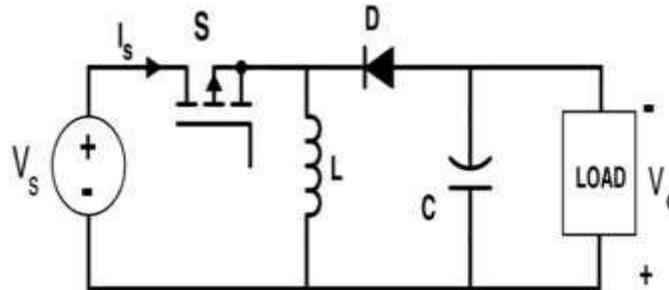


**Figure (2- 6) buck converter** The output voltage can be given by:

$$V_{out} = V_{in} / (1-D) \dots (10)$$

#### 5: Buck-Boost Converters

This converter allows the input DC voltage to be either stepped-up or stepped-down, depending on the duty cycle. The Figure (2-7) shows the buck-boost converter.



**Figure (2- 7) buck-boost converter**

The output voltage is given by the relation as mentioned below:

$$V_{out} = -V_{in} * D / (1-D) \dots (11)$$

From the above expression, we can notice that the output voltage is always reversed in polarity with respect to the input. Therefore, a buck-boost converter is also known as a voltage inverter.

#### 6: Isolated Converters

The Isolated converter has a separation between its input and output terminals. They have high isolation voltage properties. They can block the noise and interference. With this, they are able to produce a cleaner and desired DC output voltage. They are further categorized into two types.

##### I: Flyback converters

The working of this converter is similar to the buck-boost converter of the non-isolating category. The only difference is that it uses a transformer to store energy instead of an inductor in the circuit. The Figure (2-8) shows the flyback converter.

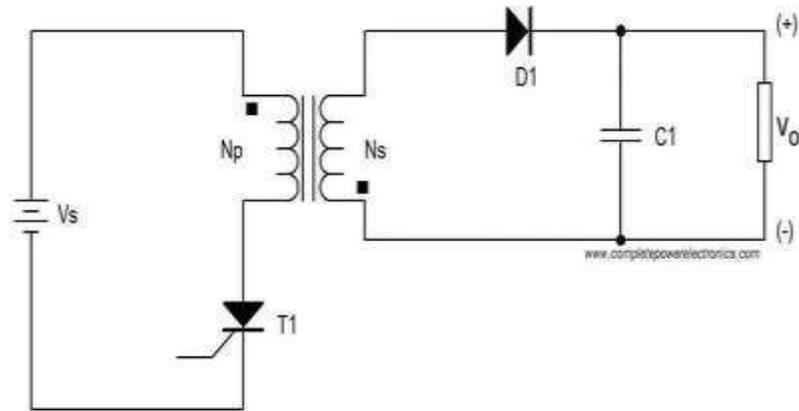


Figure (2- 8) flyback converter.

## II: Forward Converters

The working of this converter makes use of the transformer to send the energy, between the input and output in a single step.

### 2.5 Step-Up (Boost) Converters Components

The boost converter is shown in Figure (2-9). The switching of this converter operates by periodically opening and closing an electronic switch. It is called a boost converter because the output voltage is larger than the input.

The DC-DC boost converter is using to step up the input voltage at the output side (load), while step down the current value. The main components use in a DC-DC boost converter circuit are: Inductor ( $L$ ),

Diode ( $D$ ), Switching device ( $S$ ) and Capacitor ( $C$ ).

The main concept behind boost converter operation is flip its voltage polarity inductor. So the inductor will stored energy from supply side then relies it to the output side (load). where the load is supported, in addition by a DC source being the main energy source.

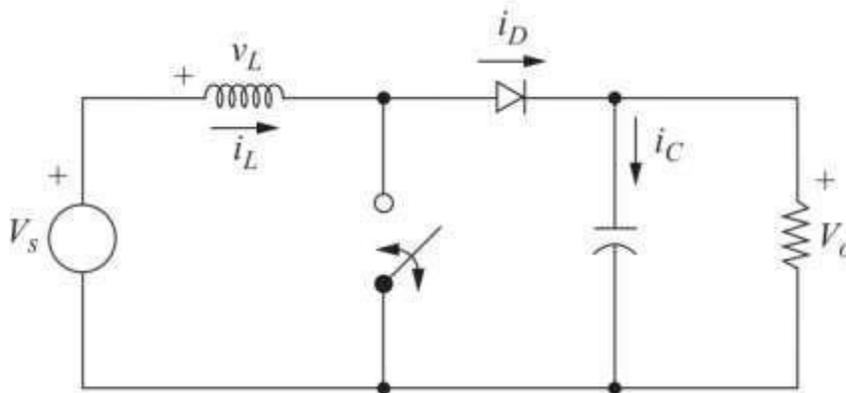


Figure (2- 9) The schematic circuit of boost Converter

### Power Electronic Switching Devices

Switches are very important and crucial components in power electronic circuits. In power electronic converters, the switches works in two states only: Fully ON (conducting), and Fully OFF (blocking). The main types of power semiconductor switches in common use are:

1. Power Diodes

2. Thyristor devices
3. Switching transistors

Power electronic switching devices are normally selected based on the rating at which they handle power, that is, the product of their current and voltage rating instead of their power dissipation rate. Consequently, the major attractive feature in a power electronic switch is its capability to dissipate low or almost no power.

**Inductor:**

Current flowing into an inductor carries energy that is stored in a magnetic field. The voltage across an inductor is the result of a self-induced electromotive force that opposes that voltage and is proportional to the time derivative of the current. The integral relationship between current and voltage in an inductor insures that current passing through an inductor is always continuous.

$$V_L = L \frac{di}{dt} \quad , \quad I_L = \frac{1}{L} \int_{t_0}^t v(t) dt + i(t_0) \quad \dots \dots (12)$$

**Capacitor:**

A capacitor also stores energy, in this case in an electromagnetic field created by oppositely charged plates. In the case of a capacitor, the energy stored is proportional to the charge on the capacitor, and charge is related to the time integral of current flowing through the capacitor. This gives rise to voltage–current relationships that are the reverse of the relationships for an inductor:

$$i_c = C \frac{dv}{dt} \quad , \quad V_c = \frac{1}{C} \int_{t_0}^t i(t) dt + v(t_0) \quad \dots \dots (13)$$

**Ferrite core**

The ferrite core is a type of magnetic core made of ferrite on which the windings of electric transformers and inductors components are formed. It is used for its properties of high magnetic permeability coupled with low electrical conductivity (which helps prevent eddy currents). Because of their comparatively low losses at high frequencies, they are extensively used in the cores of transformers and inductors in applications such as switched-mode power supplies.

**2.6 Converter terms definitions**

There are some terms generally associated with design of converters, such as: Pulse-width modulation (PWM), duty ratio ( $\delta$ ).

➤ **Pulse-width modulation (PWM)**

Pulse width modulation (PWM), is a method of controlling power delivered by an electrical signal, by effectively chopping it up into discrete parts.

The average value of voltage (and current) fed to the load is controlled by turning the switch between supply and load ON and OFF at a fast rate.

The concept of PWM is to generate fairly accurate square wave.

➤ **Duty Cycle (D):**

The duty cycle (or duty ratio) is the percentage of the ratio of pulse duration, or pulse width (PW) to the total period (T) of the waveform. It is generally used to represent time duration of a pulse. Duty

cycles can be used to describe the percent time of an active signal of switch in a switching power supply.

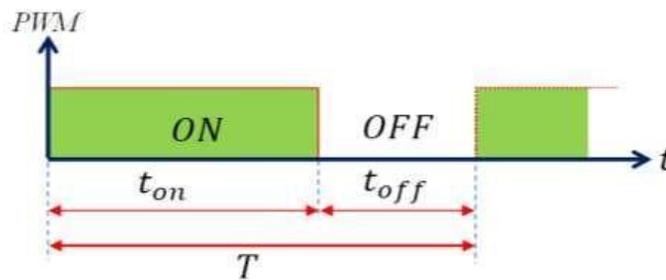
The term duty cycle describes the proportion of 'ON' time to the regular interval or 'period' of time as shown in Figure (2-10). Duty cycle is usually report as a percentage.

A period ( $T$ ) is the time it takes for a signal to complete an ON-OFF cycle. As a formula, a duty cycle (%) may be expressed as:

$$T = t_{on} + t_{off} \dots (14)$$

$$D = \frac{t_{on}}{T} , t_{on} = D T \dots(15)$$

$$t_{off} = T - t_{on} , t_{off} = (1 - D) T \dots (16)$$

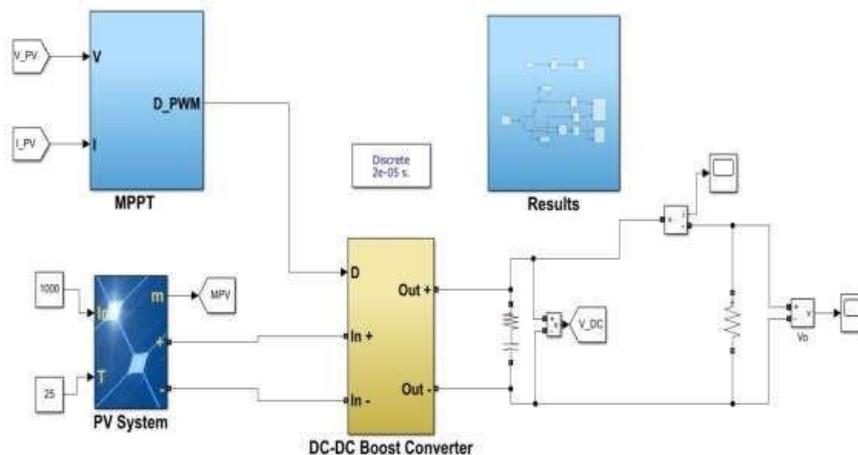


**Figure (2- 10) Pulse width modulation**

### 3. Simulation Model

#### 3.1 Introduction

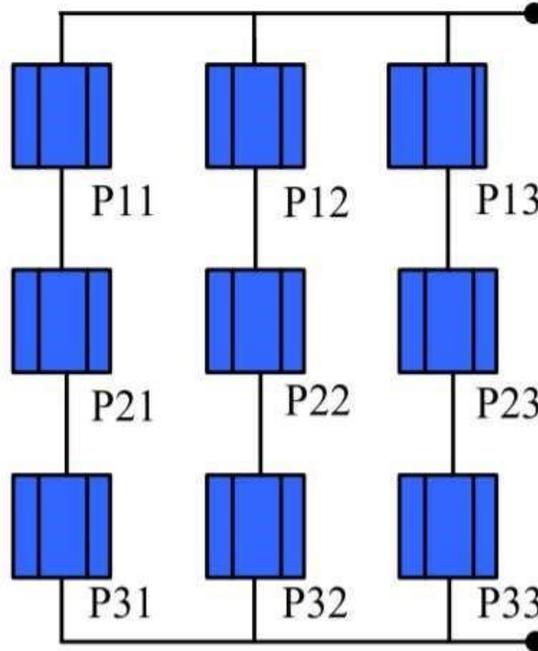
In this chapter we propose a PV solar system connected with DC-DC boost converter to supply a resistive load as shown in Figure (3.1). A DCDC boost converter used to increase the DC output voltage of the PV solar system and reduce the current to reduce losses. The Maximum Power Point Tracking (MPPT) of the PV solar system is achieved by applying Perturb and Observe (P&O) algorithm. The system designed and implemented by using MATLAB / Simulink program. DC link capacitor used between the boost and the load to reduce the ripple and make the DC voltage constant as possible, the section below shows the details design of each components of the proposed system.



**Figure (3- 1) the proposed PV system with DC-DC boost converter using MATLAB Simulink Program**

### 3.2 PV System Design

A PV array consisting of any number of PV modules that are wired in series and/or parallel to deliver particular voltage and amperage as require. The total generated power that is proposed in this work is (1800 W). We select a (9) PV panels, three connected in series and three connected in parallel each panel have (200 W) output power, and the connection diagram is shown in Figure (3.2)



**Figure (3- 2) (3\*3) PV Panel connection**

The voltage, current, and power of the proposed PV solar system can be calculated as:

$$V_{PV} = N_s \times V_{mppt} = 3 \times 37.26 = 111.78 \text{ V}$$

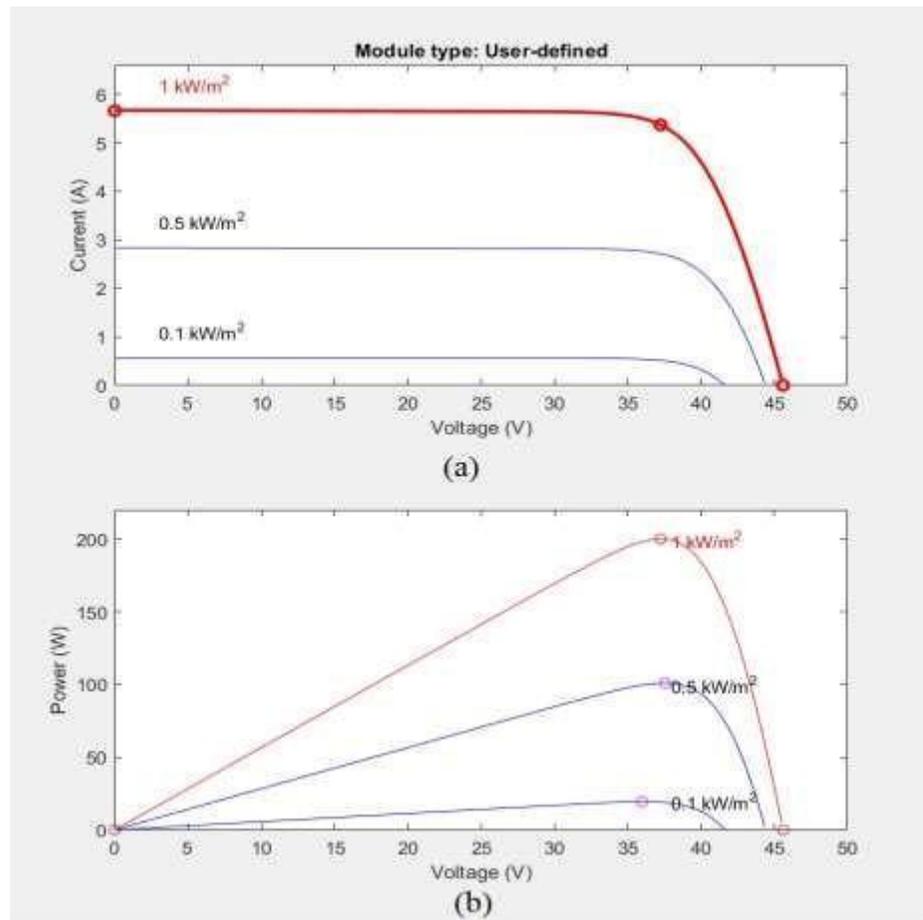
$$I_{PV} = N_p \times I_{mppt} = 3 \times 5.37 = 16.11 \text{ A}$$

$$P_{PV} = V_{PV} \times I_{PV} = 111.78 \times 16.11 = 1800 \text{ W}$$

I-V and P-V characteristics of the selected PV model under different temperatures  $25^{\circ}\text{C}$  and with  $45^{\circ}\text{C}$  are shown in Figure (3.3).

Three different values of irradiances  $1000 \text{ (W/ )}$  and  $100 \text{ (W/m}^2\text{)}$  are shown in Figure (3.3/a), while maximum output power with different irradiances is shown in Figure (3.3/b).

In the proposed system we propose the irradiances is constant at  $1000 \text{ (W/m}^2\text{)}$ , and the temperature constant at  $25^{\circ}\text{C}$ .



**Figure (3- 3) a&b): Characteristics proposed PV system under different irradiances**

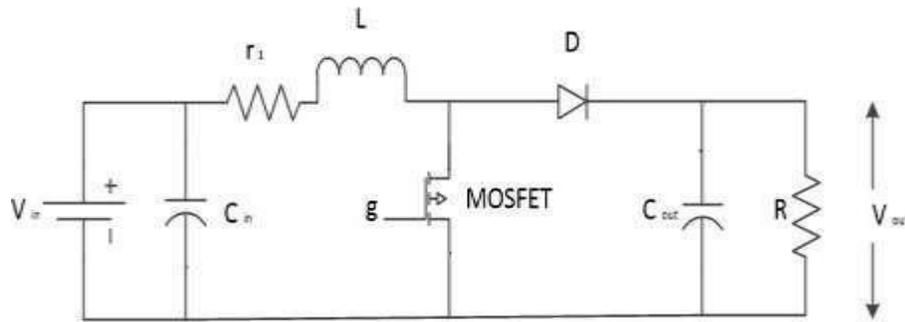
Table (I) shows the specifications of the proposed PV generator system.

**Table (I): Specifications of the proposed PV generator system.**

Parameters	Value	Unit
No. of Series Panel can be connected	3	-
No. of Parallel Panel can be connected	3	-
Total No. of Panel	9	-
Voltage of PV System at MPPT	111.78	V
Current of the PV System at MPPT	16.11	A
Total Rated Power	1800	W

### 3.3 DC-DC Boost Converter Design

In this work a unidirectional boost converter used to boost the DC voltage from 111.78 V to 220 V. This converter used the MPPT technique to extracts the maximum power generated from PV by adjusting the duty cycle (D). Figure (3.4) shows the equivalent circuit of unidirectional boost converter.



**Figure (3- 4) DC/DC Boost Converter**

The output voltage is assumed to be double of the input voltage to reduce the losses of high current in the circuit, and then the duty cycle (D) is given by:

$$D = 1 - \frac{V_{in}}{V_{out}} \quad (31)$$

Then the duty cycle D is 0.492 or 49.5%. The inductor and the output capacitor of the boost converter are given in the equations (32) and (33) respectively [4],

(32)

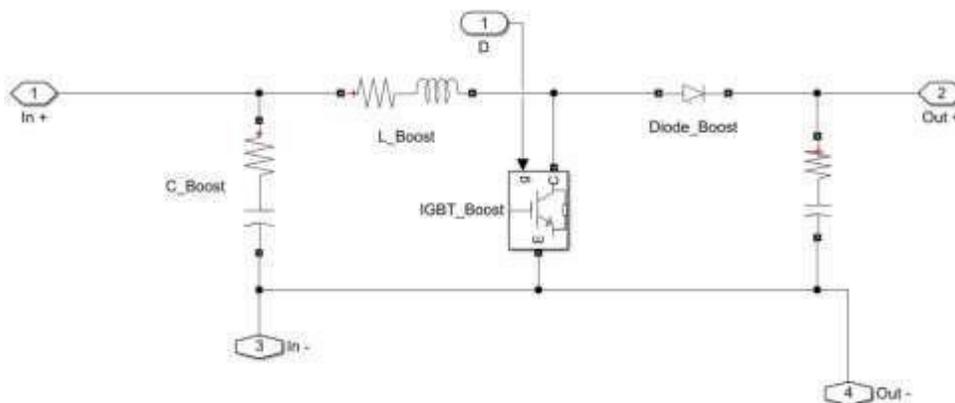
(33)

Where  $\left(\frac{\Delta V_o}{V_o}\right)$  outputs ripple voltage is 1% of the output voltage, R is output resistance and it equal to  $800^2 \text{ V}/1800 \text{ W} = 26.88\Omega$  and f is the switching frequency is 4000 Hz. the values of the input capacitor and the inductor resistance are assumed in this work. Table (II) shows specifications of the boost converter

**Table (II) Specifications boost converter, based on D =0.492 & F =4 kHz**

Parameters	Value	Unit
Inductor	0.42m	H
Capacitor	1.8 $\mu$	F
internal resistances assumed	0.001	$\Omega$
Input Capacitor assumed	1200 $\mu$	F

The DC-DC boost converter in MATLAB Simulink program is shown in Figure (3.5)



**Figure (3- 5) DC-DC Boost converter using MATLAB Simulink Program**

### 3.4 DC Link Capacitor

To minimize the voltage variation in dc link bus between the DC power converters, a parallel dc link capacitor is required; it also can keep the continuity of supply power to the inverter. To calculate the value of the DC-link capacitor  $C_{dc}$  the following expression is used:

$$C_{dc} = \frac{P_{in}}{2 w_{grid} V_{dc} V_{ripple}} \dots (34)$$

Where,  $P_{in}$  is the average power and it equal to 1800 W,  $w_{grid}$  is the angular frequency ( $2 \times \pi \times 50$ ), while the  $V_{dc}$  is the DC voltage across the DC-link capacitor, and  $V_{Ripple}$  is the peek value of the ripple voltage at it assumed to be 11 V about 5% as ripple percentage.

$$C_{dc} = \frac{1800 W}{2 * (2 * 50 * \pi) * 220 * 11} = 1.184 mF$$

DC capacitor link used in reduce the ripple in the voltage and make constant as possible, and it used between the DC converters such as between the DC-DC boost and inverter to make the input DC voltage of the inverter constant and reliable.

## 4. Results

### 4.1 Introduction

In this chapter we show results of the proposed system that shown in Figure (4.1). In the proposed system we propose the irradiances are constant at  $1000 (W/m^2)$ , and the temperature constant at  $25 ^\circ C$ . The system designed and implemented by using MATLAB / Simulink program. From chapter three the calculations of the PV output voltage and current is 111.78 V and 16.11 A respectively.

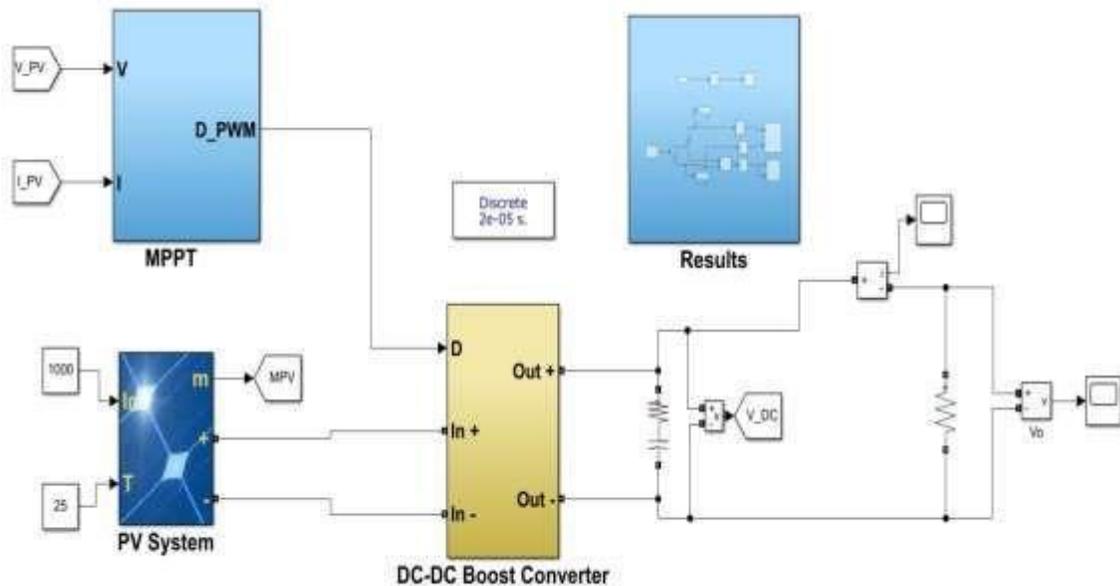
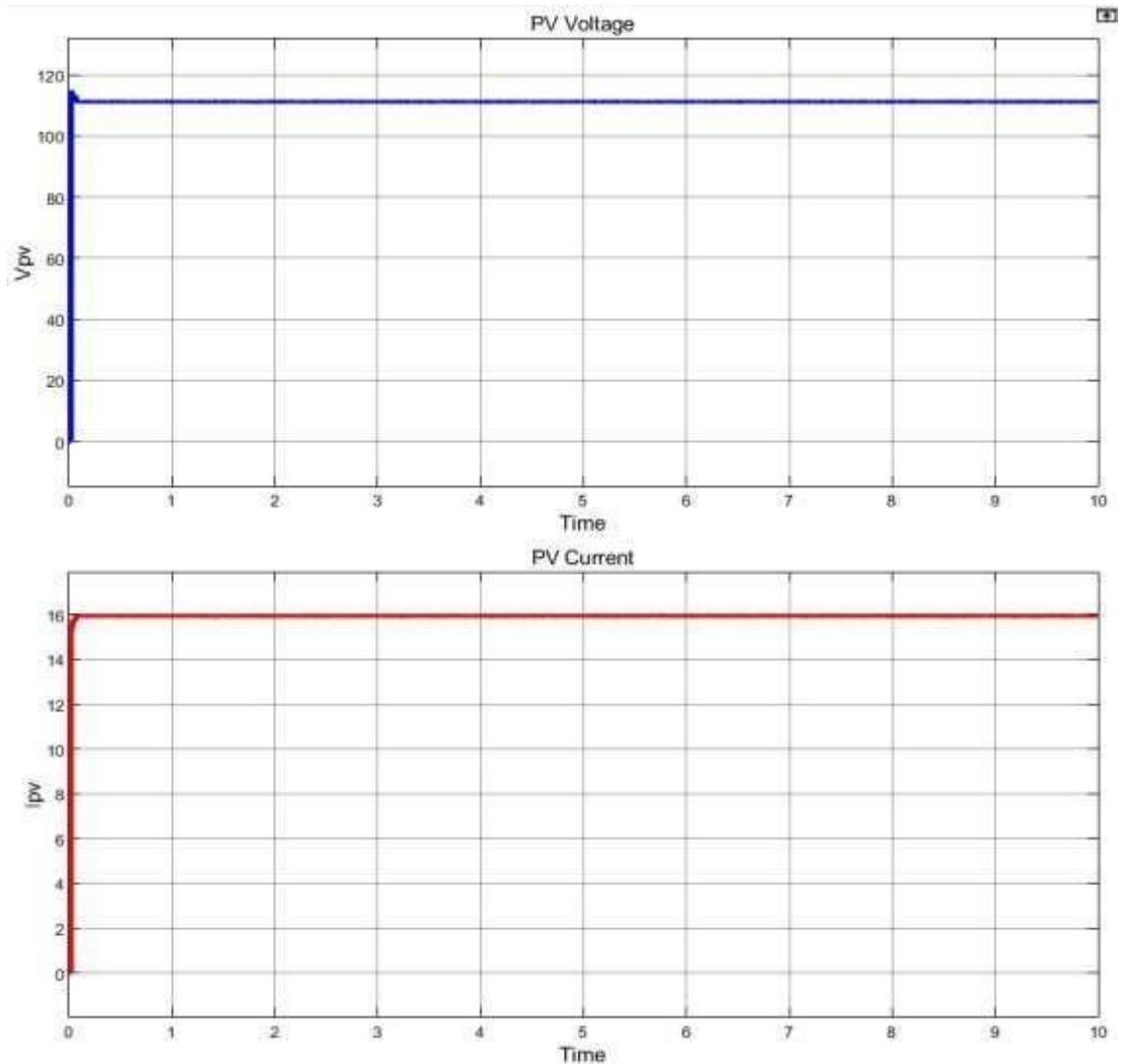


Figure (4- 1) the proposed PV system with DC-DC boost converter using MATLAB Simulink Program

Figure (4- 2) shows the output voltage and current of the proposed PV system.



**Figure (4- 3) shows the output voltage and current of the proposed PV system at Maximum Power Point Tracking**

Maximum power point tracking is a technique that used in solar systems to maximize the output power. There are many techniques satisfy the maximum output power, here in this work we will use Perturb-and-Observe (P&O) algorithm. The duty cycle of the boost converter can be vary to get the MPP, this method depend on the comparison between the previous and present values of power and voltage, which represent by  $\Delta P$  and  $\Delta V$ , when  $\Delta P/\Delta V$  is negative when the operating point is at the right side of MPP and vice versa. The output power at MPPT is shown in Figure (4.3). while the MATLAB Function of MPPT is given as below:

```
function D = PandO(V, I)
```

```
Dint = 0.42;
```

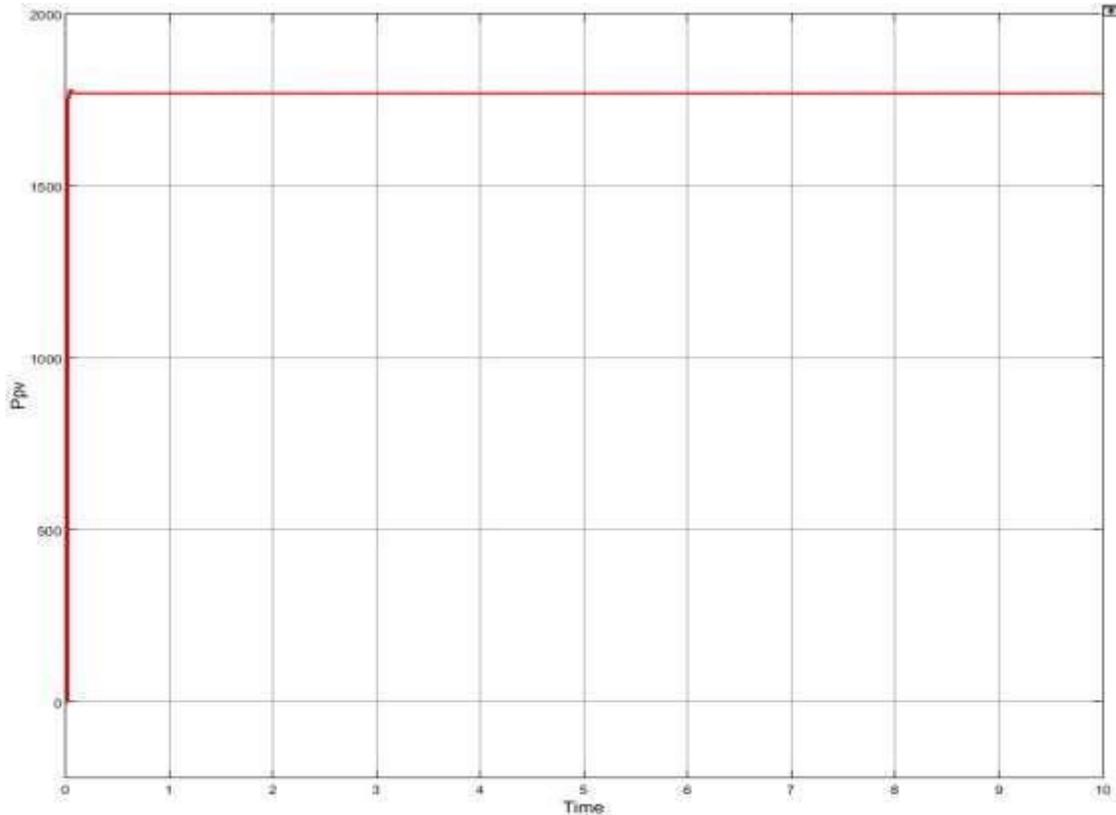
```
Dmax = 0.7; Dmin = 0.3; deltaD = 1/10000; persistent Vpre Ppre Dpre; dataType = 'double'; if isempty(Dpre)
```

```
Dpre = Dint;
```

```
Vpre=0; Ppre=0; end P= V*I; dV= V - Vpre; dP= P - Ppre; if dP < 0 if dV < 0 D = Dpre - deltaD; else if dV > 0 D = Dpre + deltaD; else D=Dpre; end end else if dV < 0 D = Dpre + deltaD; else if dV > 0 D = Dpre - deltaD; else D=Dpre; end end end if D >= Dmax || D<= Dmin D=Dpre; end Dpre=D;
```

$V_{pre}=V;$

$P_{pre}=P;$



**Figure (4- 4) Maximum output Power of the PV system**

The output voltage is rest to be 220 V and it shown in Figure (4.4) below:

### 5.1 Conclusion

One of the most promising technologies for the production of electric energy is the photovoltaic (PV), which over the last few years has shown the greatest development in comparison with other types of renewable energy sources.

In most PV systems, the voltage at which the power is generated by the PV modules differs from the operational voltage of the loads. Furthermore, if the PV system contains MPPT logic, the maximum power point voltage might vary throughout the day. Therefore a component is required in the PV system to convert the output voltage (and current) of the PV modules. Additionally, if the PV system is grid-connected, or if certain types of loads are connected, the power has to be converted from direct current (DC) to alternating current (AC).

The project presents the methodology for calculating and choosing the main elements of an autonomous PV system; a boost DC–DC converter and a MPPT controller. The parameters of the converter are selected on the basis of calculation and analysis of the possible range of voltage changes at the point of maximum power under constant irradiance and temperatures conditions. The parameters of the MPPT controller are selected based on the calculated value of the converter time constant and the nature of its electrical load.

### References:

1. Abdelaziz Salah Saidi, “Impact of large photovoltaic power penetration on the voltage regulation and dynamic performance of the Tunisian power system”, Energy Exploration & Exploitation, 2020.

2. International Energy Agency, Global EV Outlook 2021 Accelerating ambitions despite the pandemic Available online: <https://www.iea.org/> 2021.
3. Deekshith K , Dhruva Aravind , Nagaraju H , Bhaskar Reddy,” Solar tracking system” International Journal of Scientific & Engineering Research, Volume 6, Issue 9, September-2015.
4. Milad Samady Shadlu,” Comparison of Maximum Power Point Tracking (MPPT) Algorithms to Control DC-DC Converters in Photovoltaic Systems” Recent Advances in Electrical & Electronic Engineering, 2019.
5. “Introduction to Photovoltaic Systems”, RENEWABLE ENERGY THE INFINITE POWER OF TEXAS, SECO FACT SHEET NO. 11
6. <https://www.seia.org/initiatives/photovoltaics>
7. Adam Palumbo, “Design and Analysis of Cooling Methods for Solar Panels” Master thesis, YOUNGSTOWN STATE UNIVERSITY, December, 2013.
8. P. Selvabharathi S. Veerakumar I V. Kamatchi Kannan,” SIMULATION OF DC-DC CONVERTER TOPOLOGY FOR SOLAR PV SYSTEM UNDER VARYING CLIMATIC CONDITIONS WITH MPPT CONTROLLER” IOP Conf. Series: Materials Science and Engineering, 2021.
9. Nor Hanisah Baharudin , Tunku Muhammad Nizar Tunku Mansur , Fairuz Abdul Hamid , Rosnazri Ali and Muhammad Irwanto Misrun,” Topologies of DC-DC Converter in Solar PV Applications” Indonesian Journal of Electrical Engineering and Computer Science Vol. 8, No. 2, NovemBA.
10. Marrekchi, S. Kammoun, S. Sallem, M. B. A. Kammoun. A practical technique for connecting PV generator to single-phase grid. Sol. Energy. 2015; 118: 145–154er 2017.
11. Sudha Bansal, Lalit Mohan Saini and Dheeraj Joshi,” Design of a DC-DC Converter for Photovoltaic Solar system” IEEE, 2012
12. Shah Fahad, Nasim Ullah, Ali Jafer Mahdi, Asier Ibeas ans Arman Goudarzi,” An Advanced Two-Stage Grid Connected PV System: A Fractional-Order Controller” International Journal of Renewable Energy Research, Shah Fahad, March, 2019.

## References

13. Ayas Shaqour, Hooman Farzaneh, Yuichiro Yoshida and Tatsuya Hinokuma, “Power control and simulation of a building integrated stand-alone hybrid PV-windbattery system in Kasuga City, Japan” Published by Elsevier Ltd, Energy Reports 6 (2020) 1528–1544 , 2020,
14. <https://how2electronics.com/dc-to-dc-converters-design-working-applications/>
15. Karrar S. Faraj, Jasim F. Hussein,” Analysis and Comparison of DC-DC Boost Converter and Interleaved DC-DC Boost Converter” Engineering and Technology Journal Vol. 38, Part A (2020), No. 05, Pages 622-635, 2020
16. “Power Electronics” handbook, Daniel W. Hart, Valparaiso University,2010.
17. E. A. Hameed, “Study of Grid-Connected Photovoltaic System,” M.Sc. thesis, Department of Electrical Engineering, Mustansiriyah University, Baghdad, 2019.
18. A. Y. Mohammed, “Modeling and Simulation of 1MW Grid Connected Photovoltaic System,” M.Sc. thesis, Department of Electrical Engineering, University of Technology, Baghdad, 2017.
19. Daniel W. Hart, “Power Electronics” Handbook, Pearson Education, Inc, McGraw Hill 2014.

20. A. A. Jasim, "Power Quality Examination and Improvement for PV Grid-Tied System in Iraqi Distribution Network," M.Sc. Thesis, Department of Electrical Engineering, University of Technology, 2021.
21. S. Fahad, A. J. Mahdi, W. H. Tang, K. Huang, and Y. Liu, "Particle Swarm Optimization Based DC-Link Voltage Control for Two Stage Grid Connected PV Inverter," Int. Conf. Power Syst. Technol. POWERCON, 2019, pp. 2233–2241.