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Design, Simulation and Implementation of An Efficient Dc-Dc Converter For Solar Energy

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TABLE OF CONTENTS

ACKNOWLEDGEMENT	I
CONTENTS TABLE	II
FIGURES LIST	IV
TABLES LIST	VII
ABREVIATIONS LIST	VIII
SYMBOLS LIST	IX
GENERAL INTRODUCTION	2
CHAPTER I: State of the art of photovoltaic systems	
I.1. Introduction	5
I.2. Photovoltaic cell	5
I.2.1. PV cell structure	6
I.2.2. Manufacturing technique	6
I.2.3. Operating principle	9
I.3. PV-module (PVM)	10
I.3.1. The connection PVM-LOAD	11
I.3.2. The factors influence on PVM	12
I.3.3. The protection of PVM	12
I.4. Converter DC-DC	13
I.4.1. Mode operations and Specifications	13
I.4.2. Specifications	14
I.4.3. DC-DC Topologies	15
I.5. MPPT Controller	18
I.5.1. The MPPT algorithm	18
I.6. State of the art of DC-DC converter	19
I.7. Conclusion	24
CHAPTER II: Modeling and Simulink of the buck-boost converter	
II.1. Introduction	26
II.2. System modulation	26
II.2.1. Pv-cell	26
II.2.2. Buck-boost converter	30
II.2.3. Perturb and observe MPPT method	34

II.3. Buck-boost converter simulation	36
II.3.1. *SIMULINK*- parameter	36
II.3.1. *SIMULINK*- results	37
II.3.2. Discussing the results	40
II.3. Conclusion	41
CHAPTER III: Experimental validation of the proposed system	
III.1. Introduction	43
III.2. Component	43
III.2.1. Software section	43
I.2.2. Hardware section	46
III.3. Experimental results	52
III.3.1. Buck-boost	52
III.3.2. The MPPTc	54
III.4. Conclusion	55
GENERAL CONCLUSION	57
BIBIOGHRAPHY	59

FIGURE LIST

CHAPTER I: State of the art of photovoltaic systems	
Figure I.1. Solar photovoltaic sysrem	5
Figure I.2. Photovoltaic cell	6
Figure I.3. Amorphous cell	7
Figure I.4. Monocrystalline cell	8
Figure I.5. Multi-crystalline cell	9
Figure I.6. PV-module	10
Figure I.7. Direct connection	11
Figure I.8. Indirect connection	11
Figure I.9.The variation of (V-P) and (V-I)	12
Figure I.10. The variation of (V-P)	12
Figure I.11. Buck converter	15
Figure I.12. Boost converter	16
Figure I.13. Buck-boost converter	17
CHAPTER II: Modeling and simulation of the buck-boost converter	
Figure II.1. PVC without illumination	26
Figure II.2. PVC with illumination	27
Figure II.3. PVC with illumination and resistances	27
Figure II.4. (I-V) characteristics of PV-module	29
Figure II.5. (P-V) characteristics of PV-module	29
Figure II.6. Buck-boost converter	30
Figure II.7. Mode operation circuit	30
Figure II.8. Inductance voltage waveform	31
Figure II.9. Inductance current waveform	31
Figure II.10. Operating principle of PO method	34
Figure II.11. The flowchart of PO mppt method	35
Figure II.12. Buck-boost SIMULINK-model	36
Figure II.13. The duty cycle variation	37

Figure II.14. Input and output voltage 37
Figure II.15. The mosfet (V-I) variation 37
Figure II.16. The inductor (V-I) variation 38
Figure II.17. The diode (V-I) variation 38
Figure II.18. The capacitor (V-I) variation 38
Figure II.19. The duty cycle variation 39
Figure II.20. Input and output voltage 39
Figure II.21. The mosfet (V-I) variation 39
Figure II.22. The inductor (V-I) variation 39
Figure II.23. The diode (V-I) variation 40
Figure II.24. The capacitor (V-I) variation 40

CHAPTER III: Experimental validation of the proposed system

Figure III.1. Arduino. 43
Figure III.2. MATLAB. 45
Figure III.2. Pv module. 46
Figure III.3. Arduino UNO. 47
Figure III.5. The buck-boost circuit implement. 48
Figure III.6. MOSFET. 48
Figure III.7. Rectifier. 49
Figure III.8. Capacitor. 49
Figure III.9. Resistor. 50
Figure III.10. Inductor. 50
Figure III.11. Optocoupler. 50
Figure III.12. Voltage sensor. 51
Figure III.13. current sensor. 51
Figure III.14. Full system setup. 52
Figure III.15. The tension variation with D=40%. 53
Figure III.16. The tension variation with D=70%. 53
Figure III.17. The duty cycle variation. 54

Figure III.18. The current Ipv variation. 54

Figure III.19. The voltage Vpv variation. 54

Figure III.20. The power variation. 54

TABLES LIST

CHAPTER II: Modeling and simulink of the buck-boost converter

Table II.1. SIMULINK-parameter	36

CHAPTER III: Experimental validation of the proposed system

Table III.2.The buck-boost elements value.	47
Table III.3. The buck-boost test with different D.	52

ABREVIATIONS LIST

MPPT……………………Maximum Power Point Tracking

DC ………………………Direct Current

AC ………………………Alternating Current

IGBT ……………………Insulated Gate Bipolar Transistor

PI ………………………. Proportional Integral

PV ……………………...Photovoltaic

PWM …………………...Pulse Width Modulation

C-Si ……………………..Crystalline silicon.

mono-Si ………………..monocristalline Silicon.

multi-Si …………………multicristalline Silicon.

CIGS ……………………Copper indium gallium selenide solar cells.

CdTe ……………………Cadmium telluride photovoltaic.

CCM ……………………Continuous conduction mode.

DCM ……………………Discontinuous conduction mode.

PECVD ………………...Plasma-Enhanced Chemical Vapor Deposition.

SYMBOLS LIST

A …………………………………………..Ampere.

C …………………………………………..Capacitor.

W …………………………………………..Watt.

V………………………………………….. Volt.

L …………………………………………..Inductor.

%………………………………………….. Percent.

P …………………………………………..Puissance.

R …………………………………………..Resistance.

Ω …………………………………………..Ohms.

R_s *…………………………………………..series resistance.*

R_{sh} *…………………………………………..shunt resistance.*

I_{sc}*………………………………………….. short-circuit current.*

I_{MPP} *…………………………………………..MPP current.*

V_{MPP}*………………………………………….. MPP viltage .*

V_{oc}*………………………………………….. Open circuit voltage.*

V_{PV}*………………………………………….. Voltage of the PV panel.*

N_s*………………………………………….. The series cells.*

N_p *…………………………………………..The parallel cell.s*

I_{cell} *…………………………………………..cell currant in darkness.*

I_D *…………………………………………..Diode currant.*

I_{rs} *…………………………………………..Saturation current dependent on the temperature T and electrical and technological parameters of the PN junction.*

K …………………………………………..Boltzmann constant.

Q …………………………………………..Charge of the electron.

T …………………………………………..Junction temperature in K.

V_D …………………………………………..Photocell current, proportional to illumination.

D …………………………………………..Duty cycle.

I_o …………………………………………..Output current of the DC-DC converter.

V_o …………………………………………..Output Voltage of the DC-DC converter.

ΔV …………………………………………..Step size in voltage.

dP …………………………………………..Difference in power.

Dv …………………………………………..Difference in voltage.

dI …………………………………………..Difference in current.

f …………………………………………..Switching frequency.

GENERAL
INTRODUCTION

GENERAL INTRODUCTION

One of the most important sources of renewable energy nowadays which have caught the attention of many is the 'Solar Energy' and it is through harnessing this energy that we are meeting some of our energy demands. It is a known fact nowadays that non-renewable resources such as coal, oil and other such sources are almost on the verge of termination. On the other hand, renewable energy sources such as the solar energy are plentiful and it has the greatest availability compared to other energy sources. Solar energy is clean and free of emissions, since it does not produce pollutants or by-products harmful to nature therefore it is nowadays a booming industry of research, where new and more efficient modes of harnessing solar energy is a challenge.

The conversion of solar energy into electrical energy has many application fields. There are mainly two ways in which the solar to electrical conversion can be done, solar thermal and solar photovoltaic. In terms of Solar thermal, it is the conventional AC electricity generation produced by steam turbine; heat extracted from intense solar ray is used to produce steam and apart is stored in thermally insulated tanks for usage during lack of sunshine or night time. Solar photovoltaic use cells made of silicon or certain types of semiconductor materials which convert the light energy absorbed from incident sunshine into DC electricity. To make up for intermittency and night time storage of the generated electricity into battery is needed.

Modern electronic systems require high quality, compact, light-weight, reliable and efficient power supplies. For conventional low-power applications, the linear voltage regulators have generally been used. These linear regulators work on the principle of voltage divider circuit. The linear regulator can provide the output voltage only lower than the input voltage. Moreover, their energy conversion efficiency and power density are also low. This makes them unsuitable for high power applications. For higher power applications, switching mode DC-DC converters are used.

The switching mode DC-DC converters use the power semiconductor switches, which either operate in saturation or cut off region. Since the power loss is very small in these switches during the operation, the switching mode DC-DC converters can achieve higher energy conversion efficiency. Further, the modern semiconductor devices can operate at high frequencies leading to overall compact size due to reduction in the inductor and capacitor values. The switching mode DC-DC converters are now extensively used in the variety of industrial as well domestic applications owing to the advantages of controllable output voltage, compact size, light-weight and higher conversion efficiency. Some of these applications include computer power supplies, aerospace instruments, fuel cells, medical instruments, power factor correction schemes, battery chargers, variable speed dc motor drives, telecommunication equipment's, electrical vehicles, military instruments, chemical refineries, etc. It is desirable to have minimum losses in the DC-DC converters while converting one level of DC voltage to another level. Therefore, to reduce the power losses, only inductors and capacitors are used in DC-DC converters (because ideally, they have no losses). These passive components along with the semiconductor switches are assembled in different ways to obtain various topologies, each one having different properties.

Therefore, to make PV generation efficient, a competent maximum power point tracking (MPPT) technique is required to predict and to track the MPP under any weather conditions and fix the operating point of the PV system at the MPP. Maximum power point tracking (MPPT) is a well-established algorithm in PV applications to extract the maximum power from the PV panel. The maximum power transfer theorem states that, to extract maximum external power from a PV panel with finite internal impedance, the impedance of the load must equal the impedance of the PV panel source as viewed from its output terminals. Furthermore, the output characteristics of a PV solar panel depends on many operating conditions such as: irradiance, temperature, spectral of characteristics of the sunlight, dirt, and shadows. Therefore, a proper converter and selection of an efficient and proven (MPPT) algorithm are required to achieve and transfer the maximum power from the PV panel to the load under any weather conditions.

The main purpose of this work is to develop and implement an efficient buck-boost converter which are able to step-up/down the voltage from the *PV* generator.

This thesis includes a general introduction, three chapters and general conclusion. Next, an overview of each chapter is given as follows:

In the first chapter, the principal conversion of the solar energy into electrical energy is stated. Then, the effect of the partial shadowing condition with the *I-V* and *P-V* characteristics curves is studied where, the different connections between the *PV* panel and the load are discussed. Thereafter, the different mode operation, specifications and topologies of the non-isolated *DC-DC* converters such as boost, Buck and Buck-Boost, presented. At last, we talked about MPPT controller and his algorithms. Finally, a state of art about DC-DC converter.

In chapter two, the mathematical modeling of solar cells, power converters and the control algorithm are discussed. And then we simulated the power converters, in which the signals of the tension and current are discussed.

In chapter III, the mathematical model of the proposed system is Implemented via MATLAB *Simulink*. The chapter included two sections; the first part includes the software description, where the second part include the hardware description, finally, the obtained results from the experimental tests are presented and discussed presented the results and discussed them.

CHAPTER I

State of the art of photovoltaic systems

I.1. Introduction:

In the field of energy solar, the identification of the photovoltaic conversation system is required. This allows to qualify the technological process of achieving the system. On the other hand, analyzing the optimal functioning, as well as the aging of conversation chain. This form of energy is already exploited in many countries, especially in countries or regions that do not have conventional energy resources such as hydrocarbons or coal.

The accurate modeling systems are required also to design and implement the appropriate photovoltaic system to track the maximum power point (MPP).

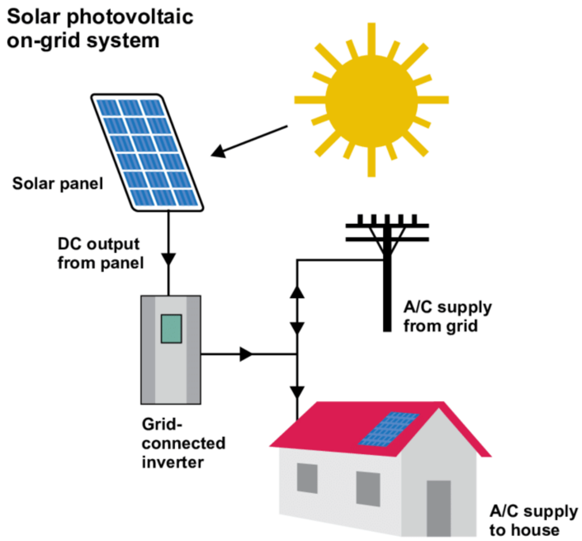

Figure I.1. *Solar photovoltaic system.*

I.2. Photovoltaic cell:

The photovoltaic cells are (PVCs) semiconductor devices; they are usually made of silicon in its various forms. They do not implement any fluid and do not contain corrosive substances and no mobile piece.(N.Duncan & K.S. Robert, 1995)

They produce electricity as long as they are exposed to solar radiations.(N.Duncan & K.S. Robert, 1995)

They do not require virtually no maintenance; they do not pollute and produce no noise. Photovoltaic cells are thus the safest and most ecologically to produce energy.

I.2.1. PV cell structure:

The basic structure of a photovoltaic cell (PVC)is a PN junction consisting a P-doped semiconductor crystal is covered with a thin doped region.(S.Streetman & B.G. Banerjee, 1995)(S.Streetman & B.G. Banerjee, 1995) Between the two areas develops a junction. The area N is covered by a metal grid that serves as the cathode, while a metal plate covers the other face of the crystal and plays the role of anode. The total thickness of the crystal is of the order of a millimeter.(A.Yamamot, Noda, & Sasaki, 1997)(Özbay, 1994)

The following figure (I.2) represented the PVC. (Mr.radjai, 2017)

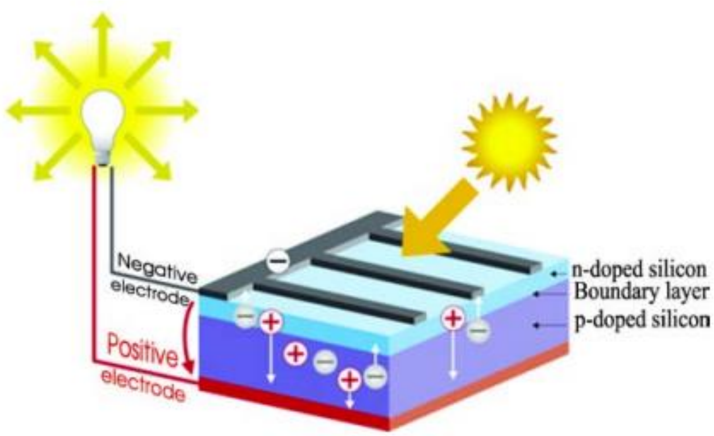

Figure I.2. *Photovoltaic cell.*

I.2.2. Manufacturing technique:

The solar cells are classified into three generations.(M.Grätzel, 2003)(Green, 2004)

a. First generation: also called conventional, traditional or wafer-based cells are made of crystalline silicon, that includes materials such as Polysilicon and Monocrystalline silicon.

b. Second generation: thin film solar cells, that include amorphous silicon, CdTe (Cadmium telluride photovoltaic) and CIGS (Copper indium gallium selenide solar cells) are widely present in the market used in standalone devices, photovoltaic power stations etc...

c. Third generation: includes a number of thin-film technologies often described as emerging photovoltaic, this generation is not yet been commercially applied, currently is still in the research or development phase.

The silicon is currently the most widely used to manufacture photovoltaic cells material. There are two main types of silicon cells:

a. Amorphous silicon cells:

The amorphous silicon solar cells are fabricated by vacuum deposition, from several gases, one of the most used techniques are PECVD (Plasma-Enhanced Chemical Vapor Deposition). The cell is very dark gray. This is the cell used in calculators and watches.(Streetman & Banerjee, Solid state electronic devices, 1995)(Sha, 2003)

The following Figure (I.3) represented the Amorphous cell.

Figure I.3. *Amorphous cell.*

Advantages of amorphous silicon cell are:

- ✓ Functions with low or diffuse illumination.
- ✓ integration on flexible or rigid substrates.

Drawbacks of amorphous silicon cell are:

- ✓ Low yield in the sun, from 5% to 7%.(Vandermersch M. , 2009)
- ✓ Need to cover larger areas than when using crystalline silicon (lowest ratio around 60(Wp / m2).(Ricaud, 2005)
- ✓ Performances which decrease with time in the early days of exposure to natural light.(E.I.Rath, R. Brinza, & Schropp, 2009)

b. Crystalline silicon cells.

The most prevalent bulk material for solar cells is crystalline silicon (C-Si), The crystalline silicon produced in the form of purified bars, of round section, square, or pseudo square, which are then cut into chips of approximately 0.2 mm thickness, dimensions 10 x 10 or 15 x 15 cm e.g.(Markvart, 2000)The realization technological process of crystalline silicon solar cells are largely based on the manufacture of electronic semiconductor devices, these cells are entirely based around the 8 concept of a P-N junction. Solar cells made of C-Si are made from wafers between 160 to 240 micrometers thick.(Grätzel, 2003)-(Mouhoub.A, 2001). Crystalline silicon (C-Si) is can be encompassing monocrystalline silicon (mono-Si) and multi-crystalline silicon (multi-Si).

b.1. Monocrystalline silicon cells:

Monocrystalline silicon (mono C-Si) is a form in which the crystal structure is homogenous throughout the material; the orientation, lattice parameter, and electronic properties are constant throughout the material.(M.A.Green, 2004)This monocrystalline material, while useful, is one of the chief expenses associated with producing photovoltaic where approximately 40% of the final price of the product is attributable to the cost of the starting silicon wafer used in cell fabrication.(Campbell.S.A, 1996)

The following figure (I.4) represented the monocrystalline cell.

Figure I.4. *Monocrystalline cell.*

Advantages of the monocrystalline silicon:

- ✓ There are a lot of manufacturers in the world.
- ✓ High efficiency from 14% to 16% (~ 150 Wc / m2).(Vandermersch, 2009)(M.Vandermersch, 2009)

Drawbacks of monocrystalline silicon:

- ✓ Lower efficiency under low light or diffuse illumination.
- ✓ Lower efficiency with increasing temperature.
- ✓ Expensive.

b.2. Multi-crystalline silicon cells:

It consists of crystals from 1mm to about 2mm assembled called grains. This material, somewhat less expensive, is made in large industrial crucibles by melting and cooling purified silicon blocks.(.A, 2005)

The following figure (I.5) represented the multi-crystalline cell.

Figure I.5. *Multi-crystalline cell.*

The advantages multi-crystalline silicon:

- ✓ Square cell allowing greater abundance in a module.
- ✓ Bullion cheaper to produce than monocrystalline.
- ✓ Average efficiency from 12% to 14%.

Drawbacks of multi-crystalline silicon:

- ✓ Lower efficiency under low light or diffuse illumination.

I.2.3. Operating principle:

A solar cell is an electronic component that converts sunlight into electricity. its operating principle is based on the photovoltaic effect discovered by Alexandre Edmond Becquerel in 1839. This conversion involves three physical phenomena, interrelated and simultaneous,(S.Astier, 2008) can be described by the following mechanisms:

- ✓ Absorption of incident photons (optical absorption) and creation of electron-hole pairs if the incident photon energy is greater than the gap of the material.
- ✓ Diffusion of minority charge carriers to the space charge zone. Transfer of electric charges in the area where they will be the majority, through the electric field that present in the space charge region of the PN junction and collect. During the diffusion of charges to the space charge zone, the electric charges can recombine and be lost.
- ✓ Power dissipation in the load and in the parasitic resistances.

It is therefore essential that the material used possesses specific optical and electrical properties to enable photovoltaic conversion.(A.Ricaud, 2005)

I.3. PV-module (PVM):

A cell of a few tens of square centimeters delivers a maximum of a few watts with a voltage less than one volt (PN junction voltage). To produce more power, more cells must be assembled to create a Pv-module (PVM) or photovoltaic panel. The series cell connection increases the voltage of the assembly, while the parallel connection allows increasing the current. The serial / parallel connection is used to obtain the desired characteristics of PV generator (PVG). Most commercial models are made up of two to four networks of cells connected in series, each of these sub-networks is itself composed of a group of cells connected in series (18 12 cells for the Sentech 85W PV module). The number of cells in each sub-network is an economical compromise between protection and significant power losses of the PV module in partial shading case.(Mr.radjai, 2017)

The following Figure (I.6) represented the PVM.

Figure I.6. *PV-module.*

I.3.1. The connection PVM-LOAD:

There is tow connection between PVM-LOAD:(Mr.radjai, 2017)

a. Direct connection:

The direct connection between the PVM and the load is mainly related to the simplicity, reliability and low cost of the operation. However, this configuration does not offer any possibility to limit or control the load voltage, which restricts to the applications requiring a fixed voltage or slightly variable. However, a closer examination of this configuration shows that even in this case, the electrical energy available at the terminals of the PV panel is highly dependent on the climatic conditions. As mentioned before, the PV panel voltage VPV changes with the change of the temperature. The power extracted from the PVM connected directly to a load is often far from the maximum power that can be delivered by the PVM.

The following Figure (I.7) represented the direct connection.

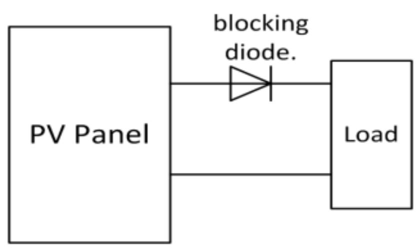

Figure I.7. *Direct connection.*

b. Indirect connection:

By intermediate stage (DC-DC converter), which is used as a power interface between the PVM and the load, to adapt them with each other and with raising/lowering of the PV output voltage.

The following Figure (I.8) represented the indirect connection

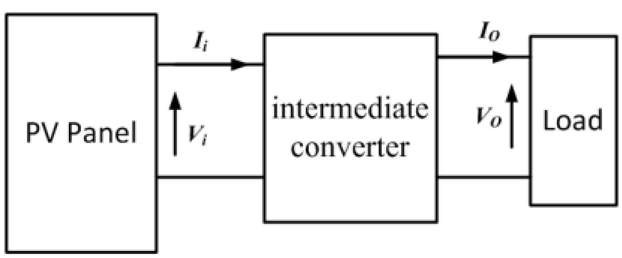

Figure I.8*. Indirect connection.*

I.3.2. The factors influence on PVM:

Electrical characteristics of PV modules are affected by many factors such as temperature, solar irradiance, dust and shading caused by birds, clouds and aging.

All those factors affect the performance and efficiency of the PV module.

The figure (I.9) shows the variation (V-P) and (V-I) with fixed temperature and variable irradiation.

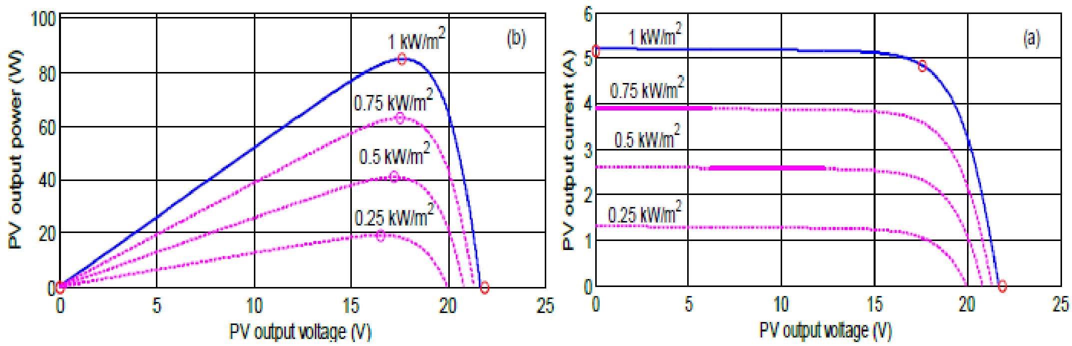

Figure I.9.The variation of (V-P) and (V-I).

The figure (I.10) shows the variation of (V-P) with variable temperature and fixed irradiation.

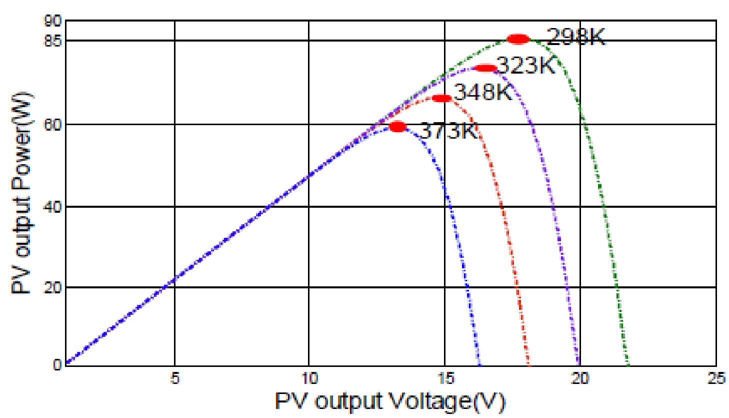

Figure I.10. The variation of (V-P).

I.3.3. The protection of PVM:

To guarantee a long lifetime of a photovoltaic installation intended to produce electrical energy over years, electrical protection must be added to the modules to avoid destructive failures due to the combination of cells in series and panels in parallel. For this purpose, two types of conventional protection are used in current installations.

a. the non-return diode-preventing negative current in the PVM. This phenomenon can occur when several modules are connected in parallel, or when a load in direct connection can switch from receiver mode to generator mode, for example a battery at night.

b. by-pass diodes- can isolate a sub-network of cells when the illumination is not homogeneous (shading effect) thus avoiding the appearance of hot spots and the destruction of poorly lit cells.(N.Femia, et al., 2008)

I.4. Converter DC-DC:

A DC-DC converter is an electronic circuit which converts a source of DC from one voltage level to another. Most DC-DC converters also regulate the output voltage. Voltage regulation is required for two reasons: the voltage on the storage element may change depending on the rate of power generation and usage (and may change a lot if the storage element is a capacitor). In addition, the load electronics may request a particular voltage to be supplied in order to minimize its power consumption.

The basic usage of DC/DC converters is to provide regulated DC voltage at the output from an unregulated DC voltage at the input. Voltage regulation is required for two reasons: the voltage on the storage element may change depending on the rate of power generation and usage (and may change a lot if the storage element is a capacitor). In addition, the load electronics may request a particular voltage to be supplied in order to minimize its power consumption. Some exceptions include high efficiency LED power sources which are kind of DC-DC converters that regulate the current through the LEDs and simple charge pumps which simply double or triple the input voltage.

Switching concept is used to control the output voltage of DC-DC converters. Earlier the DC-DC converters were known as Choppers with Silicon Controlled Rectifiers (SCRs) used for switching. Nowadays DC-DC converters generally use Metal Oxide Silicon Field Effect Transistors (MOSFETs) as a switching element, because they have better switching capabilities.(Al.Hassan.F, 2011)

I.4.1. Mode operations and Specifications:

The DC-DC converter operate on two modes:(Biswal, 2011)

a. Continuous conduction mode (CCM):

When the inductor current flow is continuous of charge and discharge during a switching period, it is called Continuous Conduction Mode (CCM).

b. Discontinuous conduction mode (DCM):

When the inductor current has an interval of time staying at zero with no charge and discharge then it is said to be working in Discontinuous Conduction Mode (DCM).

I.4.2. Specifications:

The DC-DC converter specifications are:(Foong.chian.huey, 2013)

a. Efficiency:

Efficiency is defined as:

Efficiency (%) = $\frac{Output\ power}{Input\ power} \times 100$

Efficiency is generally measured across different load current and line voltage.

b. Switching Frequency:

His is the fundamental frequency at which the DC-DC converter operates. It is typically the frequency of the Pulse-Width-Modulation (PWM) signal.

c. Line Regulation:

When the input voltage is changed from rated maximum to rated minimum while the outputs are at full load, the output voltage will also change. Line regulation is the percentage change in output voltage when the input is varied.

d. Load Regulation:

When the output load is changed from maximum rated current to minimum rated current, the output voltage changes. Load regulation is the percentage change in output voltage. For multiple output supplies, each output is measured while the loads are varied.

e. Output Ripple:

Output voltage ripple refers to the phenomenon where the output voltage rises during the on-state and falls during the off-state. Several factors contribute to the output ripple including the switching frequency, the output capacitance and inductance, load and line current, and any current limiting features of the control circuitry. At the most basic level the output voltage will rise and fall as a result of charging and discharging of the output capacitor.

f. Dynamic Response:

When a load is applied, the output voltage momentarily exceeds its final value. This overshoot is the dynamic response. It is a measure of the converter's high frequency output impedance. This specification is generally more important than the settling time of the output, which is also known as the transient response time.

I.4.3. DC-DC Topologies:

The electrical components can be combined and connected to each other in different ways, each one having different properties, buck, boost, and buck-boost converters are three basic converter topologies.

a. Buck converter:

A Buck converter is a switching power supply that converts a DC voltage into another DC voltage of lower value.(Du.X, Zhou.L, & M.Tai.H, 2009)(Hwu.K.I & J.T.Peng)

Therefore, the output voltage magnitude is always smaller than the input voltage magnitude.

An electric schema of the Buck power stage is depicted in figure (I.11).

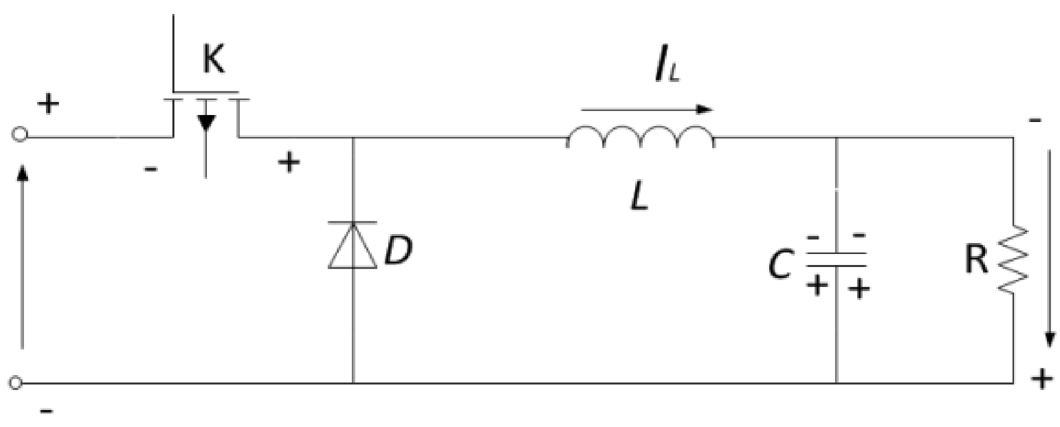

***Figure I.11**. Buck converter.*

a.1. The buck converters advantages are:

- ✓ Is very simple and need only one power switch (IGBT).
- ✓ The price and size of the Buck converter are low.
- ✓ Has large tolerance in the line voltage tolerance.
- ✓ The Buck regulator has good efficiency.

a.2. The buck converter disadvantages are:

- ✓ The output voltage ripple is high.
- ✓ The filter in the output is required.
- ✓ Has a slow response in the transient conditions.

b. Boost converter:

A Boost converter is a DC-to-DC converter with an output voltage greater than the source voltage.(Viswanathan, K.Oruganti, & R.D.Srinivasan, 2005)(Zhang & F.J.Xu, 2011)

A Boost converter is sometimes called a step-up, used to increase the voltage available from a continuous source such as PV panels, batteries, fuel cell ...etc. Therefore, the input voltage magnitude is always smaller than the output voltage magnitude. An electric schema of the Boost power stage is depicted in Figure (I.12).

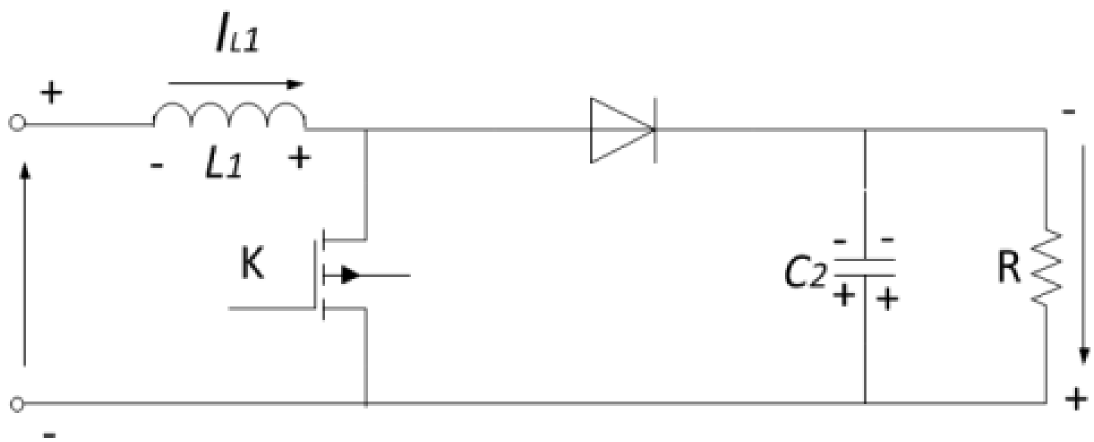

Figure I.12. *Boost converter.*

b.1. The boost converter advantages are:

- ✓ The output voltage is equal to/or greater than its outputs, that helps to connect a low voltage source with high voltage load.
- ✓ The circuit design of the converter is simple and easy of implementation, where a few components are required compared with others topologies.
- ✓ The polarity of the output voltage of the converter is also not inverted and thus it has simpler electronic circuit connection.(Kazimierczuk & K.Marian, 2015)
- ✓ Unidirectional output current.
- ✓ High efficiency.

- ✓ Low cost, only has one switch.
- ✓ The input current has a continuous (non-pulsating) waveform.
- ✓ It is easy to drive the MOSFET in the Boost converter because the gate is referenced to ground.

b.2. The boost converter disadvantages are:

- ✓ Low amount of DC step-up.
- ✓ Not suitable for high power conversion.
- ✓ The converter should not be used at D close to 1 because of its poor efficiency.
- ✓ The peak-to-peak current through the filter capacitor is very high.

c. Buck-boost converter:

The buck-boost converter is capable of producing a dc output voltage which is either greater or smaller in magnitude than the dc input voltage. The arrangement for the buck-boost converter is as shown in figure (I.13).

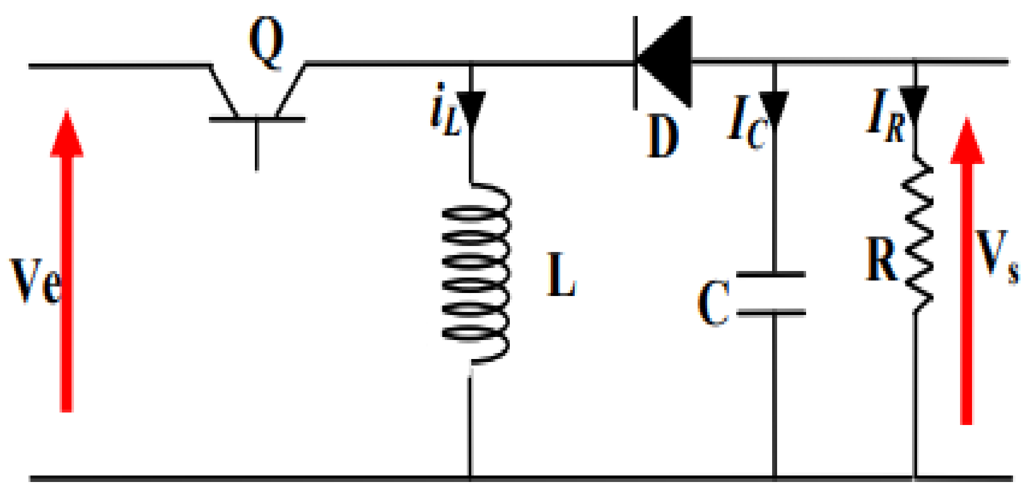

Figure I.13. Buck-boost converter.

c.1. The buck-boost converter features are:

- ✓ Pulsed input current requires input filter.
- ✓ Pulsed output current increases output voltage ripple.
- ✓ Output voltage can be either greater or smaller than input voltage.
- ✓ Its polarity of the output voltage is inverted.

I.5. MPPT Controller:

By definition, an MPPT control associated with an intermediate adaption stage, makes it possible to operate a (PVM) so as to permanently produce the maximum of its power. Thus, whatever the meteorological conditions (temperature and irradiation), the control of the converter places the system at the maximum operating point ($Vppm, Ippm$).

The MPPT command varies the duty cycle DS of the static converter CS so that the power supplied by the PVM is maximum at its terminals. In general, it is based on variation of the cyclic ratio of the CS until pieing placed on the MPP according to the evolutions of the input parameters of the CS (Ipv, Vpv).(mohamed.Amarouayache, 2014)

I.5.1. The MPPT algorithm:

The first MPPT control algorithm was implemented in 1968. Since then, different types of algorithms performing the search for the ppm have been published. These methods are different in terms of complexity, number and types of sensors needed, hardware implementation and each methods have these advantages and disadvantages.

General these methods can be categorized into three groups:

a. Indirect methods (offline):

Offline control techniques usually use the technical data from the photovoltaic panel to estimate the MPP. These data include preliminary information such as, curves (I-V) and (P-V) for different climatic conditions, the different mathematical models of the panel etc. Among these techniques are cited methods based on the regulation of the current and voltage of the photovoltaic module.

b. Direct methods (online):

Direct (online) methods use, in real time, voltages of the photovoltaic panel and/or current measurements to detect MPP. These methods do not require not the measurement of temperature and sunshine and also the knowledge of the model of the photovoltaic panel. Offline methods are less expensive, but less effective than so-called direct approaches.

c. Methods based on artificial intelligence:

Research by artificial intelligence methods for example offers great advantages for the pursuit of (MPP).

I.6. State of the art of DC-DC converter:

Since the 1940's, the growth of DC-DC converters has increased due to the high demand of DC-DC converter in industrial applications, computer hardware circuitry and trend in high power and high voltage density related applications.(Luo & F.L.YeH, 2016)

Switching mode DC-DC converters are more efficient than linear converters as the transistors operate as switches and dissipate less power. PWM DC-DC converters are capable of conducting in step-up, step-down mode and can have multiple output voltages whereas linear regulators can operate only as stepdown converters.(Kazimierczuk.M.k)

High step-up converters are especially required in the wide range of applications of energy sources like photo-voltaic panels and fuel cells which have variable input voltage range and low output voltage.(Chub, A.D.Vinnikov, F.Blaabjerg, & Peng.F.Z)(W.F.Lai, S.M.Chen, Liang.T.J, Le.K.W, & Ioinovici.A)

Research on DC-DC converters can be traced back to forty years ago when the analog DC-DC converter was first modelled and analyzed in California Institute of Technology around 1977 to 1978 due to the tremendous efforts made by **Slobodan Cuk**, **R. D. Middlebrook**, and other pioneers in an attempt to overcome the low-efficiency problem faced by linear regulators (**Middlebrook** and **Cuk**, 1977b). Since then, DC-DC converters have been flourishing in the power management IC market due to their higher efficiency, even though linear regulators are relatively easier to implement.

There are essentially three types of DC-DC converters, categorized according to the relative voltage of the input and output, namely, the buck converter, the boost converter and the buck-boost converter. Commercial DC-DC converters are typically analog, which means that they are controlled by analog controllers. Digital DC-DC converters have been conceptualized rather recently and they include the introduction of dedicated digital controllers ICs.

The dc-dc switching converters are the widely used circuits in electronics systems. They are usually used to obtain a stabilized output voltage from a given input DC voltage which is lower (**buck**) from that input voltage, or higher (**boost**) or generic (**buck**–**boost**).(M.H.Rashid, 2003)

Most used technique to control switching power supplies is Pulse-Width-Modulation (**PWM**).(Mohan.N, Undeland.T.M, & Robbins.W.P, 2002)

The conventional PWM controlled power electronics circuits are modeled based on averaging technique and the system being controlled operates optimally only for a specific condition.(Middle, R.D, & S.Cuk, 1976)(Forsyth.A.J & Mollow.S.V, 1998)

The linear controllers like **P**, **PI**, and **PID** do not offer a good large-signal transient (i.e. large-signal operating conditions).(Raviraj.V.S.C & Sen.P.C, 1997)(Castilla.M, Vicuna.L.G.de, Guerrero.J.M, Matas.J, & Miret.J, Design of voltage-mode hysteretic controllers for synchronous buck converters supplying microprocessor loads, 2005)

Therefore, research has been performed for investigating non-linear controllers. The main advantages of these controllers are their ability to react immediately to a transient condition. The different types of non-linear analog controllers are: (**a**) hysteretic current mode controllers, (**b**) hysteretic voltage-mode/V2 controllers, (**c**) sliding-mode/boundary controllers. Advantages of hysteretic control approach include simplicity in design and do not require feedback loop compensation circuit.(Castilla.M, Vicuna.L.G.de, Guerrero.J.M, Matas.J, & Miret.J, Design of voltage-mode hysteretic controllers for synchronous buck converters supplying microprocessor loads, 2005)(Castilla.M, Vicuna.L.G.de, Guerrero.J.M, Matas.J, & Miret.J., Design of voltage-mode hysteretic controllers for synchronous buck converters supplying microprocessor loads, 2005)

The analysis and design of a hysteretic PWM controller with improved transient response have been proposed for buck converter in 2004.(Nabeshima, T.Sato, T.Yoshida, S.S.Chiba, & Onda.K, 2004)

The use of switched mode(SM) control techniques in variable structure systems (VSS) makes these systems robust to parameter variations and external disturbances.(Utkin.V, Guldner.J, & Shi.J.X, Sliding Mode Control in Electromechanical Systems, 1999)(Edwards.C & Spurgeron.S.K, 1998) Sliding mode control has a high degree of design flexibility and it is comparatively easy to implement. This explains its wide utilization in various industrial applications, e.g.: automotive control, furnace control, etc…(Utkin.V, Guldner.J, & Sh.J.X, Sliding Mode Control in Electromechanical Systems, 1999)(Venkataramanan.R, 1986)

Switched mode DC-DC converters represent a particular class of the VSS, since their structure is periodically changed by the action of controlled switches and diodes. So, it is appropriate to use sliding mode controllers in dc-dc converters.(Bilalovic.F, Music.O, & Sabanovic.A, 1983)

It is known that the use of SM (non-linear) controllers can maintain a good regulation for a wide operating range. So, a lot of interest is developed in the use of SM controllers for dc-dc converters.(Venkatramanan.R, Sabanovic.A, & Cuk.S, 1985)(Tan.S.C, Lai.Y.M, Tse.C.K, & Martinez-

Salamero.L, Special family of PWM based sliding mode voltage controllers for basic dc-dc converters in discontinous conduction mode, 2007)

Siew-Chong Tan presented a detail discussion on the use of SM control for dc-dc power converters.(Tan.S.C, La.Y.M, & C.K.Tse, General design issues of sliding-mode controllers in dc-dc converters, 2008)

In 1983 and 1985, the implementation of sliding mode control for dc-dc converters is first presented.(Venkatramanan.R, Sabanovic.A, & Cuk.S, 1985)(Bilalovic.F, Music.O, & Sabanovic.A, 1983)

Then SM controller is applied in higher order converters in 1989.(Huang.S.P, Xu.H.Q, & L.Y.F.Liu, 1989)

Huang and all, applied SM control for cuk switching regulator. After this, a series of related works on the cuk converter was carried out.(Fossas.E, Martinez.L, Ordinas.j, & Fundam.I, 1992)(Mahadavi.J & Emadi.A, 1996)

Fossa's and **Pas**, applied a second-order SM control algorithms to buck converter for reduction of chattering.(Fossas.E & Pas.A, Second order sliding mode control of a buck converter, 2002)

Then, two types of SM-control for boost and buck-boost converters: one using the method of stable system center and the other using sliding dynamic manifold.(Shtessel.Y.B, Zinober.A.S.I, & Shkolnikov.I.A, Boost and buck-boost power converters control via sliding modes using method of stable system centre, 2002)(Shtessel.Y.B, Zinober.A.S.I, & Shkolnikov.I.A, Boost and buck-boost power converters control via sliding modes using dynamic sliding manifold, 2002) is proposed by **Yuri B.**

Shtessel. **Sira-Ramirez,** proposed a hysteresis modulation type of SM controller to achieve a generalized proportional integral (GPI) continuous control of a buck converter.(H.Sira-Ramirez, 2003)

Sira-Ramirez also presented a tutorial revisit of traditional sliding mode control approach for the regulation of DC-DC power converters, of the buck, boost and buck-boost type and proposed the use of GPI control technique to improve the system robustness.(Sira-Ramirez.H, On the generalized PI sliding mode control of DC-TO-DC power converters, 2003)

Donoso-Garciaetal. and **Shtessel and all**, proposed the use of SM control for current distribution and output-voltage regulation of multiple modular dc-dc converters.(Donoso-Garcia.P.F, P.C.Cortizo, R.Menez.Mendes, & M.A.Severo, 1996)(Shtessel.Y.B, Raznopolov.O.A, & Ozerov.L.A, Sliding mode control of multiple modular DC-to-DC power converters, 1996)

Sira-Ramirez and **Rios-Bolivar**,applied extended linearization method in SM-controller design that has excellent self-scheduling properties.(Sira-Ramirez.H & Rios-Bolivar.M, Sliding mode control of DC-to-DC power converters via extended linearization, 1994)

They also proposed to combine a SM control scheme with passivity-based controllers into the dc-dc converter that enhances its robustness properties.(Sira-Ramirez.H, Ortega.R, Perez-Moreno.R, & Garcia-Esteban.M, 1995)(Sira-Ramirez.H, Escobar.G, & Ortega.R, On passivity-based sliding mode control of switched DC-to-DC power converters, 1996)

In 1997, **Carrasco and all**, proposed neural controller with SM controllers to improve the robustness, stability and dynamic characteristic of the PWM dc/dc power circuit with power factor corrector.(Carrasco.J.M., Quero.J.M, Ridao.F.P, Perales.M.A., & Fanquelo.L.G, 1997)

The nonlinear behavior exhibited by current mode-controlled boost converter is studied by **Morel**.(Morel.C, Application of slide mode control to a current mode control boost converters, 2002)(Morel.C, lide mode control via current mode control in DC-DC converters, 2002)

Then, he introduced a practical SM control method aiming to eliminate chaotic behavior and keep the desired current-controlled property.

The standard method (slope compensation) only partly cures this major drawback and, even though it eliminates chaos, the converter is not current-controlled any more. He concluded that the proposed method does not only provide stability, it also increases the input voltage variation domain for which the system remained stable.

Mattavelliand all, proposed a general-purpose sliding-mode controller, which is applicable to most dc-dc converter topologies. The circuit complexity is same as current mode controllers and it provides extreme robustness and speed of response against line, load and parameter variations. The same group derived small signal models for dc-dc converters with SM control, which allows the selection of control coefficients, the analysis of parameter variation effects, the evaluation of the closed loop performances like audio susceptibility, output and input impedances, and reference to output transfer function.(Mattavelli.P, Rossetto.L, & Spiazzi.G, Small-signal analysis of DC–DC converters with sliding mode control, 1997)(Mattavelli.P, Rossetto.L, Spiazzi.G, & Tent.P, General-purpose sliding-mode controller for DC/DC converter applications, 1993)

Despite various advantages of SM controller, the practical implementation of this controller for DC-DC converters is rarely discussed. This is due to the lack of understanding in its design and systematic procedure for developing such controllers.

Escobar and all, performed experiments to compare five different control algorithms on dc-dc boost converter. He concluded that nonlinear controllers provide a promising alternative to the linear average controller.(Escobar.G, Ortega.R, Sira-Ramirez.H, Vilain.J.P, & Zein.I, 1999)

Alarcon and all, presented the design of analog IC SM control prototype with linear sliding surface for switching converters.(E.Alarcon, A.Romero, A.Poveda, Porta.S, & Martinez-Salamero.L, 2001)

Ahmed and all, presented an analysis and experimental study of SM controlled buck converter. They also showed the implementation of the SM controller for buck-boost converter through control desk dSPACE.(Ahmed.M, Kuisma.M, Tosla.K, & Silventoinen.P, 2003)(M.Ahmed, Kuisma.M, Tosla.K, Silventoinen.P, & Pyrhonen.O, 2003)

Dominguez and all (Dominguez.F, Fossas.E, & Martinez.L, 1994) presents a stability analysis of buck converter with input filter by means of SM control technique.

Zhang li and **QIU Shui-sheng** implemented Proportional-Integral sliding mode controller in dc-dc converters. They showed that the implementation of PI SM control is simpler than other SM control schemes and steady state error is eliminated.(Li.ZHANG & Shui-sheng.Q.I.U, 2005)

Castilla and all.(Castilla.M, Vicuna.L.C.de, Lopez.M, Lopez.O, & Matas.J, 2000) created a novel design methodology of SM control schemes for quantum resonant converters. The method is based on the imposition of a specified output-voltage dynamic response, and it provides a set of sliding surfaces guaranteeing high robustness and large signal stabilities.

Chong Tan presented a systematic approach for designing a practical SM controller for buck converter.(Tan.S.C, Lai.Y.M, Cheung.M.K.H, & Tse.C.K, 2005)

Steady-state switching frequency of sliding mode-controlled dc-dc converters is generally affected by line and load variation. For line variation, an adaptive feed forward control that varies the hysteresis band in the hysteresis modulator of the SM controller in the event of any change of the line input voltage and for load variation, an adaptive feedback controller that varies the control parameter with the change of output load is proposed by**Siew-Chong Tan** DC-DC converters can be operated either in continuous conduction mode (CCM) or in discontinuous conduction mode (DCM).(Tan.S.C, Lai, Tse.C.K, & Cheung.M.K.H, 2006)

DC-DC converters that operated in DCM provide faster transient response (due to its low inductance) at the expense of higher device stresses. He also presented a fixed frequency PWM based sliding mode controllers for dc-dc converters operating in DCM.(Tan.S.C, Lai.Y.M, Tse.C.K, Martinez-Salamero.L, & Cid-Pastor.A, Design of pulse-width-modulation based sliding mode controllers for power converters operating in discontinuous conduction mode, 2006)

Since these products have only been around for the past few years, they have not even achieved a 10% market penetration into the overall power supply market. Nevertheless, they have been made possible mainly due to the advance of semiconductors and the reduction of supply voltage.

I.7. Conclusion:

In this chapter, we have talked in general about the principal equipment of our system which are a PWM, static converters and MPPT strategies.

Firstly, an overview about the components of the solar energy conversion and their working principle are given. Then, we present the power electronic converters used in that system, by presenting the types, advantages and drawbacks and their importance in the solar energy systems. After that, we present a general explanation of the MPPT strategies and the synchronized mechanism between the PWM and CS. Finally, a state of the art about the dc-dc converter design is presented.

CHAPTER II

Modeling and simulation of the buck-boost converter

II.1. Introduction:

The DC-DC switch mode converters are variable structure system and therefore, they are considered as non-linear time variant systems. The mathematical modeling of the DC-DC converter is important in order to investigate the dynamic and the steady-state behaviors.

The mathematical modeling provides us information about the system behaviors to generate the suitable duty cycle thanks to the input and the output voltage. Moreover, modeling also plays a key role in controller design of DC-DC converters to regulate the output voltage. For proper control design, it is mandatory to have an accurate and precise dynamic model of the converter.

The significant work has been adopted for the modeling of a buck-boost DC-DC converter.

II.2. System modulation:

The system mathematical representation facilitates its study and understanding.

The system was divided into three subsystem models.

II.2.1. Pv-cell:

The photovoltaic-cell (PVC) equation without the illumination equal to the diode equation in darkness:

$$I_{pv} = I_D = I_s\left[e^{\frac{qV_D}{nkT}} - 1\right] \qquad \dots \text{(II.1)}$$

with:

$$V_T = \frac{AkT}{q} \qquad \dots \text{(II.2)}$$

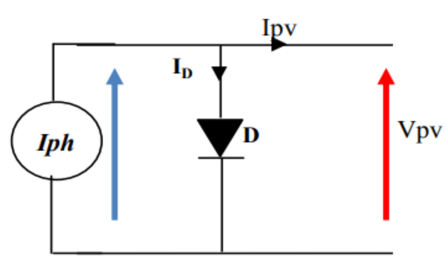

Figure II.1. *PVC without illumination.*

Where:

$\boldsymbol{I_{pv}}$: cell currant in darkness.

$\boldsymbol{I_D}$: diode currant.

$\boldsymbol{I_s}$: saturation current dependent on the temperature T and electrical and technological parameters of the PN junction. (Mathieu & H.Fanet, 2009)

$\boldsymbol{K}$: Boltzmann constant.

$\boldsymbol{q}$: charge of the electron (1, 6.10-19 C).

$\boldsymbol{T}$: junction temperature in K°. (1,38.10 -23 j/K).

$\boldsymbol{V_D}$: voltage applied on the diode.

$\boldsymbol{A}$: the PVC quality factor = 1.3.

$\boldsymbol{V_T}$: the PVC thermal tension.

$\boldsymbol{n}$: junction non-ideality factor (1<n<2).

With the illumination, the expression (II.1) will be as follow: (S.Astier, 2008)

$$I_{pv} = I_{ph} - I_D = I_{ph} - I_0 \left[e^{\frac{qV_{pv}}{nkT}} - 1 \right] \quad \ldots \text{(II.3)}$$

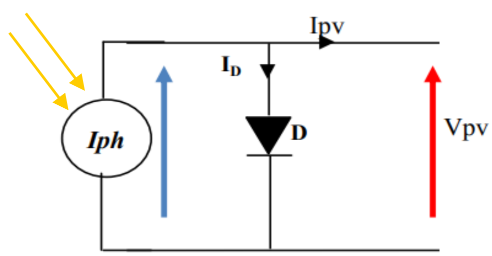

Figure II.2. PVC with illumination.

Where:

$\boldsymbol{I_{ph}}$**:** is the photocell current, proportional to illumination.

To reflect the current generated by the illuminated cell and different losses of connectivity that modeled by resistances, two terms are added Rs, Rsh, Figure (II.2).

Therefore, output cell current can be expressed in the form: (S.Astier, 2008)

$$I_{pv} = I_{ph} - I_0 \left[e^{\frac{qV_{pv}}{nkT}} - 1 \right] - \frac{V_{pv} + R_S I_{pv}}{R_{sh}} \quad \ldots \text{(II.4)}$$

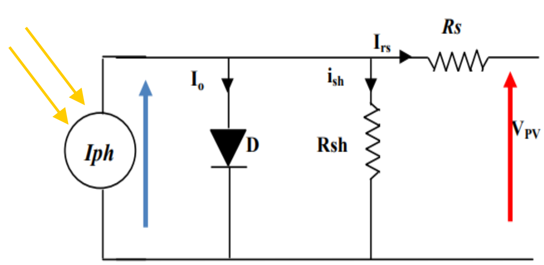

Figure II.3. *PVC with illumination and resistances.*

Where:

Rs: series resistance.

Rsh: shunt resistance.

The important parameters of PV cells are could be obtained from P-V and I-V curves, or from the equation (II.4).

The most common parameters are the following: (S.Astier, 2008)

a. Short-circuit current (Isc):

The short-circuit current Isc of the dipole is the current that would cross it if its terminals were connected by perfect conductor of zero resistance. In the ideal case (**Rs** is null, **Rsh** is infinite), we need to impose the voltage Vpv zero in equation (II.4) to get Isc equation, the equation of short-circuit current it will be as follow:

$$I_{sc} = \left(\frac{I_{ph}}{1+\frac{R_S}{R_{sh}}}\right) \quad \ldots \text{(II.5)}$$

b. Open circuit voltage (Voc):

It is the voltage across the cell when the latter is in open circuit, that is to say when the positive pole and the negative pole are electrically isolated from other electrical circuits (the current passing through it is zero). In this case, the power supplied by the cell **P = V× I** is zero. we need to impose the current Ipv zero in equation (II.4) to get Voc equation. The equation of the open circuit voltage it will be as follow:

$$V_{oc} = V_T \, ln\left(\frac{I_{ph}}{I_0} + 1\right) \quad \ldots \text{(II.6)}$$

c. Fill factor (FF):

It is the ratio between the maximum power delivered by the cell on the product of the short circuit current and open circuit voltage (Isc*Voc).

$$FF = \frac{I_{mpp}V_{mpp}}{I_{sc}V_{oc}} \quad \ldots \text{(II.7)}$$

d. The efficiency:

It is the ratio between the energy provided and the incident light power Pin. This measurement is done under standard illumination and temperature conditions.

The equation of the factor form is as follow:

$$\eta = \frac{P_{mpp}}{P_{in}} = \frac{FFI_{sc}V_{oc}}{P_{in}} \quad \ldots \text{(II.8)}$$

The relative equation of the PVM formed by the series and parallel connection of cells is:

$$I = N_p I_{ph} - N_p I_0 \left[e^{\frac{N_S V + \frac{N_S R_S I}{N_p}}{N_S n V_T}} - 1 \right] - \frac{N_S V + \frac{N_S R_S I}{N_p}}{\frac{N_S R_{sh}}{N_p}} \quad \dots \text{(II.9)}$$

Where:

$\boldsymbol{Ns}$: The series cells.

$\boldsymbol{Np}$: The parallel cells.

The electrical characteristics of the photovoltaic module are the same like the photovoltaic cells with proportional reports. These reports depend on the number of cells connected in series/ parallel. The relationship of the current and voltage of the PV module is non-linear. The I-V and P-V curves are very important for studying of the PV module characteristics.

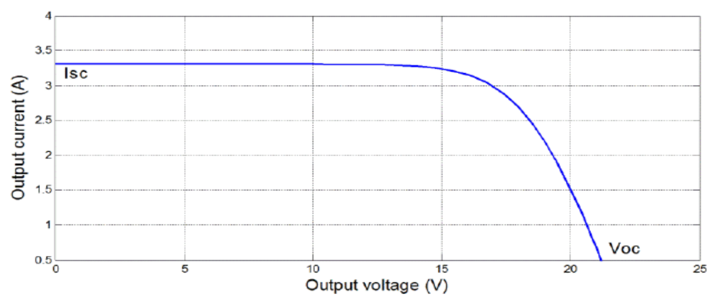

Figure II.4. (I-V) characteristics of photovoltaic module.

The I-V characteristic of the figure can be divided into three distinct parts each one is corresponding to an operation mode:

a. First one, between 0 V and 15 V, where the cell behaves as a generator of current;

b. Second one, for a current IPV less than 4A, wherein the cell is similar to a voltage generator.

c. Third one, between the two preceding ones, corresponds to rapid variations of the internal impedance of the cell.

The power of the PVM is the product of the output current and voltage across its terminal's equation (II.10), figure II.5 represents the P-V curve:

$$P = I_{PVM} V_{PVM} \quad \dots \text{(II.10)}$$

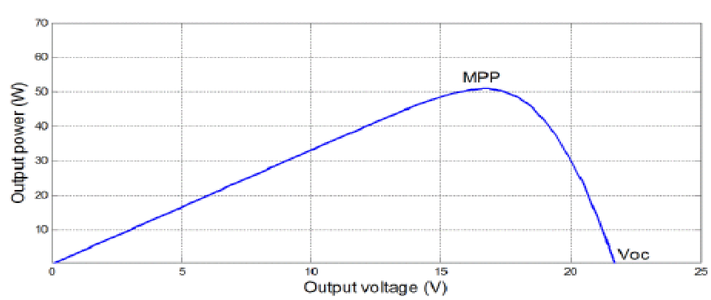

Figure II.5. *(P-V) characteristics of photovoltaic module***.**

II.2.2. Buck-boost converter:

A buck-boost DC-DC converter is shown in figure (II.6). Only a switch is shown, for which a device belonging to transistor family is generally used. Also, a diode is used in series with the load.

The inductor, L is connected in parallel after the switch and before the diode. The load is of the same type as given earlier. A capacitor, C is connected in parallel with the load. The polarity of the output voltage is opposite to that of input voltage here. (Saurabh.Kasat, 2004)

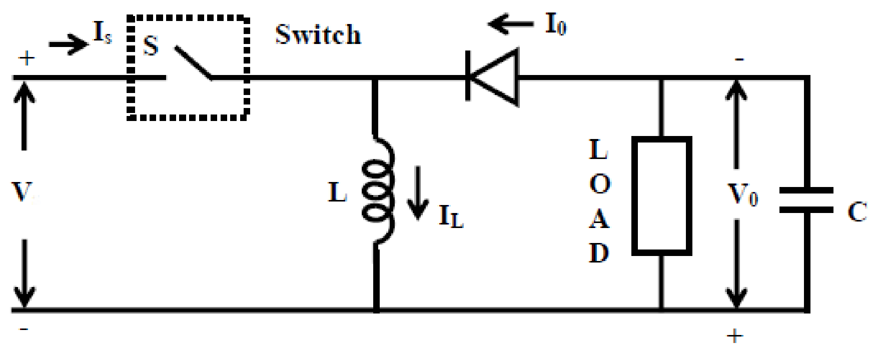

Figure II.6. *Buck-boost converter.*

The circuit operation divided into two modes:

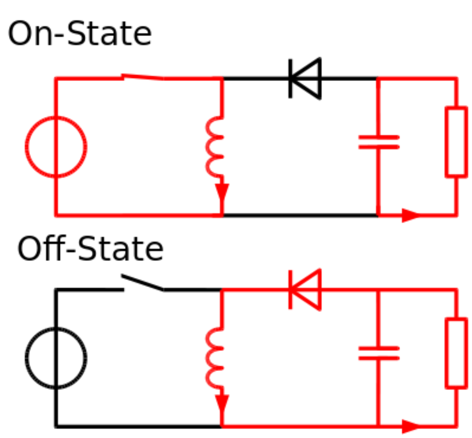

Figure II.7. *Circuit mode operation.*

During On-State when the transistor Q1 is on, input voltage is applied across the inductor and the current in inductor L rises linearly. At this time the capacitor C, supplies the load current, and it is partially discharged.

During Off-State when the transistor is off, the voltage across the inductor reverses in polarity and the diode conducts. During this interval the energy stored in the inductor supplies the load and, additionally, recharges the capacitor.

The steady state inductor current and voltage waveform is shown in figure (II.8) and (II.9).

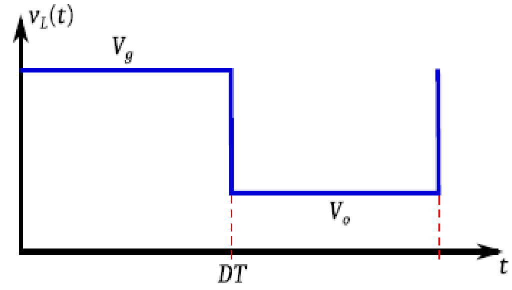

Figure II.8. *Inductance voltage waveform.*

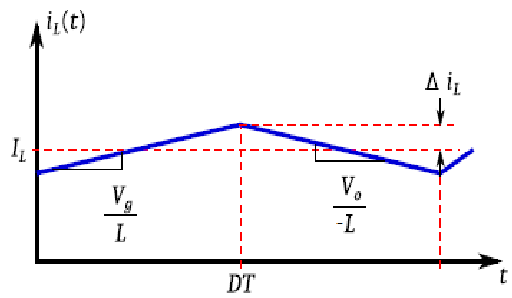

Figure II.9. *Inductance current waveform.*

From the wave form we have:

$$T = T_{on}+T_{off} \qquad \text{… (II.11)}$$

$$T_{on} = DT \qquad \text{… (II.12)}$$

$$T_{off} = T - DT \qquad \text{… (II.13)}$$

$$\Delta i_L = iL_{max} - iL_{min} \qquad \text{… (II.14)}$$

And:

$$f_{sw} = \frac{1}{T} \qquad \text{… (II.15)}$$

So:

$$D = \frac{T_{on}}{T} \qquad \text{… (II.16)}$$

$$T_{on} = DT \qquad \text{… (II.17)}$$

$$T_{off} = T - DT \qquad \text{… (II.18)}$$

By using kirchov voltage law (KVL):

Mode 1:

switch is on and diode is off.

$$V_g = V_L \,, V_L = L\frac{di_L}{dt} = V_g \,, \frac{di_L}{dt} = \frac{\Delta i_L}{\Delta t} = \frac{V_g}{L} \qquad \text{… (II.19)}$$

Since the switch is closed for a time $\boldsymbol{T_{on}}$we can say $(\Delta t = T_{on} = DT)$:

$$(\Delta i_L)_{closed} = \left(\frac{V_g}{L}\right) DT. \qquad \text{… (II.20)}$$

Mode 2:
switch is off and diode is on.

$$V_o = V_L\,, V_L = L\frac{di_L}{dt} = V_o\,, \frac{di_L}{dt} = \frac{\Delta i_L}{\Delta t} = \frac{V_o}{L}. \qquad \text{… (II.21)}$$

Since the switch is open for a time T_{off}we can say $\left(\Delta t = T_{off} = T - T_{on} = T - DT = (1 - D)T\right)$:

$$(\Delta i_L)_{open} = \left(\frac{V_o}{L}\right)(1 - D)T. \qquad \text{… (II.22)}$$

Using the inductor volt balance principle to find the steady state output voltage equation yields:

$$(\Delta i_L)_{closed} + (\Delta i_L)_{open} = 0 \qquad \text{… (II.23)}$$

$$\left(\frac{V_g}{L}\right) DT + \left(\frac{V_o}{L}\right)(1 - D)T = 0 \qquad \text{… (II.24)}$$

$$\frac{V_o}{V_g} = -\frac{D}{1-D} \qquad \text{… (II.25)}$$

With change polarity

$$\frac{V_o}{V_g} = \frac{D}{1-D} \qquad \text{… (II.26)}$$

It may be observed that, for the rangeb the output voltage is lower than the input voltage, thus, making it a buck DC-DC converter. For the range $\mathbf{0.5 > \boldsymbol{D} \geq 1}$ the output voltage is higher than the input voltage, thus, making it a boost DC-DC converter.

For $\boldsymbol{D} = \mathbf{0.5}$ the output voltage is equal to the input voltage. So, this circuit can be termed as a buck-boost converter. Also, it may be called as step-up/down chopper. It may be noted that the inductor current is assumed to be continuous. The range of $\boldsymbol{D}$ is somewhat reduced due to the reasons given earlier. The expression for the output voltage can be obtained by using other procedures.

The $\boldsymbol{D}$ varies between 0 and 1 and thus output voltage can be lower or higher than the input voltage in magnitude but opposite in polarity.

Note that the source is never connected directly to the load in the buck boost converter.

Energy is stored in the inductor when the switch is closed and transferred to the load when switch is open. Hence, the buck boost converter is also referred to as an indirect converter.

Power absorbed by the load must be the same as that supplied by the source.

Where:

$$P_o = P_g \quad \text{… (II.27)}$$

$$P_o = \frac{{V_o}^2}{R} \quad \text{… (II.28)}$$

$$P_g = V_g I_g \quad \text{… (II.29)}$$

Average source current is related to average inductor current by:

$$I_g = I_L D \quad \text{… (II.30)}$$

Resulting in:

$$\frac{{V_o}^2}{R} = V_g I_L D \quad \text{… (II.31)}$$

With:

$$V_o = V_g \frac{D}{(1-D)} \quad \text{… (II.32)}$$

Substituting for Vo using equation (II.32) and solving for:

$$I_L = \frac{{V_o}^2}{V_g D R} = \frac{P_o}{V_g D} = \frac{V_g D}{R(1-D)^2} \quad \text{… (II.33)}$$

Maximum and minimum inductor current is determined using equation (II.20) and (II.33):

$$I_{max} = I_L + \frac{\Delta I_L}{2} = \frac{V_g D}{R(1-D)^2} + \frac{V_g}{2L} DT \quad \text{… (II.34)}$$

$$I_{min} = I_L - \frac{\Delta I_L}{2} = \frac{V_g D}{R(1-D)^2} - \frac{V_g}{2L} DT \quad \text{… (II.35)}$$

For continuous current, the inductor current must remain positive. To determine the boundary between continuous and discontinuous current I_{min} is set to zero:

$$L_{min} = \frac{(1-D)^2 R}{2f} \quad \text{… (II.36)}$$

The output voltage ripple for the buck boost converter is:

$$I_{c_{on}} = -I_o \quad \dots \text{(II.37)}$$

$$I_{c_{off}} = I_L - I_o \quad \dots \text{(II.38)}$$

$$C\frac{dV_c}{dt} = I_{c_{on}} = -I_o \quad \dots \text{(II.39)}$$

$$C\frac{dV_c}{dt} = I_{c_{off}} = I_L - I_o \quad \dots \text{(II.40)}$$

$$\Delta V_c = \Delta V_o = \frac{1}{C}\Delta Q \quad \dots \text{(II.41)}$$

$$\Delta Q = T_{on} I_o = DT I_o \quad \dots \text{(II.42)}$$

By compensation equation (II.42) in (II.41):

$$\Delta V_c = \frac{1}{C} DT I_o \quad \dots \text{(II.43)}$$

$$\Delta V_c = \frac{1}{C} DT \frac{V_o}{R_o} \quad \dots \text{(II.44)}$$

From equation (II.32):

$$\Delta V_c = \frac{1}{C} D \frac{1}{f}\frac{1}{R_o}\frac{V_g D}{(1-D)} \quad \dots \text{(II.45)}$$

II.2.3. Perturb and observe MPPT method:

The MPPT perturb and observe (PO) method is an iterative technique used in photovoltaic (PV) systems to optimize the power output of solar panels. It starts by setting an initial operating point and

measures the power output. Then, it perturbs the operating point and compares the new power output with the previous one. if the power increases, it continues perturbing in the same direction otherwise, it

changes the direction. This iterative process is repeated, gradually adjusting the operating point until it reaches the maximum power point (MPPT) where the panel's output power is maximized. The algorithm dynamically tracks the (MPP) by adapting to changing environmental conditions. While it has some limitations, such as oscillations and local maxima, the MPPT perturb and observe algorithm remains popular due to its simplicity and effectiveness in optimizing (PV) system performance.

The figure (II.10) presented MPPT (PO) method.

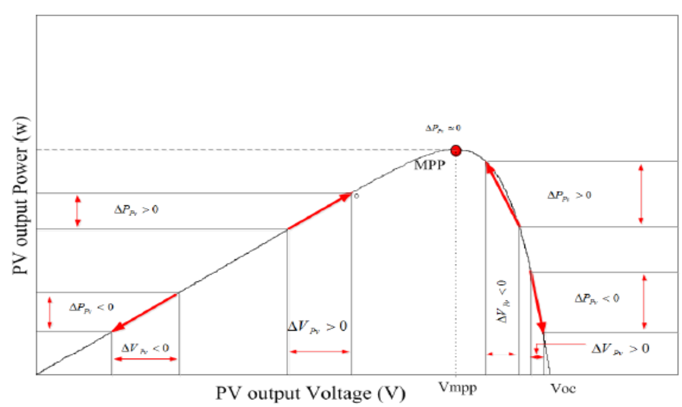

Figure II.10. *The operating principle of PO method.*

a. Benefits of using the P&O method:

- ✓ The simplicity of its algorithm.
- ✓ Ease of implementation.
- ✓ It has comparatively less implementation cost.
- ✓ It is comparatively a more accurate method.

b. Limitations to using this method:

- ✓ It cannot determine when it has actually reached the MPP. Under steady state operation the output power oscillates around the MPP.
- ✓ This method is quite slow to find the MPP if the voltage is far away from MPP.
- ✓ In any case if there is any shadow on any of the panels (as they are in series of parallel) then the power-voltage curve of the PV will have several peaks and the P&O will not be able to distinguish them and find the genuine peak.

$$\frac{dP_{pv}}{dV_{pv}} = 0 \; At \; MPP \qquad \ldots \text{(II.46)}$$

$$\frac{dP_{pv}}{dV_{pv}} > 0 \; Left \; side \; of \; MPP \qquad \ldots \text{(II.47)}$$

$$\frac{dP_{pv}}{dV_{pv}} < 0 \; Right \; side \; of \; MPP \qquad \ldots \text{(II.48)}$$

At the extreme point of any P-V curve, MPP is defined by (II.46), (II.47) and (II.48) are used to determined MPP's location (to the left or right). The merits of (PO) are high tracking capability, simple and fast dynamic. (Bollipo, 2021)

The flowchart of (PO) technique represented in figure (II.11).

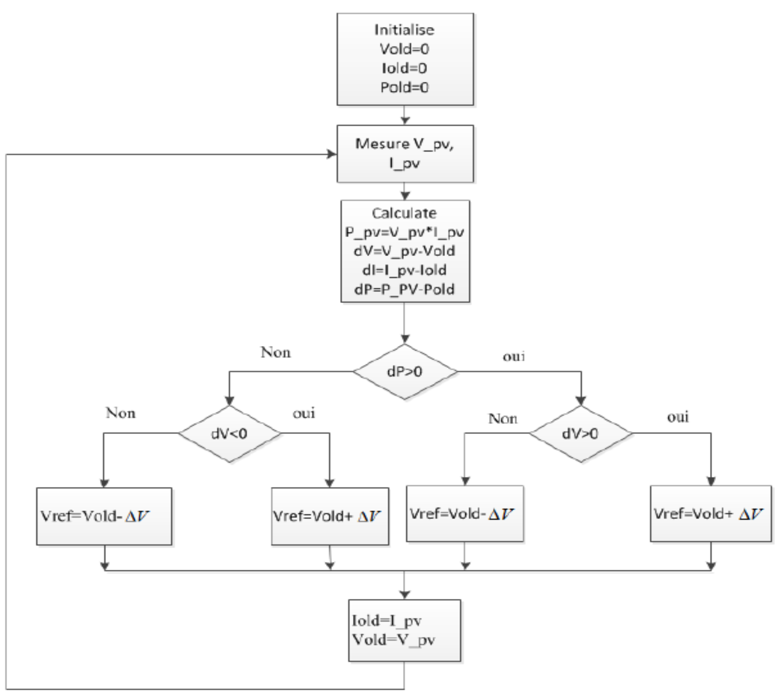

Figure II.11. *The flowchart of PO mppt method***.**

This strategy essentially searches for a difference in PV cell power (dp) and then a change in PVC voltage (dv). As a function of the obtained values, D is perturbed. The actual point appears to be in the left half of the MPP if the $dP = dV$ is positive; if the $dP = dV$ is negative, the actual point appears to be in the right half. Additionally, this step continues until $dP = dV$ equals zero.

II.3. Buck-boost converter simulation:

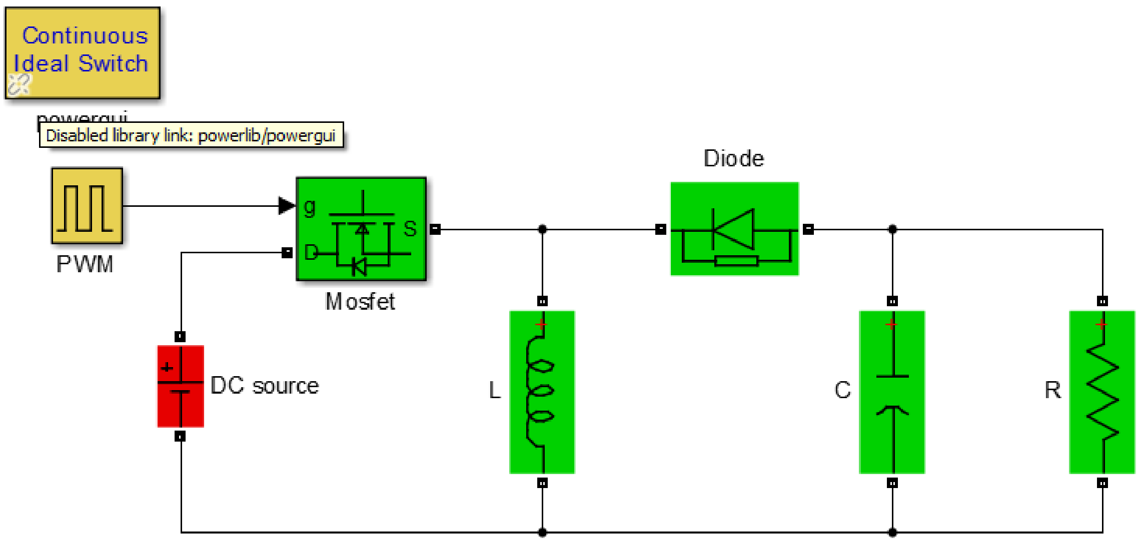

Figure II.12. *Buck-boost SIMULINK-model.*

II.3.1. *SIMULINK*- parameter:

ELEMENT	***VALUE***
Vg	*15 v*
Vo	*235 v*
Duty cycle	*0.94*
Frequency	*10000 HZ*
Inductor	*0.000077 H*
Capacitor	*0.000470 F*
Load	*100 ohms*

Table II. I. *SIMULINK-parameter*

II.3.1. *SIMULINK*- results:

a. For (D=94%):

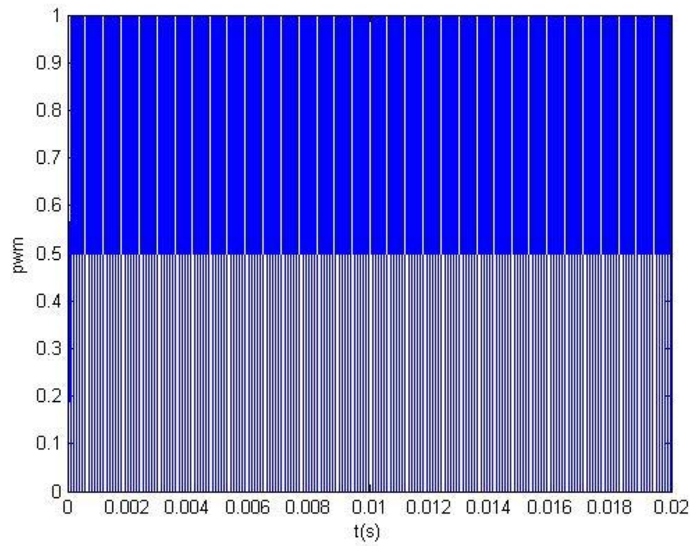

Figure II.13. *The duty cycle variation.*

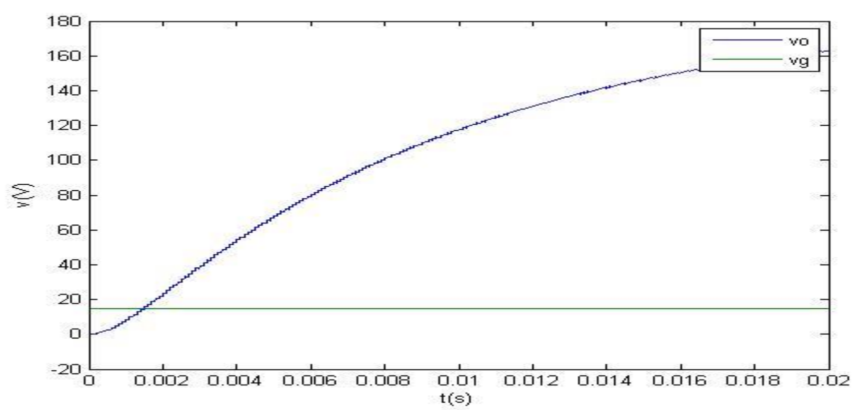

Figure II.14. *The input and output voltage.*

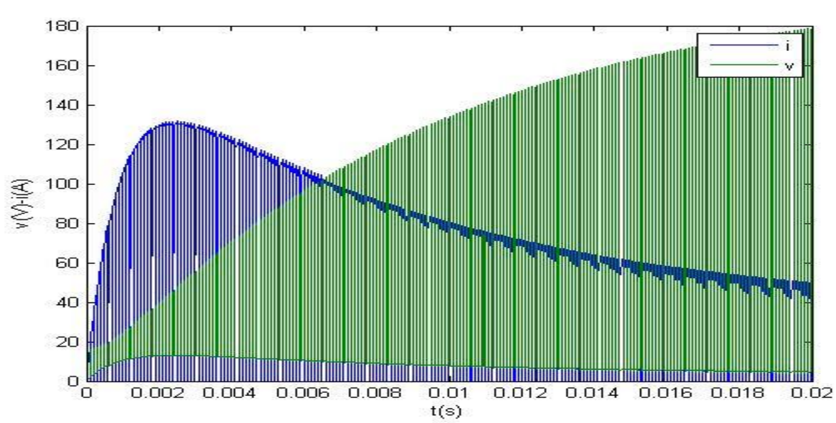

Figure II.15. *The mosfet (V-I) variation.*

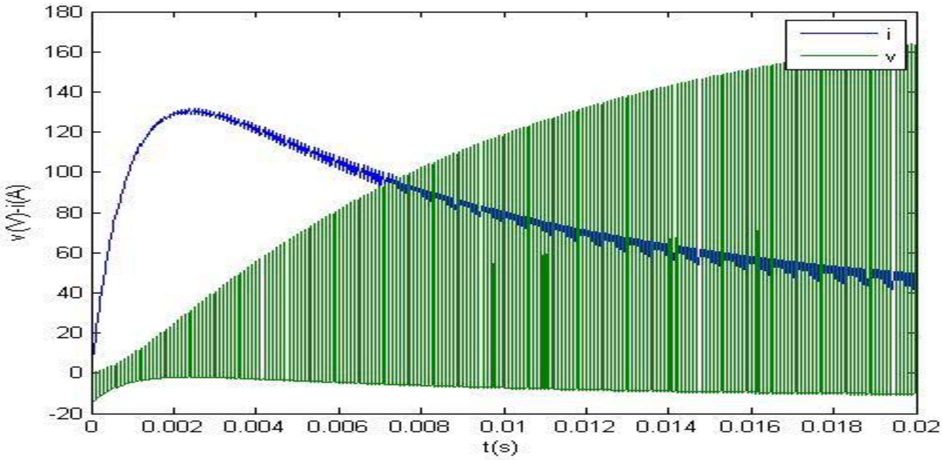

Figure II.16. *The inductor (V-I) variation.*

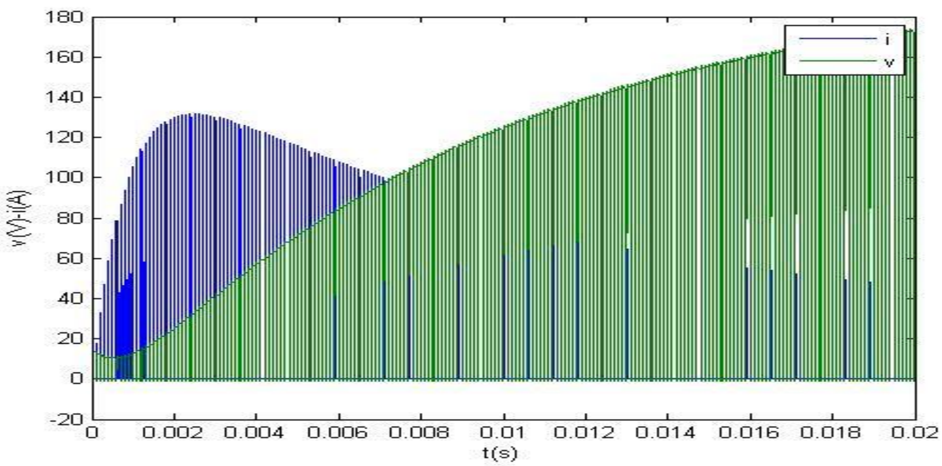

Figure II.17. *The diode (V-I) variation.*

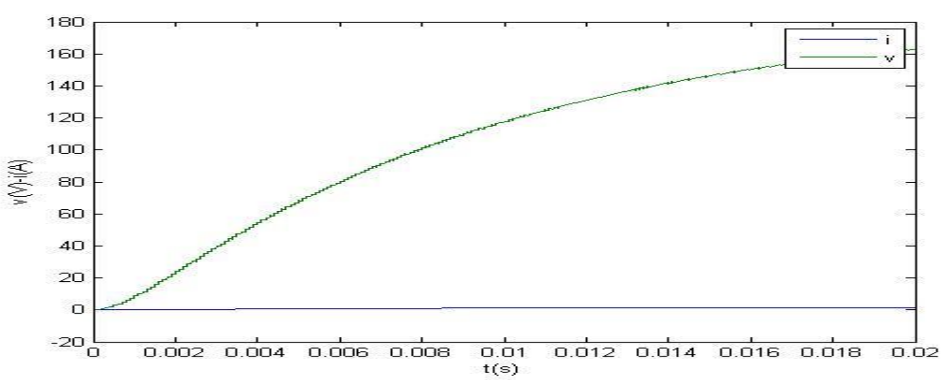

Figure II.18. *The capacitor (V-I) variation.*

b. For (D=10%):

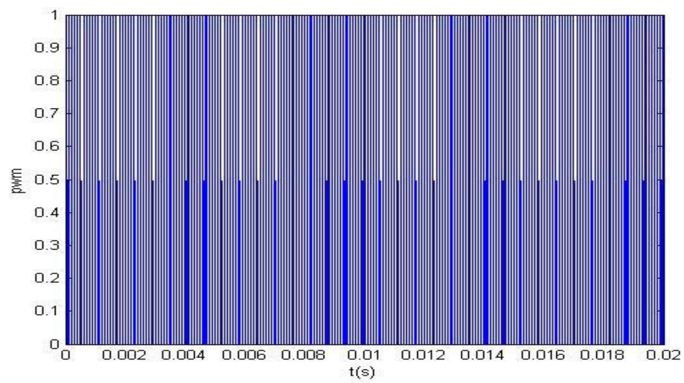

Figure II.19. *The duty cycle variation.*

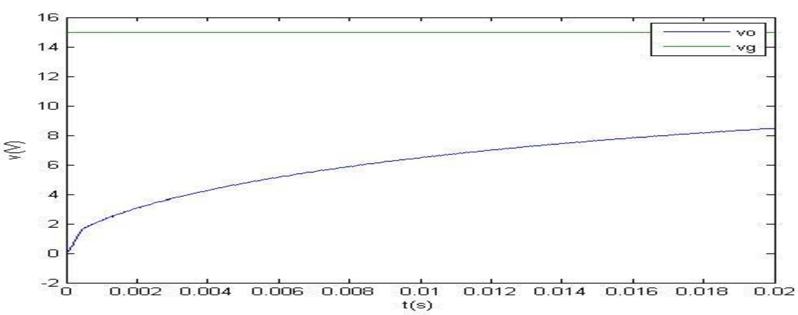

Figure II.20. *The input and output voltage.*

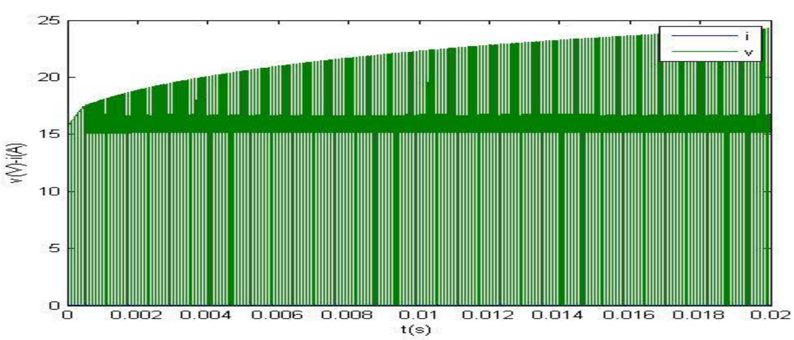

Figure II.21. *The mosfet (V-I) variation.*

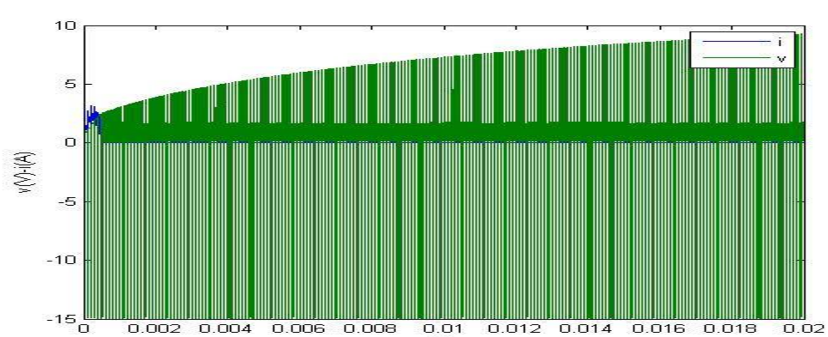

Figure II.22. *The inductor (V-I) variation.*

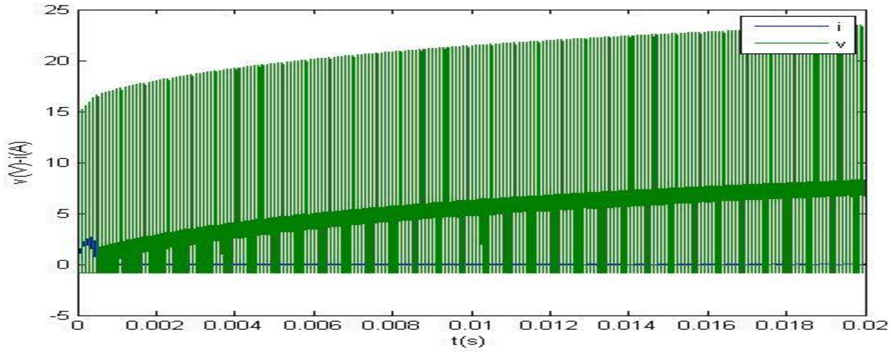

Figure II.23. *The diode (V-I) variation.*

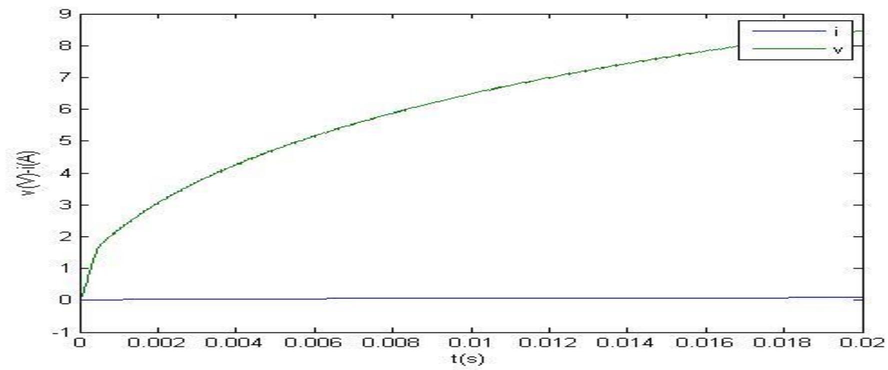

Figure II.24. *The capacitor (V-I) variation.*

II.3.2. Discussing the results:

a. For (D=94%):

We note that the output-voltage higher than the input-voltage, so the DC-DC converter works to set-up the input-voltage (boost), by sending the PWM signals from pulse generator to the MOSFET and then, she sends the modified current to the inductor which stored it in the first stage and unload it in the second stage. After that the capacitor works to filtered the voltage before it comes out.

b. For (D=10%):

We note that the input-voltage higher than the output-voltage, so the DC-DC converter works to set-down the input-voltage (buck), by sending the PWM signals from pulse generator to the MOSFET

and then, she sends the modified current to the inductor which stored it in the first stage and unload it in the second stage. After that the capacitor works to filtered the voltage before it comes out.

II.3. Conclusion:

In this chapter we have divided the working methodology into two parts.

Firstly, the mathematical modeling of the optical cell, the buck-boost converter and the MPPT PO controller are addressed by presenting the corresponding expressions. Then We talked in particular about the buck-boost converter; which operate in two stages (on/off). At the first stages the inductor works to assemble the current and in the second stage reflects the polarity and unloads the current, from this principal the buck-boost converter works.

The buck-boost converter receives the electrical current supply from the solar panel and the controller is connected to generate the PWM signals and track the maximum power point.

Finally, the implementation of the buck-boost converter into MATLAB-Simulink is proposed in which the obtained Simulation results was analyzed and discussed at the finale of this chapter.

CHAPTER III

Experimental validation of the proposed system

III.1. Introduction:

This chapter discusses the software and hardware development and implementation of the project and procedures that are being used to develop the project including the equipment, tools and processes used. The methodology process utilizes both software simulation and hardware construction. It is virtual to simulate the system by using the software to get the simulation result before hardware designation can be made. The selection of the electrical components for the hardware is also important in order to reduce the cost, increase the system efficiency and increase the reliability of the proposed converter scheme.

III.2. Component:

III.2.1. Software section:

This section consists of the all the software we used during this project. The software used are:

a. Arduino software.
b. MATLAB (Simulink).

a. Arduino:

Figure III.1. *Arduino.*

Arduino is an open-source electronics platform based on easy-to-use hardware ang software. Arduino boards are able to read inputs-light on a sensor, a finger on a button, or a twitter message- and turn it into an output -activating a motor, turning on an LED, publishing something online. You can tell your board what to do by sending a set of instruction to the micro-controller on the board. To do so you use the Arduino programming language based on wiring, and the Arduino software ide, based on processing. Over the years Arduino has been the brain of thousands of projects, from everyday objects to complex scientific instruments. A worldwide community of makers – students, hobbyists, artists, programmers, and professionals -has gathered around this open-source platform, their contributions have added up to an incredible amount of accessible knowledge that can be of great help to novices and expert alike. Arduino was born at the lvrea interaction design institute as an easy tool for fast prototyping, aimed at students without a background in electronics and programming. As soon as it reached a wider community, the ARDUINO board started changing to adapt to new needs and challenges, differentiating its offer from simple 8-bit boards to products for IoT applications, wearable, 3D printing, and embedded environments.

Arduino features:

Inexpensive- Arduino boards are relatively inexpensive compared to other microcontroller platforms. The least expensive version of the Arduino module can be assembled by hand, and even the pre-assembled Arduino modules cost less than $50.

Cross-platform- The Arduino software runs on windows, Macintosh OSX, and Linux operating systems. Most microcontroller systems are limited to windows.

Simple, clear programming environment- the Arduino software (IDE) is easy-to-use for beginners, yet flexible enough for advanced users to take advantage of as well. for teachers it's conveniently based on the processing programming environment, so students learning to program in that environment will be familiar with how the Arduino IDE works.

Open source and extensible software- the Arduino software is published as open-source tools, available for extension by experienced programmers. The language can be expanded through C++ libraries, and people wanting to understand the technical details can make the leap from Arduino to the AVR C programming language on which is based. Similarly, you can add AVR-C code directly into your Arduino programs if you want to.

Open source and extensible hardware- the plans of the Arduino boards are published under a Creative commons license, so experienced circuit designers can make their own version of the module, extending it and improving it. Even relatively inexperienced users can build the breadboard version of the module in order to understand how it works and save money.

b. MATLAB:

Figure III.2. MATLAB.

Matrix la Boratory is basically popular with the name MATLAB. In one sentence MATLAB is the Language of Technical Computing. The MATLAB platform is optimized for solving engineering and scientific problems. The matrix-based MATLAB language is the world's most natural way to express computational mathematics. Built-in graphics make it easy to visualize and gain insights from data. A vast library of prebuilt toolboxes let's us get started right away with algorithms essential to our domain. The desktop environment invites experimentation, exploration, and discovery. These MATLAB tools and capabilities are all rigorously tested and designed to work together.

MATLAB features:

Simulink: Simulink® is a block diagram environment for multidomain simulation and Model-Based Design. It supports simulation, automatic code generation, and continuous test and verification of embedded systems.

- ✓ Language Fundamentals: Syntax, operators, data types, array indexing and manipulation.
- ✓ Mathematics: Linear algebra, differentiation and integrals, Fourier transforms, and other mathematics.
- ✓ Graphics: Two- and three-dimensional plots, images, animation, visualization.
- ✓ Data Import and Analysis: Import and export, preprocessing, visual exploration.
- ✓ Programming Scripts and Functions: Program files, control flow, editing, debugging.
- ✓ App Building: App development using App Designer, GUIDE, or a programmatic Workflow.
- ✓ Advanced Software Development: Object-oriented programming; code performance; unit testing; external interfaces to Java®, C/C++, .NET and other languages.
- ✓ Desktop Environment: Preferences and settings, platform differences.

- ✓ Supported Hardware: Support for third-party hardware, such as webcam, Arduino®, and Raspberry Pi™ hardware.

I.2.2. Hardware section:

This section consists of the all the hardware we used during this project. The hardware used are:

a. CEM 80M-36 Module:

Figure III.3. *Pv module.*

In our production we use a PV module of the photovoltaic type CEM 80M-36. This PV module is made of monocrystalline silicon and consists of 36 elementary PV cells. It can deliver under standard test conditions (CST) a power of 80 Wc, a current of 4.53A at an optimum voltage of 18.5V.

- ✓ Maximum power (Pmax): 88Wc.
- ✓ Power tolerance: 3%.
- ✓ Current at (Iop): 4.53 A.
- ✓ Voltage at (Vop): 18.5 V.
- ✓ Short circuit current (Icc): 4.66 A.
- ✓ Open circuit voltage (Voc): 22.3 V.

b. Arduino microcontroller:

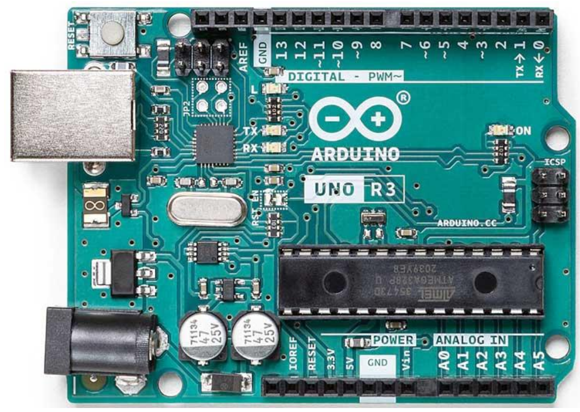

Figure III.4. *Arduino UNO.*

As mentioned above we have used Arduino as microcontroller for implementing our project and it can be defined as the heart of our project. Arduino is a combination of both physical programmable circuit board and software. As a matter of fact, it is almost like an IDE (integrated development environment) that we use in our personal computer. That is why we chose to use Arduino to get a more precise result in our project. The current sensor senses the current, the voltage sensor senses the voltage and they fed the result into Arduino and therefore Arduino compares them with the preset instruction and changes accordingly to extract the result.

c. Buck-boost:

The buck-boost converter circuit elements and values are:

ELEMENT	VALUE	NUMBER
MOSFET	*IRFP260N*	*3*
REACTIFIER	*MBR2060CT*	*8*
CAPACITOR	*470uF/250v - 470uF/450v*	*1 - 9*
INDUCTOR	*3.8 mH*	*2*
RESISTOR	*100 and 260 ohms*	*4 - 7*
OPTOCOUPLER	*A3120*	*5*
ISOLATER	*B0515S-1W*	*6*

Table III. 1.The buck-boost elements value.

The buck-boost circuit represented in figure (III.4).

Figure III.5. The buck-boost circuit implement.

c.1. MOSFET IRFP260N:

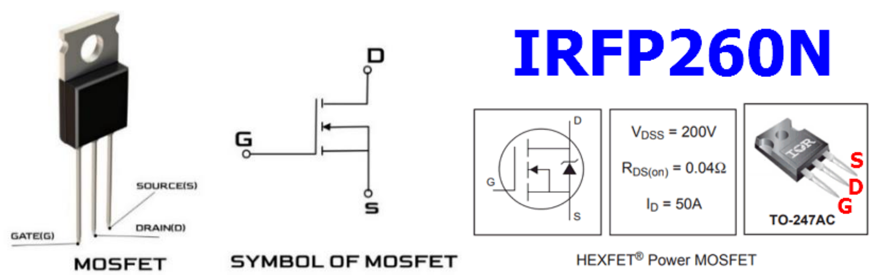

Figure III.6. MOSFET.

The MOSFET (Metal Oxide Semiconductor Field Effect Transistor) is a semiconductor device which is widely used for switching and amplifying electronic signals in the electronic devices.
The MOSFET is a core of integrated circuit and it can be designed and fabricated in a single chip because of these very small sizes. The MOSFET is a four-terminal device with source (S), gate (G), drain (D) and body (B) terminals. The body of the MOSFET is frequently connected to the source terminal so making it a three-terminal device like field effect transistor. The MOSFET is very far the most common transistor and can be used in both analog and digital circuits. The MOSFET works by electronically varying the width of a channel along which charge carriers flow (electrons or holes). The charge carriers enter the channel at source and exit via the drain. The width of the channel is controlled by the voltage on an electrode is called gate which is located between source and drain**.** It is insulated from the channel near an extremely thin layer of metal oxide.

The aim of the MOSFET is to be able to control the voltage and current flow between the source and drain. It works almost as a switch. The working of MOSFET depends upon the MOS capacitor. The

MOS capacitor is the main part of MOSFET. The semiconductor surface at the below oxide layer which is located between source and drain terminal. It can be inverted from p-type to n-type by applying a positive or negative gate voltage respectively. When we apply the positive gate voltage the holes present under the oxide layer with a repulsive force and holes are pushed downward with the substrate. The deflection region populated by the bound negative charges which are associated with the acceptor atoms. The electrons reach channel is formed. The positive voltage also attracts electrons from the n+ source and drain regions into the channel.

c.2. Thyristor (DIODE MBR2060CT):

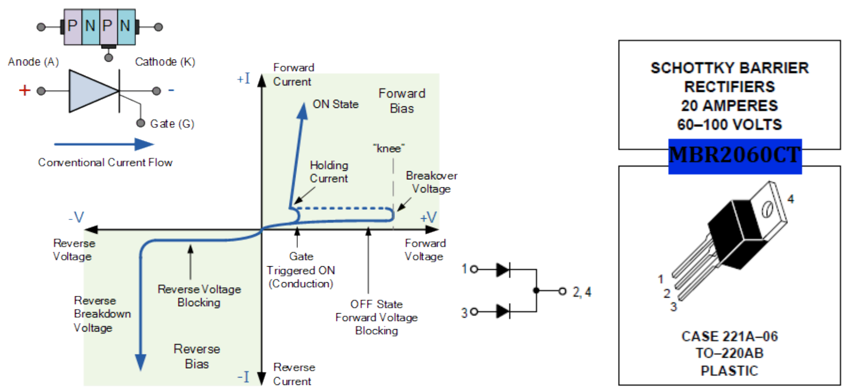

Figure III.7. Rectifier.

A Thyristor is a four-layer semiconductor device, consisting of alternating P-type and N-type materials (PNPN). A thyristor usually has three electrodes: an anode, a cathode and a gate, also known as a control electrode. The most common type of thyristor is the silicon-controlled rectifier (SCR).

c.3. CAPACITOR:

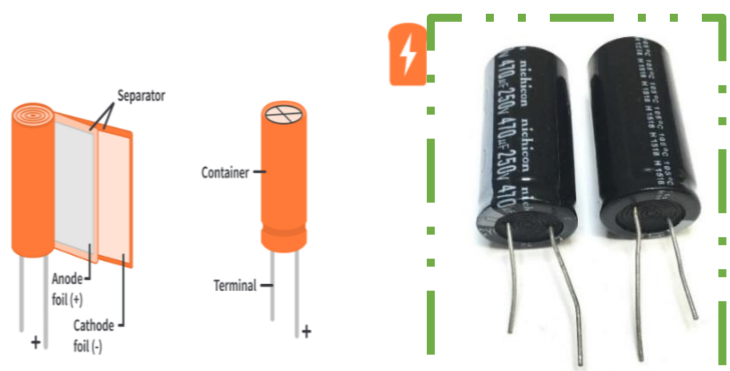

Figure III.8. Capacitor.

A capacitor is a device that stores electrical energy in an electric field by virtue of accumulating electric charges on two close surfaces insulated from each other. It is a passive electronic component with two terminals. The effect of a capacitor is known as capacitance.

c.4. RESISTOR:

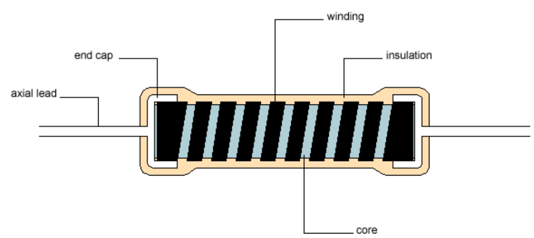

Figure III.9. Resistor.

A resistor is a passive two-terminal electrical component that implements electrical resistance as a circuit element. Ln electronic circuits, resistors are used to reduce current flow, adjust signals levels, to divide voltages, bias active elements, and terminate transmission lines, among other uses.

c.5. INDUCTOR:

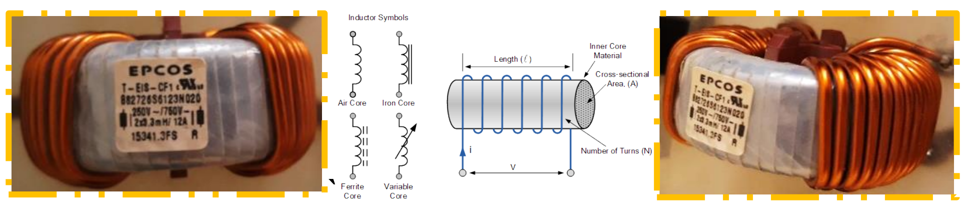

Figure III.10. Inductor.

An inductor, also called a coil, choke, or reactor, is a passive two-terminal electrical component that stores energy in magnetic field when electric current flows through it. An inductor typically consists of an insulated wire wound into a coil.

c.6. OPTOCOUPLER:

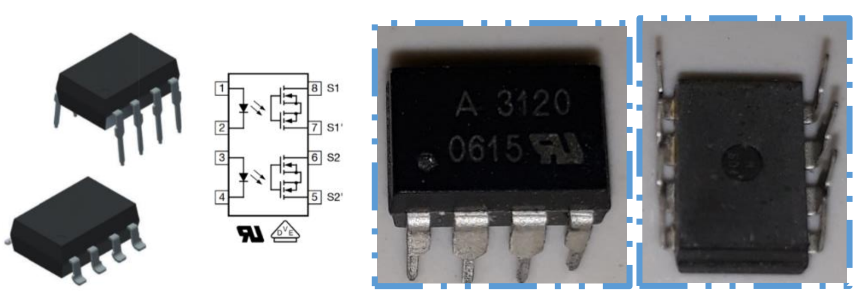

Figure III.11. Optocoupler.

An optocoupler, also known as an opto-isolator or photocoupler, is an electronic device made up of a led emitter combined with a photodetector, separated from each other in proximity. There are many types of photodetectors, most of which are variations on a photodiode or phototransistor. Optocouplers manage to send signals between circuits with separate, providing an isolated galvanic barrier between them. Therefore, an optocoupler is a solution for circuits that need to be isolated from each other for safety or regularity reasons and need to have interaction in between.

d. Sensor:

d.1. Voltage sensor :

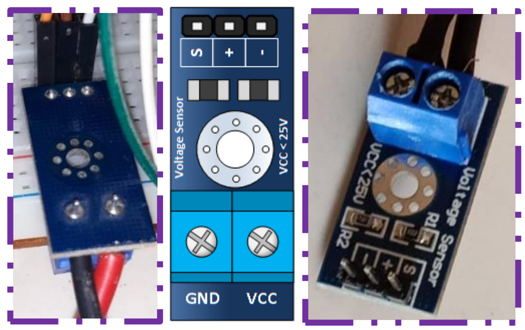

Figure III.12. Voltage sensor.

a voltage sensor is a device that measures voltage. Voltage sensor can measure the voltage in various ways, from measuring high voltages to detecting low current levels. These devices are essential for many applications, including industrial controls and power systems.

d.2. Current sensor:

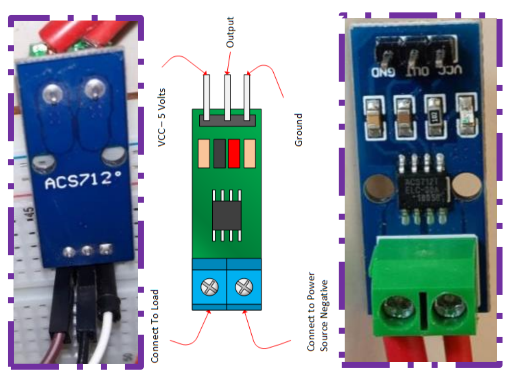

Figure III.13. Current sensor.

A current sensor is a device that detects electric current in a wire and generates a signal proportional to that current. The generated signal could be analog voltage or current or a digital output.

III.3. Experimental results:

The figure (III-13) shows the complete system of the MPPTc with the buck-boost converter.

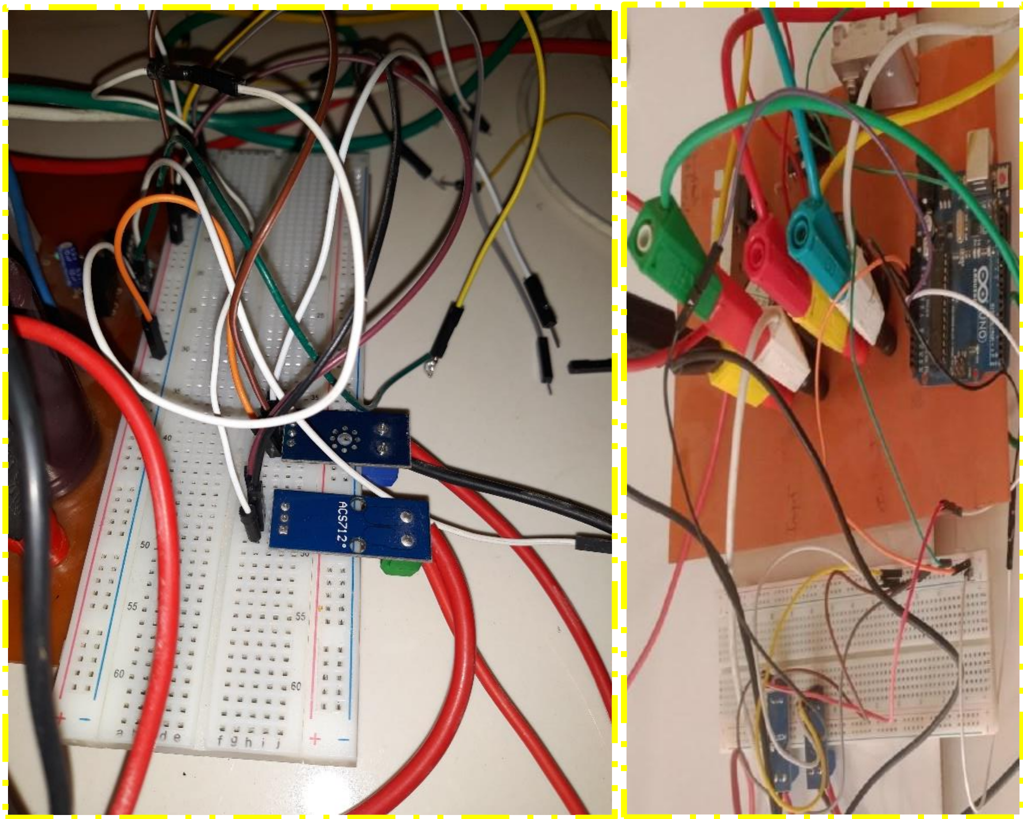

Figure III.14. *Full system setup.*

III.3.1. Buck-boost:

By performing the complete assembly, the Arduino microcontroller use -the MPPT PO algorithm- and measures the IPV and VPV signals, which are filtered through the A0 and A1 pins. The microcontroller will process this information and multiply it to calculate the average power. We simulated the operation of the system for different cyclic ratio values *D* to confirm the operating modes:

D	**Vpv (v)**	**Vload (v)**
40%	20	18
70%	20	25.74

Table III.2. *The buck-boost test with different D.*

The figure (III.14) shows the output voltage of the chopper during the test with a cyclic ratio *D* of 40%.

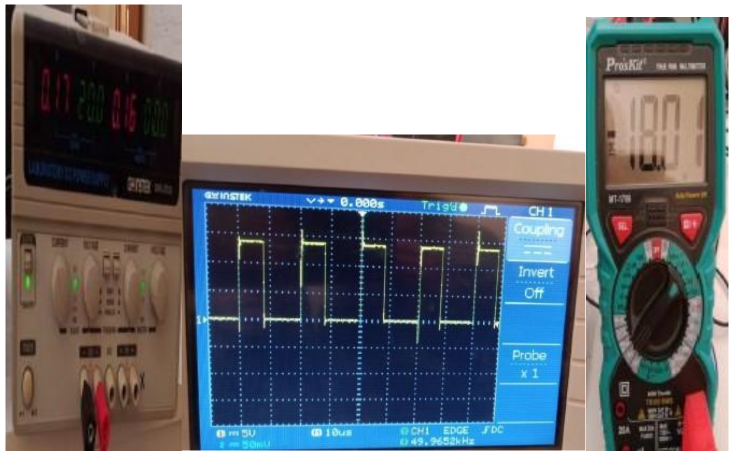

Figure III.15. *The tension variation with D=40%.*

The figure (III.15) shows the output voltage of the chopper during the test with a cyclic ratio *D* of 40%.

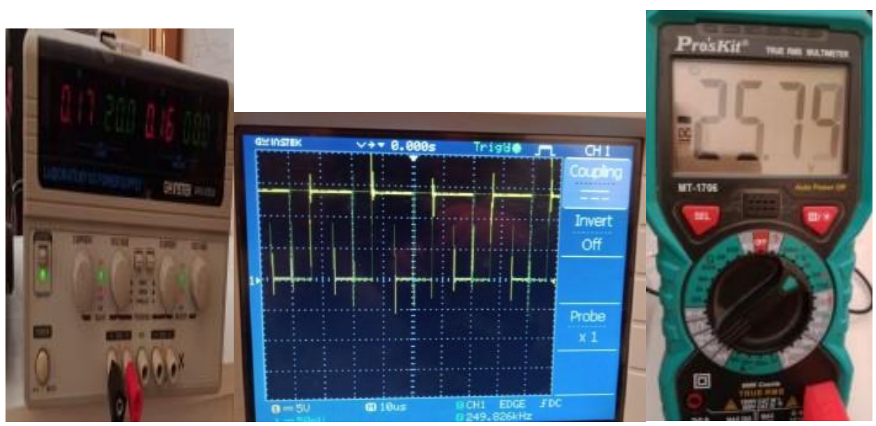

Figure III.16. *The tension variation with D=70%.*

III.3.2. The MPPTc:

The practical results of current, power, voltage and cyclic ratio to the realized photovoltaic system are given on the figures (III.17) (III.18) (III.19) (III.20), for a resistive load of 50 and with fixed illumination, applying the P&O algorithm.

These results show that the PV system functions and the speed of maximum power point tracking and oscillation around the operating point of the P&O algorithm.

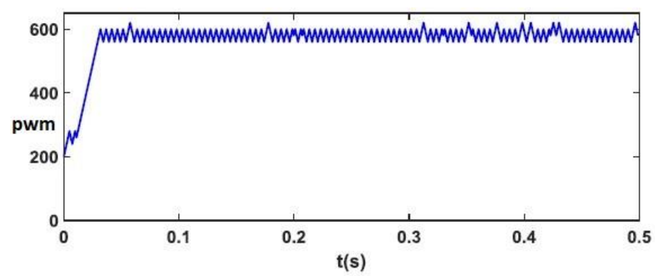

Figure III.17. *The duty cycle variation.*

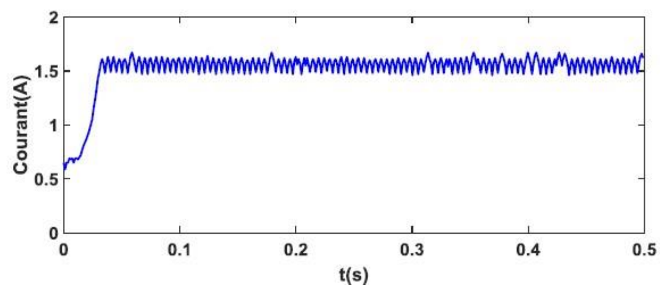

Figure III. 18 *The current Ipv variation.*

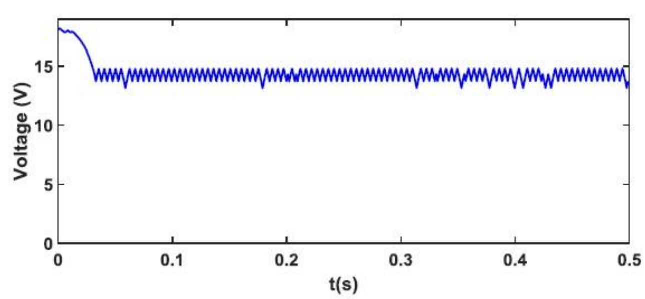

Figure III.19. *The voltage Vpv variation.*

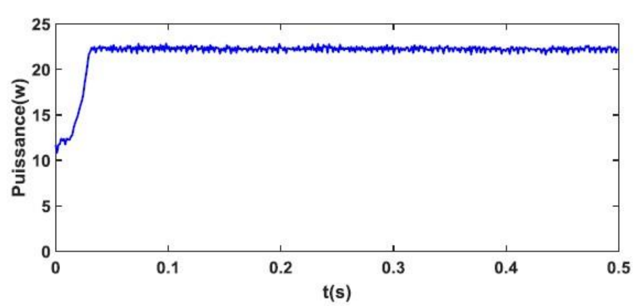

Figure III.20. *The power variation.*

III.4. Conclusion:

In this chapter, we discussed the practical implementation of a buck-boost chopper using the Arduino UNO board for a PV system. We also introduced the various components utilized in the system, such as the 80 M-36 EMC module, current sensor, and voltage sensor. To evaluate the system's performance, we conducted tests using the MPPT control method known as P&O.

The purpose of the MPPT control method is to maximize the power transfer from the PV module to the load by continuously tracking the maximum power point. By applying the P&O algorithm, we aimed to optimize power extraction from the PV system.

The test results demonstrated that the PV system effectively transferred the maximum power available from the PV module to the load. This outcome signifies the successful operation of the MPPT control method in achieving optimal power conversion and utilization within the PV system.

GENERAL CONCLUSION

General conclusion

This thesis focuses on the simulation and implementation of a photovoltaic system using Buck-Boost converters. The versatility of this converter, which can raise or lower voltage, allows the system to adapt to varying weather conditions and load fluctuations. The primary objective of this study is to enhance the efficiency of photovoltaic systems by exploring different Maximum Power Point Tracking (MPPT) control algorithms.

The contribution of this work lies in the understanding and implementation of an MPPT control algorithm capable of continuously tracking the maximum power point under diverse atmospheric conditions. The initial phase involved providing an overview of PV systems, including the fundamental principles of the PV effect, PV cells, and the performance of photovoltaic generators. Various types of DC-DC converters used in photovoltaic systems, such as the Devotee Chopper, Booster Chopper, and Blended Chopper (Devotee-Booster), were examined. Among the MPPT control algorithms discussed, the Perturb and Observe (P&O) algorithm was chosen for its simplicity, relying solely on voltage and current measurements from the photovoltaic panel. The paper elaborates on the tracking mechanism employed by the P&O algorithm to extract maximum power, highlighting its ability to maintain the optimum point even when faced with sudden variations in illumination or load.

The simulation and implementation results provide validation for the effectiveness of both the DC-DC converter and the MPPT control algorithm utilized in the study. The DC-DC converter demonstrates its capability to adjust the output voltage to optimal levels by either increasing or decreasing the voltage provided by the PV generator through manipulation of the duty cycle. This feature allows the converter to adapt to changing conditions and ensures efficient power transfer within the system. On the other hand, the MPPT control algorithm, specifically the Perturb and Observe (P&O) algorithm, exhibits accurate tracking of the maximum power point of the photovoltaic generator. By minimizing oscillations around the reference point, the algorithm optimizes power extraction from the PV module. Additionally, it enables the system to maintain the optimal operating point even in the face of unexpected variations in illumination or load conditions. As a result, the overall efficiency of the photovoltaic system is enhanced. In conclusion, the simulation and implementation results confirm the effectiveness of the DC-DC converter and the selected MPPT control algorithm in maximizing power generation and improving the overall performance of the photovoltaic system.

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Abstract:

The photovoltaic (PV) power generation systems have a small impact on the environment and are suitable for a wide range of applications—it is cheap, available everywhere and readily convertible to useful electrical energy by photovoltaic panels. It has been estimated that for meeting the world's power requirement, an area of the size of Algeria is required to be covered completely with solar panels. Thus, in order to efficiently use this resource, various control strategies like MPPT, etc., are developed. By utilizing maximum power point tracking, we can utilize the full energy that would be wasted from the solar panel by increasing or decreasing the duty cycle. For that, an efficient power electronics converter is required. This dissertation aims to study the analysis, the designing and the testing of such a buck-boost converter.

Key words:

Photovoltaic energy, Photovoltaic panels, Maximum power point tracking, Dc-Dc power converters.

Résumé:

Les systèmes de production d'énergie photovoltaïque (PV) ont un faible impact sur l'environnement et conviennent à un large éventail d'applications - ils sont bon marché, disponibles partout et facilement convertibles en énergie électrique utile à l'aide des panneaux photovoltaïques. Il a été estimé que pour répondre aux besoins énergétiques mondiaux, une zone de la taille de l'Algérie doit être entièrement recouverte de panneaux solaires. Ainsi, afin d'utiliser efficacement cette ressource, diverses stratégies de contrôle telles que MPPT, etc., sont développées. En utilisant le suivi du point de puissance maximal, nous pouvons utiliser toute l'énergie qui serait gaspillée par le panneau solaire en augmentant ou en diminuant le rapport cyclique. Pour cela, un convertisseur d'électronique de puissance efficace est nécessaire. Ce mémoire vise à étudier l'analyse, la conception et le teste d'un convertisseur buck-boost.

Mots clés :

Énergie photovoltaïque, Panneaux photovoltaïques, Suivi du point de puissance maximale, Convertisseurs de puissance continu-continu.

الملخص:

أنظمة توليد الطاقة الكهروضوئية لها تأثير ضئيل على البيئة وهي مناسبة لمجموعة واسعة من التطبيقات - فهي رخيصة ومتوفرة في كل مكان وقابلة للتحويل بسهولة إلى طاقة كهربائية مفيدة عن طريق الألواح الكهروضوئية. تشير التقديرات إلى أنه لتلبية متطلبات الطاقة العالمية ، يلزم تغطية مساحة بحجم الجزائر بالكامل بألواح شمسية. وبالتالي ، من أجل استخدام هذا المورد بكفاءة ، تم تطوير استراتيجيات تحكم مختلفة مثل MPPT ، وما إلى ذلك. من خلال استخدام الحد الأقصى لتتبع نقاط الطاقة ، يمكننا الاستفادة من الطاقة الكاملة التي سيتم توليدها من الألواح الشمسية عن طريق زيادة أو تقليل دورة العمل. لذلك ، يلزم وجود محول فعال لإلكترونيات الطاقة. تهدف هذه الأطروحة إلى دراسة, تصميم واختبار لمحول الطاقة مستمر-مستمر.

كلمات مفتاحية :

الطاقة الكهروضوئية ، الألواح الكهروضوئية ، الحد الأقصى لتتبع نقطة الطاقة MPPT ، محولات الطاقة DC-DC.