Order N° : ....

Serial Number: ....

People's Democratic Republic of Algeria

Ministry of Higher Education and Scientific Research

Final Master Dissertation

Presented at

The University of Echahid Mohamed LakhdarAmmara of El Oued

Faculty of Technology Department of

Electrical Engineering In preparation

for obtaining the

ACADEMIC MASTER

Electrical Control

Presented by KHECHEKHOUCHE MOHAMMED

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Theme

Realization and Implementation of a Boost Chopper supplying Different Loads

Discussed in 17/06/2021 in front of the committee composed by:

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Academic Year : 2020/2021

Dedication

I dedicate this modest work to:

- My dear Mather and My dear Father who have not stopped encouraging me and helping me to follow well my studies.
- My sisters **Samira, Sara, Fatma,** and **Rahmma** and my brother **Yassine**.
- All my family and my best friends who have supported me during my studies.

Khechekhouche Mohammed Tahar

Dedication

I dedicate this modest work to:

- My dear Mather and my dear Father who have not stopped encouraging me and helping me to follow well my studies.
- My brother **Aymen and Ilyes**, and my sister **Halima**.
- My grandmother **Halima**, my uncles **Nekker, Yacoube, Massoud and Kamel**.
- All my family, my best friend who have supported me during my studies.

Reghioua Mohammed

Thanks and gratitude

First of all, we thank ALLAH who gave us this well there for us to live this day, ALLAH who gave us the strength and patience to finish this job.

We would like to express our deep appreciation and gratitude to supervisors: **Dr. BORNI Abdelhalim** and **Dr. BESSOUS Noureddine** that have proposed and directed this Master dissertation. Our thanks also go to the members of the committee for accepting the discussion of this work to improve it.

We would like to thank the officials and all the staff Department of Electrical Engineering for the facilities they have granted us to perfect this work.

Finally, we would like to thank all those who have contributed, closely or by far, to our training and the development of this modest work.

ملخص:

الهدف من المذكرة هو دراسة وانجاز مهشر اشارة كهربائية من المستمر الى المستمر. ثم سلطنا الضوء على دراسة المحول الرافع (القاطع الرافع) وكيفية انجازه تطبيقيا وكذا طريقة تحديد مختلف القيم للحصول على قيم متوافقة مع مواصفات الجانب التجريبي. في دراستنا هذه ، تحققنا من العمل المنجز بناء على دراسة مقارنة. حيث ركزت هذه الدراسة على محاكاة القاطع الرافع اثناء التشغيل من خلال معالجة جميع قيم عناصرها. بالإضافة الى ذلك ، تم ادراج واستنتاج جميع العمليات التحليلية لمعادلات لنظام كهربائي المعروض. كل هذا كان سعيا لإيجاد افضل نقطة تشغيل المحول. حاولنا كذلك الحصول على اداء ومردود جيدين للمحول الرافع المنجز تطبيقيا ومقارنته بنتائج المحاكاة. بفضل الانجاز التطبيقي ، قمنا بتجسيد الشكل الحقيقي للمحول بنجاح والذي غالبنا ما يتم استعماله في جميع نماذج وتجهيزات الطاقات المتجددة.

Abstract:

The goal of the master dissertation is to study and realize an electrical signal chooper from DC to DC (Chopper) to implement it. Then, we shed light on the study of the elevator converter (Boost Chopper) with its implementation. We determine the parameters to have values compatible with the specifications of the experiment. In our study, we verified the work done based on a comparative study. This study focused on simulations of the boost chopper during operation by processing all the values of the chopper elements. In addition, the analytical processes of the equations are all deduced from the posed electrical system. All of this is done with efforts to find the best operating point. We also tried to get a good performance of the realized boost converter and compare it with the simulation results. Thanks to the prototype's implementation, we have embodied the true form of the chopper, which is integrated into almost all models of renewable energies.

Résumé :

Le but du mémoire est d'étudier et de mettre en œuvre un convertisseur de signal électrique du continu au continu (Hacheur). Ensuite, nous éclairons l'étude du convertisseur élévateur (hacheur élévateur), ainsi que la réalisation de celui-ci afin de l’implémenter. Nous avons déterminé les paramètres pour avoir des valeurs compatibles avec le cahier de charge de l’expérimentation. Dans notre étude, nous avons vérifié le travail effectué en se basant sur étude comparative. Cette étude a focalisé sur les simulations de l’hacheur élévateur pendant le fonctionnement en traitant toutes les valeurs des éléments de l’hacheur. En plus, les processus analytiques des équations tout déduites du système électrique posé. Tout cela est effectué avec des efforts pour trouver le meilleur point de fonctionnement. Nous avons aussi essayé d’avoir un bon rendement du convertisseur élévateur réalisé et de le comparer avec les résultats de simulation. Grâce à l'implémentation réalisée, nous avons incarné la véritable forme de l'hacheur qui est intégré presque dans tous les modèles des énergies renouvelables.

Key words :

boost chopper : القاطع الرافع

duty cycle : دورة العمل

wave form : شكل الموجة

buck chopper : القاطع الخافض

supplying : يغذي

loads : حمولات

Symbols

V_e **:** typical input voltage V_s **:** desired

output voltage V_{OUT} **:** desired output

voltage V_{IN} **:** typical input voltage

$V_{IN(min)}$ **:** minimum input voltage

V_D **:** forward voltage of the rectifier diode

$I_{OUT(max)}$ **:** maximum output current necessary in the application

$I_{D\ moy}$ **:** average current of the rectifier diode .

$I_{SW(max)}$ **:** the maximum switch current in the system is calculated

$I_{LIM(min)}$ **:** minimum value of the current limit of the integrated switch (given in the data sheet)

I_S **:** maximum output current necessary in the application

I_D **:** average current of the rectifier diode

ΔI_L**:** inductor ripple current calculated

ΔV_{OUT} **:** desired output voltage ripple.

$\Delta V_{OUT(ESR)}$ **:** additional output voltage ripple due to capacitors ESR.

k : duty cycle calculated

α **:** rapport cyclique

: efficiency of the converter, e.g. estimated 80%

D:duty cycle calculated

: minimum switching frequency of the converter

L:selected inductor value

P_D **:** the power dissipation of the diode

$C_{OUT(min)}$ **:** minimum output capacitance.

ESR : equivalent series resistance of the used output capacitor

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CHAPTER II: Overview and the constitutions of a boost converter

CHAPTER III: Results and Discussion (Simulation and realization)

General Introduction

Power electronics is the part of electrical engineering that deals with changes in the presentation of electrical energy. For this, it uses static semiconductor converters. Thanks to progress on these components and their implementation,[34] the dc-dc converter been invented.

The DC-DC converters have become essential components in many industrial and military applications over the past decades. Thanks to their increasingly high efficiency, their small footprint as well as their reduced weight and costs, they have replaced conventional linear power supplies, even for low power levels.

In many technical applications, it is required to convert a constant voltage DC source into a variable voltage DC output. DC-DC converter converts voltage directly from DC to DC and is known simply as DC converter. The AC transformer is equivalent to an alternating current transformer with a continuously variable cycle ratio. It can be used to step down or step up a DC voltage source, like a transformer.

DC converters are widely used for traction motor control in electric automobiles, trolley cars, marine hoists, forklifts trucks, and mine haulers. They provide high efficiency, good acceleration control and fast dynamic response. They can be used in regenerative braking of DC motors to return energy back into the supply. This attribute results in energy savings for transportation systems with frequent steps. DC converters are used in DC voltage regulators.[35]

In this work, we will devote our study on DC-DC Boost Converter, where we will study a theory on it, and then we will put that study under trial between the truth and the theoretical, where we will compare the real results with the theoretical results, then we will judge the effectiveness of this converter.

The Master dissertation is organized as follows:

- Chapter I: It presents a bibliographical summary on converters. Precisely, this chapter has focused the study on the boost chopper.
- Chapter II: The analytical study dedicated to the realization of a chopper is well presented in this part.
- Chapter III: The last chapter presents a comparative study with a discussion of the results obtained.

We finished our work by general conclusion.

CHAPTER I : Generalities about The Boost Converter :

I.1 Introduction:

The demand for high-efficiency DC/DC converters is increasing dramatically, especially for use in battery-operated devices such as cellular phones and laptop computers. In these devices, it is intrinsic to extend battery life. By employing DC-DC converter power-saving techniques, power efficiency can be significantly increased, thereby extending battery life [1]. The boost is a popular non-isolated power stage topology, sometimes called a step-up power stage [2].

I.2 Definition of a DC/DC converter:

The chopper or DC - DC converter is a power electronics device that allows the (average) voltage value of a DC voltage source to be modified, using several electronic switches controlled with high efficiency [3]. Figure (I.1) shows the global schematic diagram of the chopper.

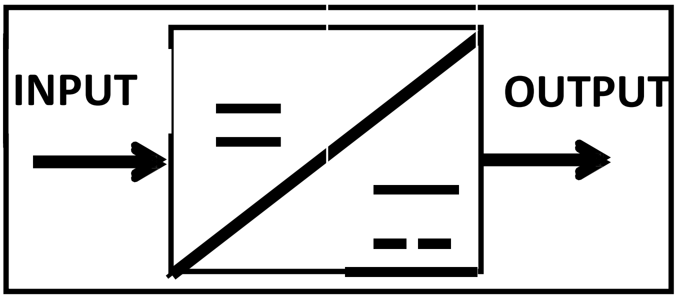


Fig I.1: schematic diagram of the chopper [4].

I.3 Types of DC/DC converter:

The study of the DC-DC converters is one of the simplest studies. The differences in chopper structures depend on the specifications imposed on the system for choosing the type of DC-DC converter, taking into account the nature of the input and output networks.

Different types of voltage converters can be given by [5]:

*- Buck-Boost converter

*- Buck converter

*- Boost converter

I.3.1 Buck-Boost converter:

A Buck-Boost converter contains a switching power supply that converts a direct voltage into another direct voltage of different values, of reverse polarity. Figure (I.2) shows the operating principle of this converter. Figure (I.3) illustrates the conduction intervals of the switch and the diode as well as the waveforms of the currents (left) and voltages (right) [6].

I.3.1.1 Structure of Buck-Boost converter:

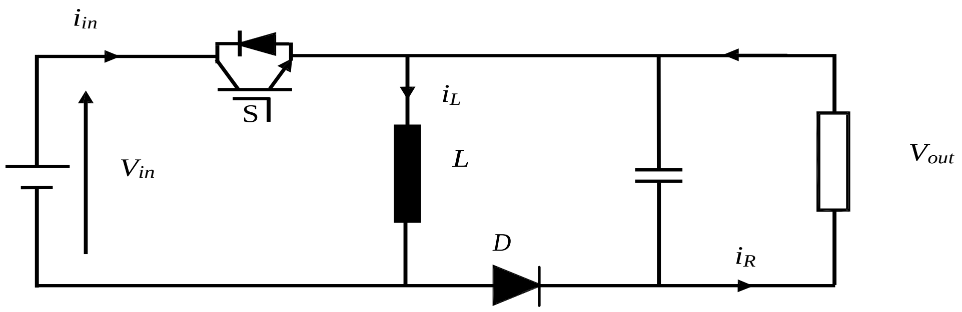


Fig I.2: Basic diagram of a buck-boost converter [7].

I.3.1.2 Waveforms of Buck-Boost converter:

The current and voltage waveforms of the Buck-Boost converter as follow :

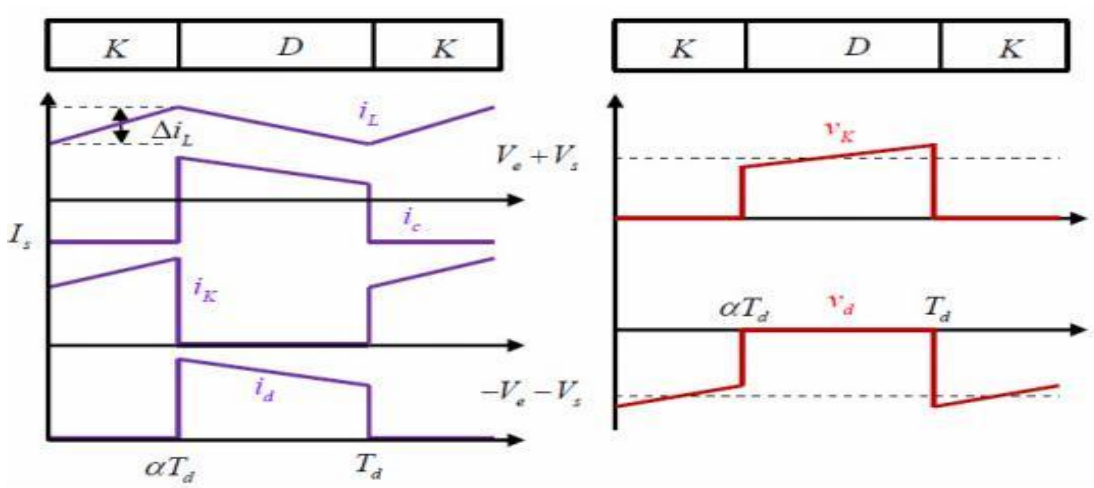


Fig I.3: Waveforms of the currents and voltages of the Buck-boost converter[8].

I.3.1.3 Applications of Buck-boost converter:

The Buck-boost converter has several uses in many areas, We mention the following uses :

- It is used in the self regulating power supplies.

- It has consumer electronics.
- It is used in the Battery power systems.
- Adaptive control applications.
- Power amplifier applications

I.3.1.4Advantages of Buck Boost Converter:

This converter has several advantages, including the following:

- It gives higher output voltage.
- Low operating duct cycle.
- Low voltage on MOSFETs [9].

I.3.1.5 Disadvantages of Buck Boost Converter:

Input current and charging current of the output capacitor is discontinuous as it results in large filter size and more EMI issues.

-Output is inverted which results in complex sensing and feedback circuit. As sensed voltage is negative, the inverting op-amp is needed for feedback and closed-loop control.

-High gain cannot be achieved with this converter type as efficiency is poor for high gain (i.e. very small duty cycle or large duty cycle).

-There is no isolation from the input side to the output side which is very critical for many applications.

-Transfer function of the converter contains the right half-plane as zero which introduces control complexity. Hence it is very difficult to control such converter type [10].

I.3.2 Buck converter:

A step-down chopper or series chopper is a switching power supply that converts a DC voltage into another DC voltage of lower value, this type of converter is used for applications that can be classified into two categories:

*- Applications aimed at obtaining a fixed (and sometimes regulated) DC voltage from a higher DC voltage generator.

*- Applications allowing to obtain an adjustable voltage but always lower than that present at the input [11].

I.3.2.1 Structure Buck converter:

And next, we're going to show the Buck converter Structure:

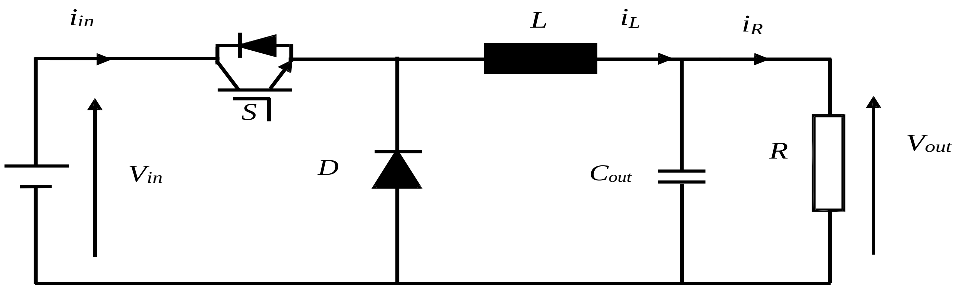


Fig I.4: Basic diagram of a buck converter[12].

I.3.2.2 Waveforms of Buck converter:

The current and voltage waveforms of the Buck converter as follow :

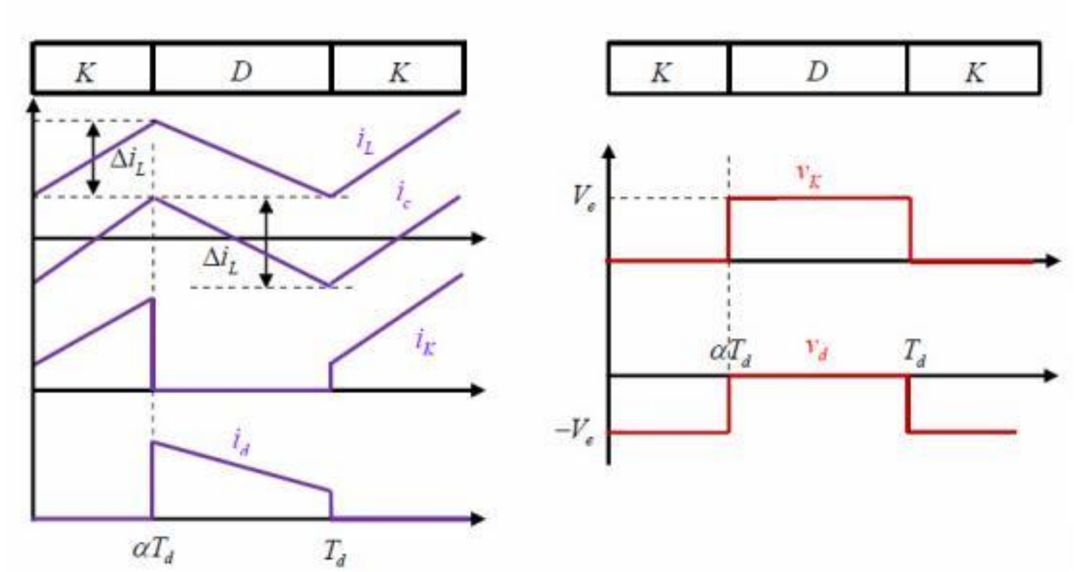


Fig I.5 : Buck converter currents and voltages waveforms[6].

I.3.2.3 Applications of Buck converter:

It has many uses, some of which are mentioned in the following:

-USB On-The-Go

-Battery Charger-

-Solar Chargers

-Power Audio Amplifiers

-Pure Sinewave Power Inverter

-Quadcopters

-Brushless Motor Controllers

-Brushed Motor Controllers

-POL Converter for PCs and Laptops[13].

I.3.2.4 Advantages and Disadvantages of Buck Converters:

The output voltage is independent of load, so Volt regulation is excellent output is linked with the input voltage, so the line regulation is poor output voltage < Input voltage, dependent on each other no isolation between supply and low voltage section and can have potential safety problem [14].

I.3.3 Boost converter:

The DC–DC boost converter (BC) is a switching power converter with a higher output voltage value than its input voltage. Due to their small size, power, and cost-efficiency; the BCs are used in many industrial applications [15].

I.3.3.1 Structure Boost converter (components):

It has two complementary switches positioned so as to form a bi-positional "power-pole" switch:

- The first is a switch that can be controlled in voltage or current on starting and blocking, placed in parallel with the power source and the inductor. This switch may be of the BJT bipolar transistor, MOSFET field-effect transistor, or IGBT insulated gate bipolar transistor.

- The second is a self-priming and locking unidirectional switch, placed in anti-parallel with the Power supply-controllable switch branch.

Passive elements L and C placed in order serving as inductive and capacitive accumulators from the input to the output and forming a filter for the current and the voltage respectively [4].

I.3.3.1.1 Inductance element :

Large inductance values tend to increase the start time slightly while small inductance values allow the coil current to surge to higher levels before the switch is turned off. It is recommended to use ferrite core inductors or equivalent inductors. It must be ensured that the rated inductor saturation current of the highest efficiency should be used in a coil with low DC resistance. The inductance of the boost is determined based on the maximum permissible ripple current at the minimum duty cycle, α, at the maximum input voltage, V input. Given that the switching frequency, Fs, the value of the boost inductor can be optimally determined to set the operating mode of the transformer in the required load and line range [16].

I.3.3.1.2 Diode element:

The boost diode reverse voltage rating is limited to the output voltage. The diode conducts when the power switch is in the “OFF” state and provides a current path for the inductor to the output. Similar to the IGBT's the worst–case peak current through the diode occurs at low line input voltage and maximum load. Other important considerations in selecting the diode besides its ability to block the required off–state voltage stress. In addition, they have sufficient peak and average current handling capability which have also the fast switching characteristics, low reverse–recovery, and low forward voltage drop [16].

***- Diode properties :**

It has many characteristics, the most important of which are the following:

- A passive switch
- Single-quadrant switch
- can conduct positive on-state current
- can block negative off-state voltage
- provided that the intended on-state and off-state operating points lie on the diode i-v characteristic, then switch can be realized using a diode [17].

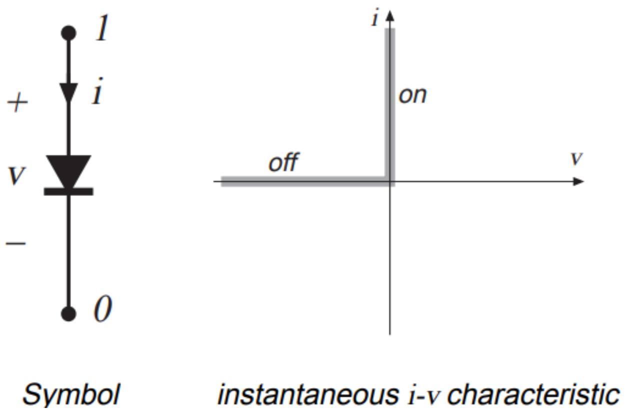


Fig I.6 : The Diode[17].

I.3.3.1.3 Transistor:

***-MOSFET « Metal Oxyd Silicon – Filed Effect Transistor »:**

It is a switch that can be controlled on and off by a voltage between its gate and its source. It is characterized by:

- able to switch low and moderately low powers
- very fast in terms of switching frequency
- Isolation of the "Gate" gate control part of the Drain-Source power part
- Very small dimensions (submicronic technology)
- Very low consumption of power
- High input impedance
- Positive electro thermal behavior (increased on-state resistance when temperature rises) which prevents thermal runaway
- Presence in applications in the field of telecommunications and conversion at low power and high frequency [4].

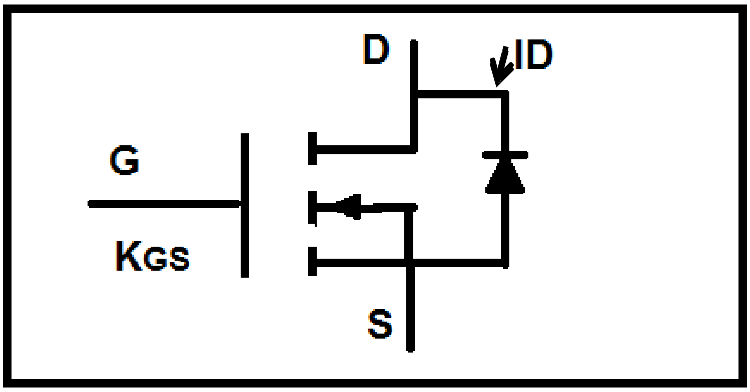
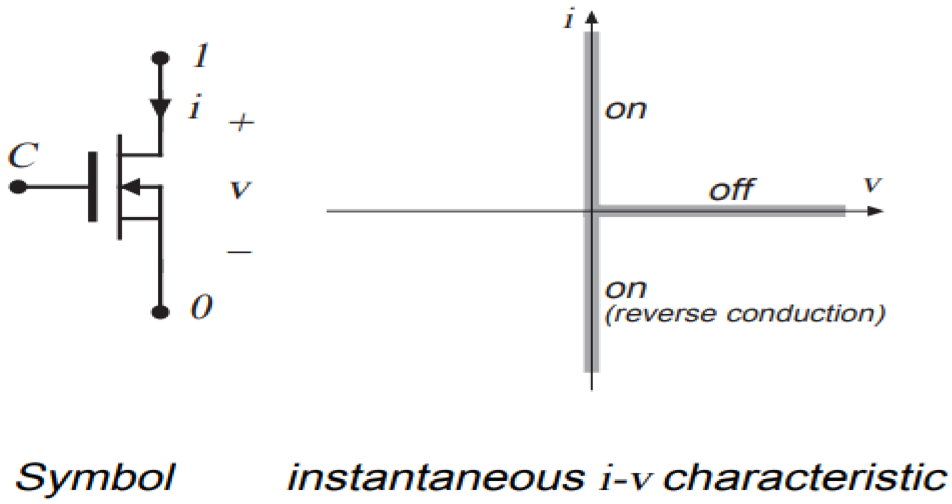


Fig I.7 : Diagram of MOSFET transistor[18].



FigI.8 : The I –V of MOSFET transistor[17].

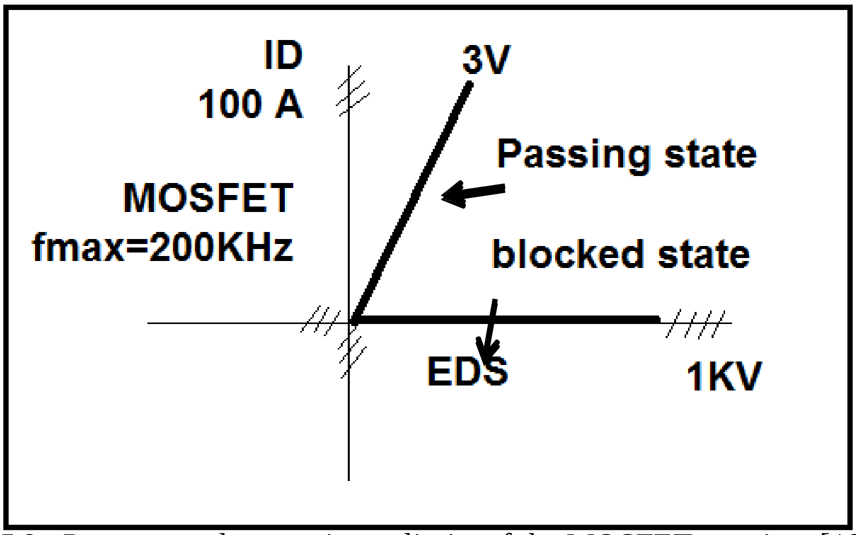


Fig I.9 : Property and approximate limits of the MOSFET transistor[18].

***- IGBT « Insulated Gate Bipolar Transistor »**

Conduction in the IGBT transistor is turned on or off by applying an appropriate voltage to the trigger. The three terminals are named collector C, emitter E and base B. The maximum frequency is equal to 50 kHz [18].

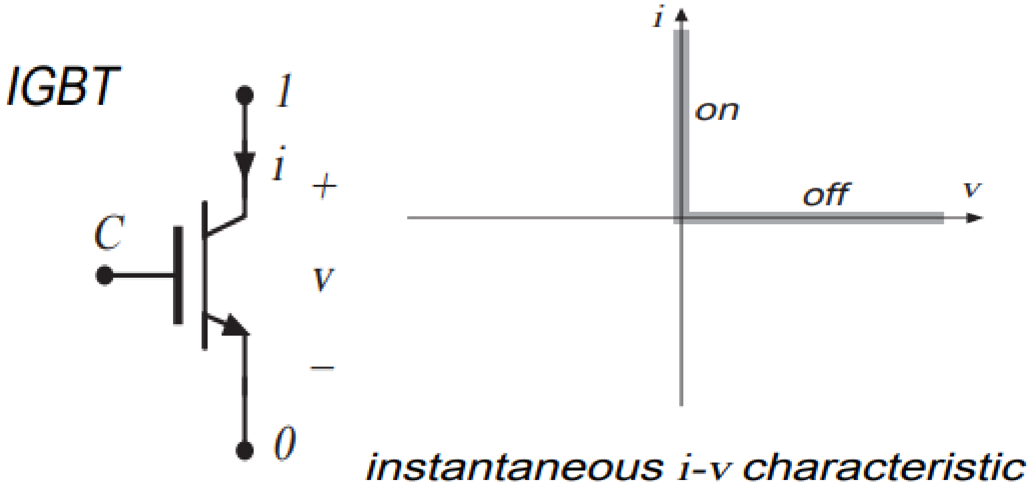


Fig I.10 : The I –V of IGBT transistor[17].

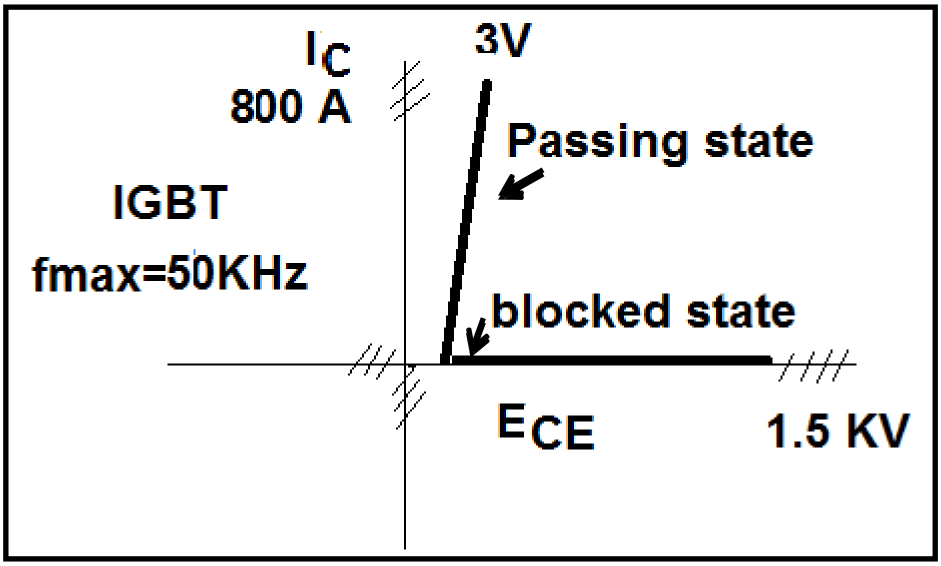


Fig I.11 : Property and approximate limits of the IGBT transistor[18].

***- BGT « Bipolar Junction Transistor »:**

It is a switch that can be closed and opened by a current at the base. It supports medium powers and medium switching frequencies. It is especially found in home automation modules and small businesses such as chargers, connectors and interfaces [4].

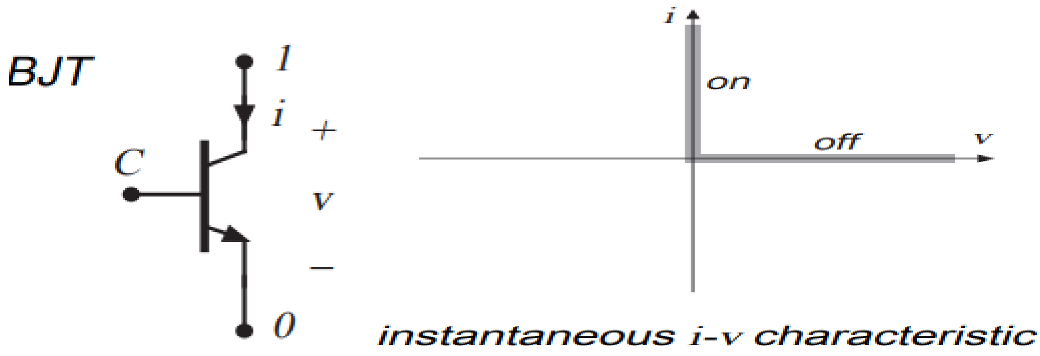


Fig I.12 : The I –V of BJT transistor[17].

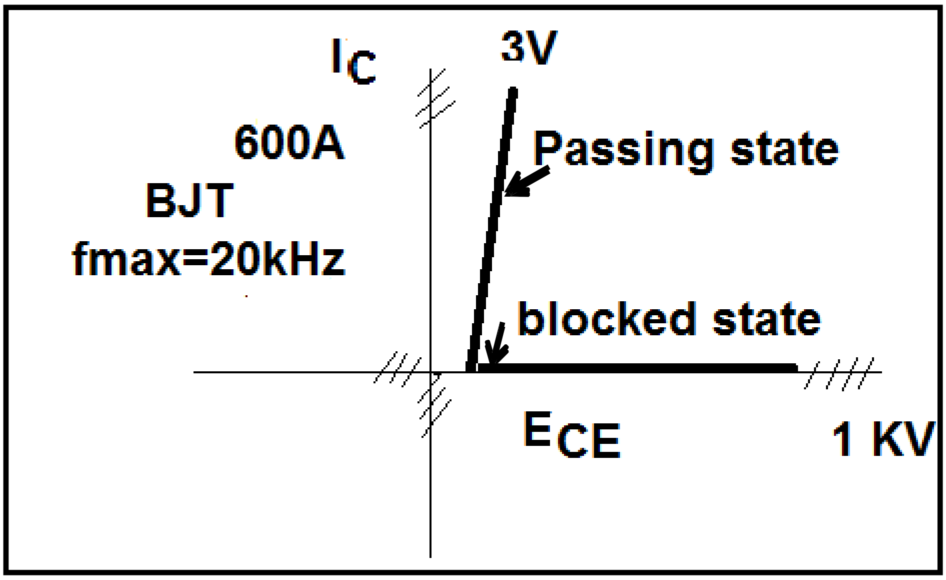


Fig I.13 : Property and approximate limits of the BJT transistor[18].

***- BJT and IGBT properties :**

The characteristics of these transistors are so many and we mentioned some of them in what came:

- An active switch, controlled by terminal C
- Single-quadrant switch
- can conduct positive on-state current
- can block positive off-state voltage
- provided that the intended on-state and off-state operating points lie on the transistor i-v characteristic, then switch can be realized using a BJT or IGBT[17].

I.3.3.1.4 Duty cycle:

The duty cycle α is the ratio between the time when the switch S is in the on state (S ON) and the period as shown by the following relation:

$$\alpha = \frac{The.time.when.the.switch.ON}{The.period} = \frac{T\ (ON\ )}{T} \quad (I.1)$$

With :

0 <α< **1** [18].

I.3.3.1.5 Capacitance element :

The primary criterion for selecting the output filter capacitor is its capacitance and equivalent series resistance, ESR. Since the capacitor’s ESR affects efficiency, low-ESR capacitors will be used for best performance. For reducing ESR is also possible to connect few capacitors in parallel. The output filter capacitors are chosen to meet an output voltage ripple specifications, as well as its ability to handle the required ripple current stress[19].

I.3.3.1.6 Basic diagram of a Boost converter :

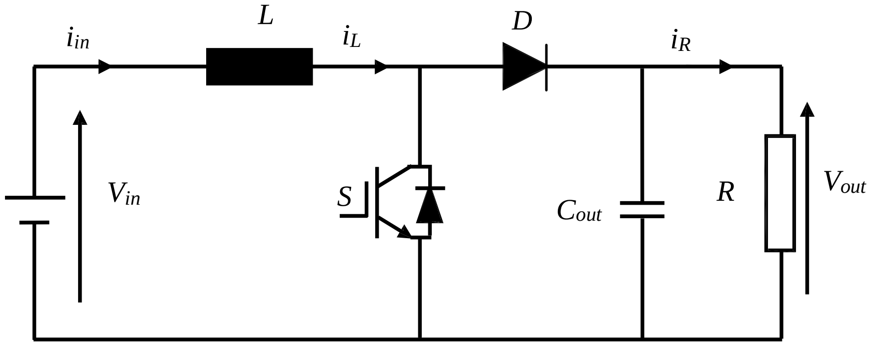


Fig I.14: Schematic of boost converter[20].

I.3.3.1.7 Types of the Boost converter :

***-IDD Interlaced Double Chopper Booster:**

These's a diagram for Interlaced Double Chopper Booster :

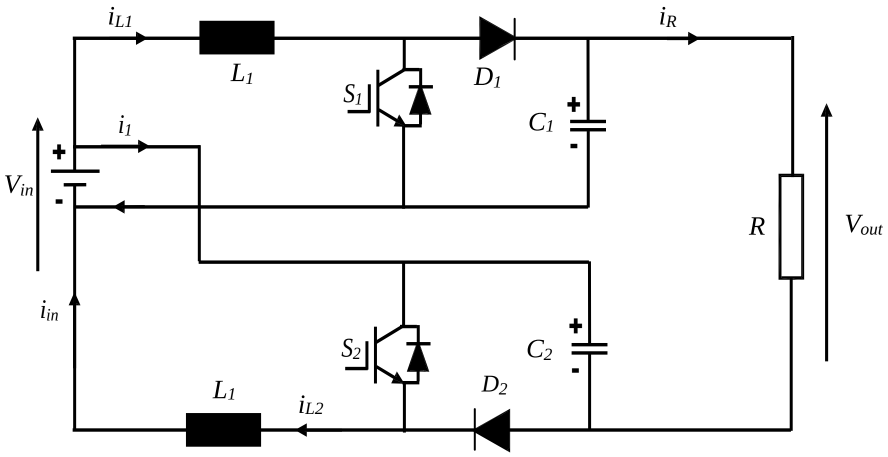


Fig I.15: Schematic of IDD - Interlaced double booster chopper[21].

The output voltages can therefore be expressed in the following form:

$$V_{OUT} = V_{IN} * \frac{1+\alpha}{1-\alpha} \tag{I.2}$$

***-Single-switch quadratic boost:**

And here it is the diagram of Single-switch quadratic boost :

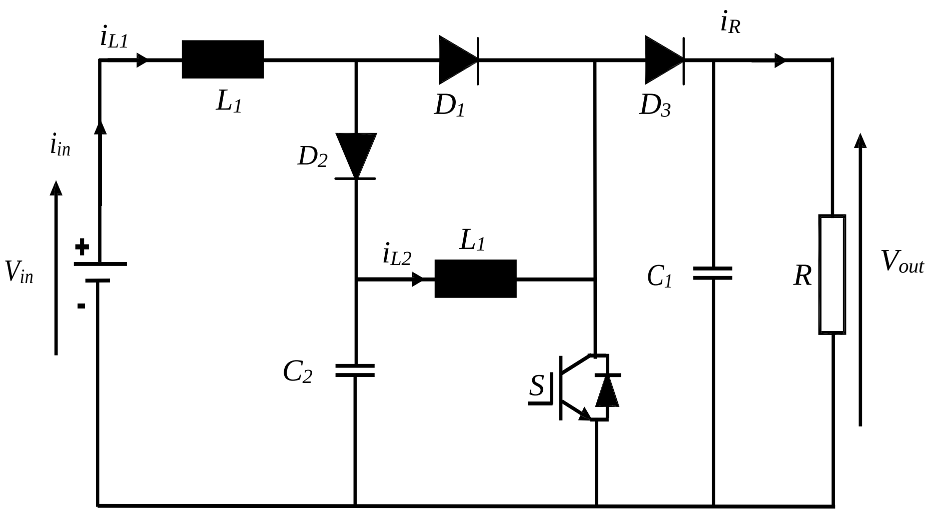


Fig I.16: Schematic of Single-switch quadratic boost[22].

The voltage gain can be written as follows :

$$\frac{V_{OUT}}{V_{IN}} = \frac{1}{(1-\alpha)^2} \tag{I.3}$$

***-Double cascade booster chopper:**

These's a diagram for Double cascade booster chopper :

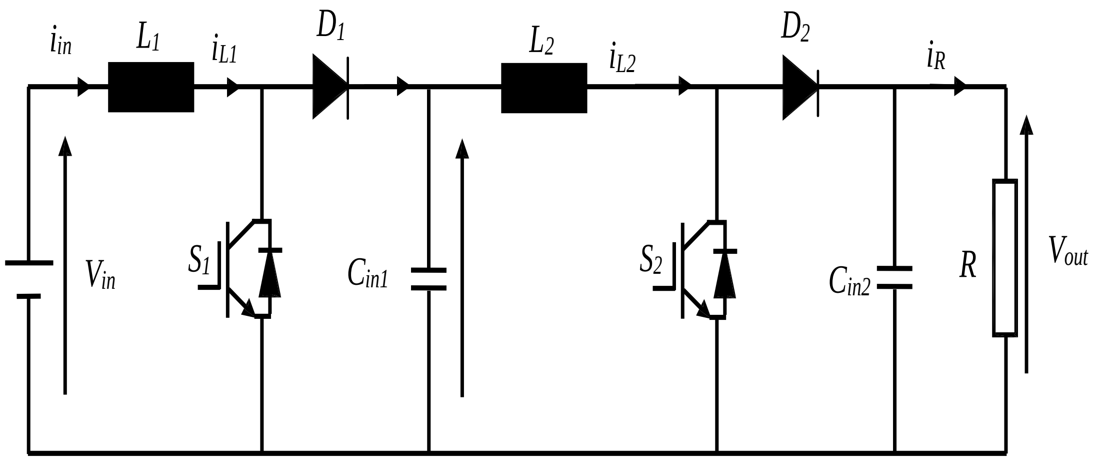


Fig I.17: Schematic of Single-switch quadratic boost[21].

The ratio of the double cascade booster chopper can therefore be written as follows:

$$\frac{V_{OUT}}{V_{IN}} = \frac{1}{1-\alpha 1} * \frac{1}{1-\alpha 2} \qquad (I.4)$$

I.3.3.2 Principle and operation of Boost converter:

According to the chopping principle (high frequency switching), the chopper transfers energy from a source to a load by recharging and discharging storage cells L and C at the same ON and OFF rate of the switch.

During closing, the diode will be reverse biased and it blocks spontaneously. The coil recharges with a current from a previous minimum level to another maximum. At the end of this closing time ton, the switch opens at the request of an external command applied in the form of a duty cycle between the duration ton and the switching period T. During this opening OFF, the Acquired inductive charge will be transmitted to the output capacitor C and to the load element (Resistance R for example) through a freewheel link via the diode which is forward biased and becomes conductive [4].

The DC/DC converter has two modes, a Continuous Conduction Mode, CCM for efficient power conversion and Discontinuous Conduction Mode DCM for low power or stand-by operation [23].

I.3.3.3 Boost Converter Analysis:

I.3.3.3.1 Continuous Conduction Mode :

Under CCM, it is divided into two modes:

Mode 1 begins when the switch SW is turned on at t = 0 as shown in Figure I.15. The input current which rises flows through inductor L and switch SW. During this mode, energy is stored in the inductor and load is supplied by capacitor current.

Mode 2 begins when the switch is turned off at t = kT. The current that was flowing through the switch would now flow through inductor L, diode D, output capacitor C, and load R as shown in Figure I.16. The inductor current falls until the switch is turned on again in the next cycle. During this time, energy stored in the inductor is transferred to the load together with the input voltage. Therefore, the output voltage is greater than the input voltage and is expressed as :

$$V_{OUT} = \frac{1}{1-\alpha} V_{in} \tag{I.5}$$

where Vout is the output voltage, α is duty cycle, and Vin is input voltage [24].

In this mode (CCM) the current of the inductor is always between **Im** and **IM**

Where **Im** is the minimum value of the inductor current and **IM** is the highest value of the inductor current

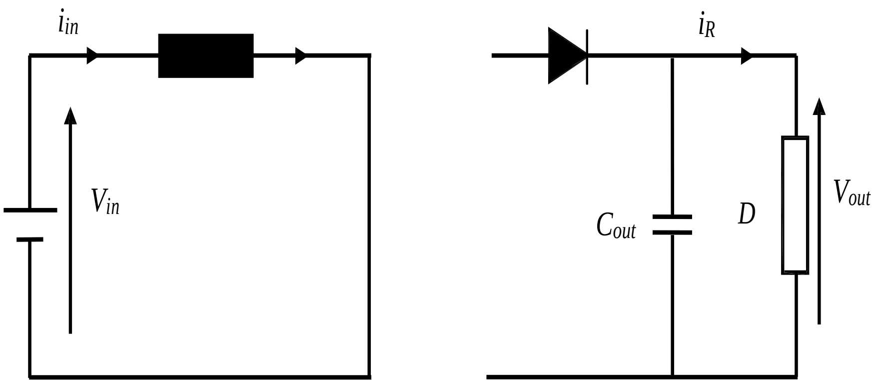


Fig I.18: Circuit diagram of boost converter during Mode 1[25].

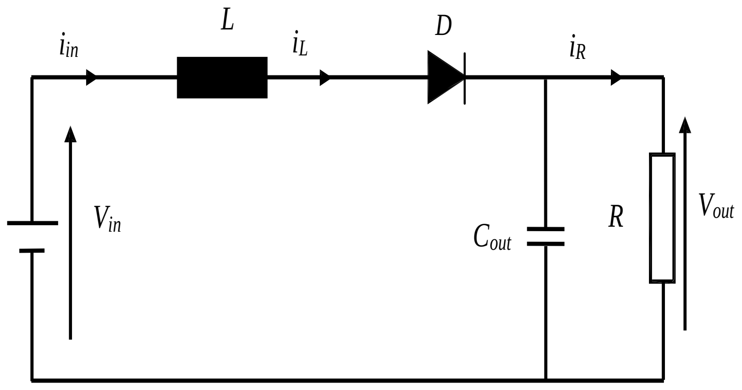
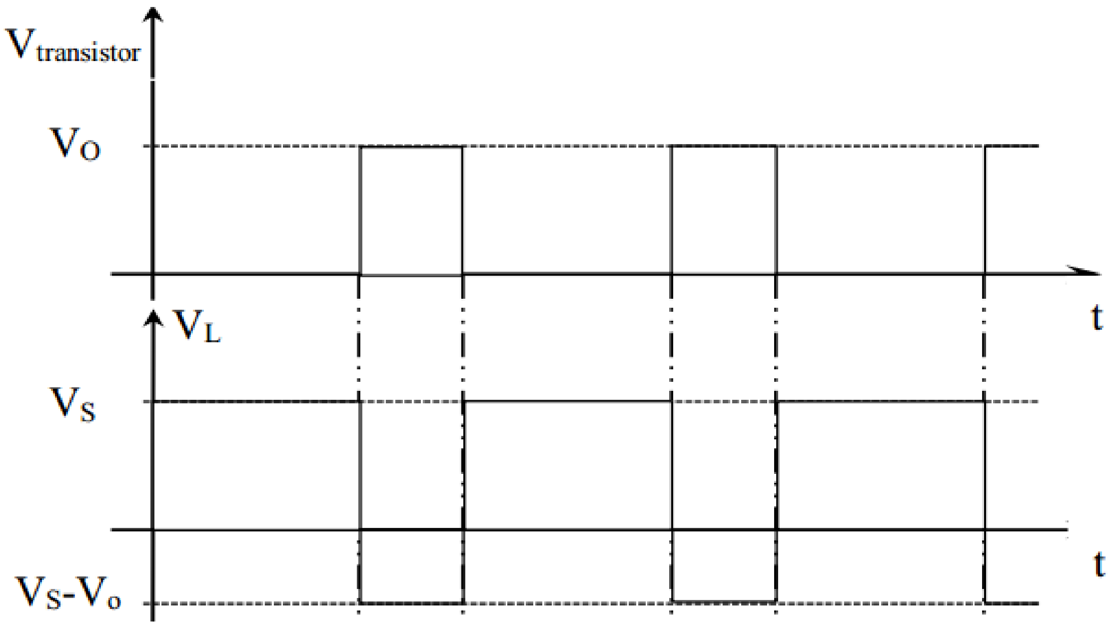


Fig I.19: Circuit diagram of boost converter during Mode 2[25].

- Waveforms of BOOST converter in CCM:

In the following diagram we will present the current and voltage waveforms for some of the distinctive elements of the BOOST converter :



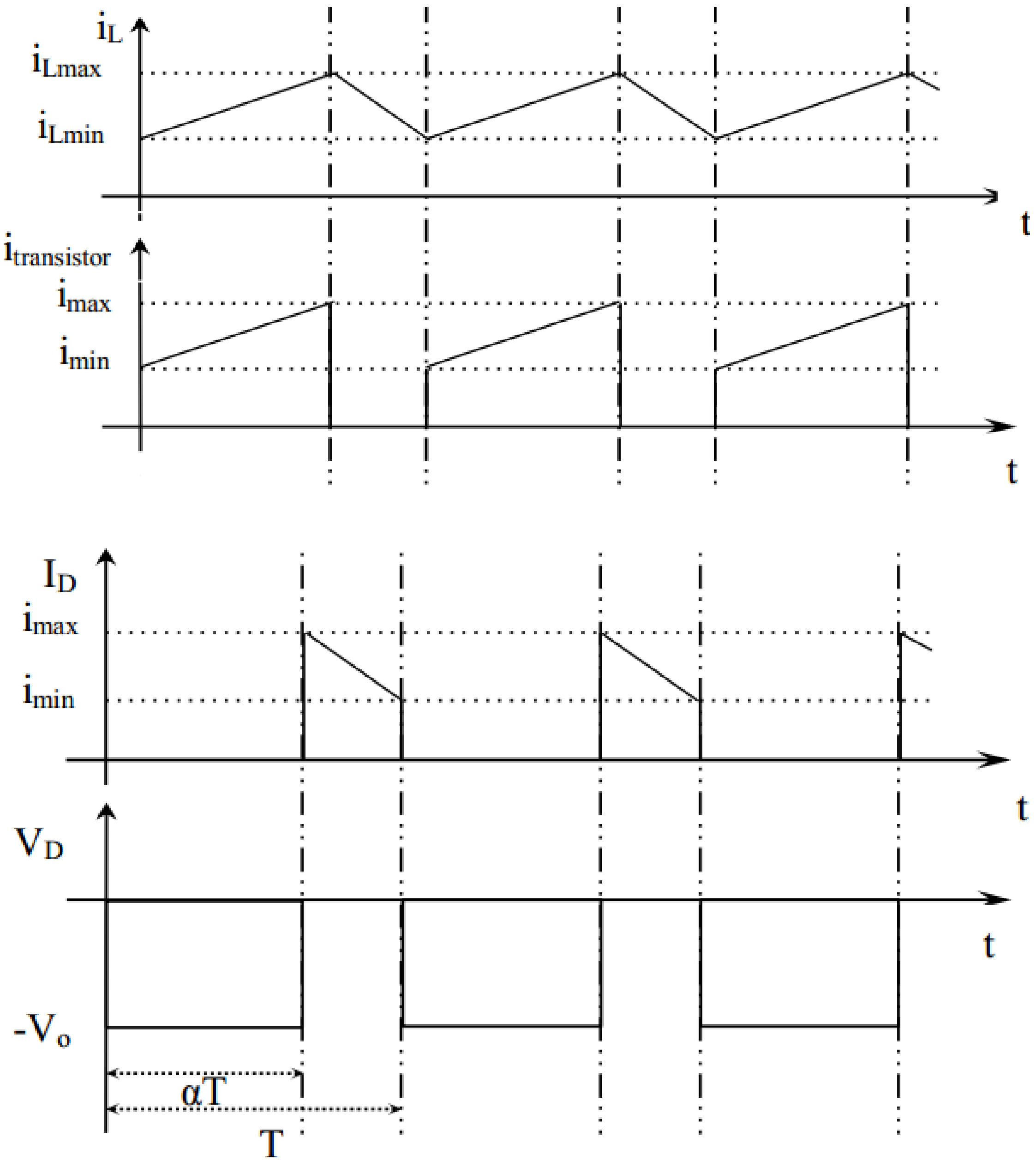


Fig I.20: Boost converter waveforms at CCM [18].

I.3.3.3.2 Discontinuous Conduction Mode :

In DCM, a switching cycleis composed of three intervals. The first two are the same as in CCM, where energy is stored in the inductor during the ON time of the switch, and transferred to the load during the OFF time of the switch. In DCM, however, all of the energy in the inductor transfers to the load during this second interval. The third interval begins when the energy in the inductor is depleted, and terminates at the end of the switching period the next time [26].

- Waveforms of BOOST converter in DCM:

These diagrams shows how the BOOST converter works in DCM (Discontinuous Conduction Mode) :

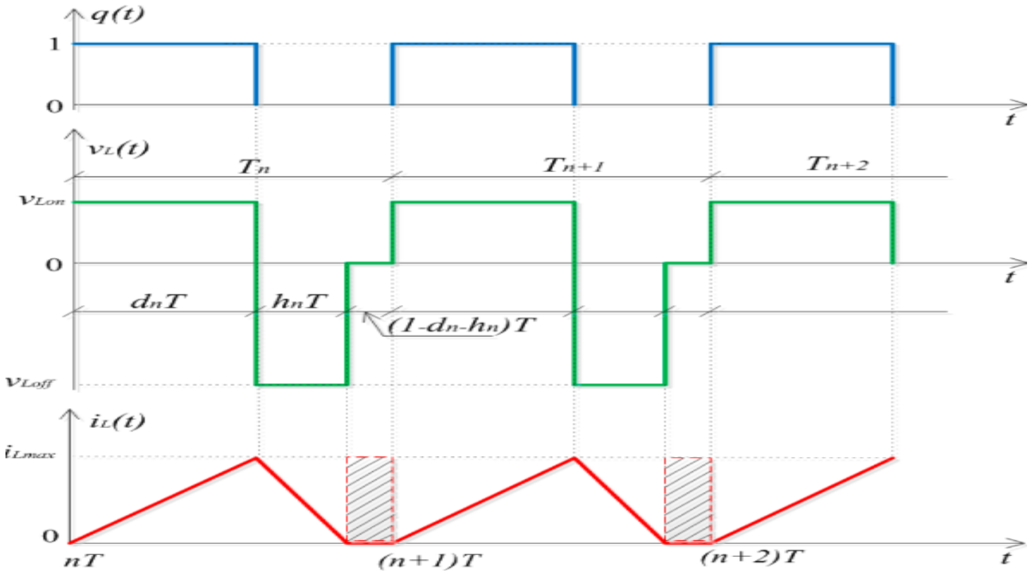


Fig I.21: Boost converter waveforms at DCM[27].

I.3.3.4 Advantages of Boost converter:

And we mentioned some of its most important features in the following :

-It will set up the output voltage without a transformer.

-It gives high-efficiency due to single switch operation

I.3.3.5 Disadvantages of Boost Converter:

Here are some of the disadvantages of Boost Converter :

-High peak current flows through to switch.

-Output voltage is highly sensitive to changes in duty cycle.

-Large inductor and capacitor is required to provide ripple free output

I.3.3.6Applications of Boost Converter:

It has many uses and the most important of these uses is the following:

- ✓ The boost topology is very popular for capacitive load applications such as photo-flashers and battery chargers.
- ✓ Furthermore, the continuous input current makes the boost a popular choice as a pre-regulator, placed before the main converter.
- ✓ The main functions being to regulate the input supply and to greatly improve the line power factor[28].

I.4 CONCLUSION:

In this chapter, we presented general information about the DC-DC converters and discussed their types (buck, buck-boost, and boost Converter). In addition, we devoted our study to the boost Converter type when we talked about the most important components which we will know how to determine in the next chapter.

II.1. Introduction:

In the previous chapter, we talked about the boost converter components, how to determine the appropriate values in components to achieve the desired effort, and how to choose the special components used in this study. In this chapter, we're going to see how to select the components of the BC and how to calculate each component value.

II.2. Calculate of the Maximum Switch Current:

The first step to calculate the switch current is to determine the duty cycle, α , for the minimum input voltage. The minimum input voltage is used because this leads to the maximum switch current. The formula of the duty cycle (α) is given by:

$$\alpha = 1 - \frac{V_{in(\min)} \times \eta}{V_{OUT}} \qquad \text{(II.1)}$$

with,

$V_{IN(min)}$: minimum input voltage

V_{OUT}: desired output voltage

: efficiency of the converter, e.g. estimated 80%

The efficiency is added to the duty cycle calculation, because the converter has to deliver also the energy dissipated. This calculation gives a more realistic duty cycle than just the equation without the efficiency factor.

Either an estimated factor, e.g. 80% (which is not unrealistic for a boost converter worst case efficiency), can be used or see the Typical Characteristics section of the selected converter's data sheet [29].

The next step to calculate the maximum switch current is to determine the inductor ripple current. In the converters data sheet normally a specific inductor or a range of inductors is named to use with the IC. So either uses the recommended inductor value to calculate the ripple current, an inductor value in the middle of the recommended range or, if none is given in the data sheet, we use the one calculated in the **Inductor Selection** (The next element).

$$\Delta I_L = \frac{V_{in(\min)} \times \alpha}{f_S \times L} \qquad \text{(II.2)}$$

with

: minimum input voltage

α :duty cycle αcalculated in **Equation II.1**

: minimum switching frequency of the converter

L:selected inductor value

Now it has to be determined if the selected IC can deliver the maximum output current.

$$I_{MAXOUT} = \left(I_{LIM\ (\min)} - \frac{\Delta I_L}{2} \right) \times (1 - \alpha) \qquad \text{(II.3)}$$

with

$I_{LIM(min)}$: minimum value of the current limit of the integrated switch (given in the data sheet)

ΔI_L: inductor ripple current calculated in **Equation II.2**

α : duty cycle calculated in **Equation II.1**

If the calculated value for the maximum output current of the selected IC, I_{MAXOUT}, is below the systems required maximum output current, another IC with a higher switch current limit has to be used.

Only if the calculate value for I_{MAXOUT} is just a little smaller than the needed one, it is possible to use the selected IC with an inductor with higher inductance if it is still in the recommended range. A higher inductance reduces the ripple current and therefore increases the maximum output current with the selected IC.

If the calculated value is above the maximum output current of the application, the maximum switch current in the system is calculated isgiven by:

$$I_{SW\ (\max)} = \frac{\Delta I_L}{2} + \frac{I_{MAXOUT}}{1 - \alpha} \qquad \text{(II.4)}$$

with

ΔI_L:inductor ripple current calculated in **Equation II.2**

$I_{OUT(max)}$: maximum output current necessary in the application

α : duty cycle calculated in **Equation II.1**

This is the peak current, the inductor, the integrated switch(es) and the external diode has to withstand.

II.3. Inductor Selection:

Often data sheets give a range of recommended inductor values. If this is the case, it is recommended to choose an inductor from this range. The higher the inductor value, the higher is the maximum output current because of the reduced ripple current.

The lower the inductor value, the smaller is the solution size. Note that the inductor must always have a higher current rating than the maximum current given in **Equation II.4** because the current increases with decreasing inductance.

For parts where no inductor range is given, the following equation is a good estimation for the right inductor:

$$L = \frac{V_{IN} \times (V_{OUT} - V_{IN})}{\Delta I_L \times f_S \times V_{OUT}} \qquad \text{(II.5)}$$

with

V_{IN}: typical input voltage

V_{OUT}: desired output voltage

f_s: minimum switching frequency of the converter

ΔI_L: estimated inductor ripple current, see below

The inductor ripple current cannot be calculated with **Equation II.1**because the inductor is not known. A good estimation for the inductor ripple current is 20% to 40% of the output current.

$$(0.02 to 0.04) \times I_{OUT(\max)} \times \frac{V_{OUT}}{V_{IN}} \qquad \text{(II.6)}$$

ΔI_L: estimated inductor ripple current

$I_{OUT(max)}$: maximum output current necessary in the application

II.4. Diode Selection:

The peak current in the diode is identical to that passing through switch K.

All of the current flowing from the source to the load passes through diode D.

The average value of the current in the diode is equal to the output current therefore [30]:

$$I_{D\,moy} = I_S \tag{II.7}$$

with

$I_{D\,moy}$: average current of the rectifier diode.

I_S: maximum output current necessary in the application.

To reduce losses, Schottky diodes should be used .Schottky diodes have a much higher peak current rating than average rating. Therefore the higher peak current in the system is not a problem.

The other parameter that has to be checked is the power dissipation of the diode whichis calculated by [31]:

$$P_D = I_D \times V_D \tag{II.8}$$

with

I_D : average current of the rectifier diode.

V_D:forward voltage of the rectifier diode.

Best practice is to use low ESR capacitors to minimize the ripple on the output voltage. Ceramic capacitors are a good choice if the dielectric material is X5R or better[32 , 33].

If the converter has external compensation, any capacitor value above the recommended minimum in the data sheet can be used, but the compensation has to be adjusted for the used output capacitance.

With internally compensated converters, the recommended inductor and capacitor values should be used or the recommendations in the data sheet for adjusting the output capacitors to the application should be followed for the ratio of L × C.

With external compensation, the following equations can be used to adjust the output capacitor values for a desired output voltage ripplewritten by:

$$C_{OUT\ (\min)} = \frac{I_{OUT\ (\max)} \times \alpha}{f_S \times \Delta V_{OUT}} \tag{II.9}$$

with

$C_{OUT(min)}$:minimum output capacitance.

$I_{OUT(max)}$: maximum output current of the application.

α : duty cycle calculated with **Equation II.1**

f_S:minimum switching frequency of the converter.

ΔV_{OUT}:desired output voltage ripple.

The ESR of the output capacitor adds some more ripple, given with the equation:

$$\Delta V_{OUT\ (ESR)} = ESR \times \left(\frac{I_{OUT\ (\max)}}{1-\alpha} + \frac{\Delta I_L}{2} \right) \tag{II.10}$$

with

$\Delta V_{OUT(ESR)}$:additional output voltage ripple due to capacitors ESR.

ESR : equivalent series resistance of the used output capacitor

$I_{OUT(max)}$: maximum output current of the application.

α : duty cycle calculated with **Equation II.1**

ΔI_L: inductor ripple current from **Equation II.2** or **Equation II.6**[31]

II.5. Transistor Selection:

The peak current I_M in switch K is reached at t = αT. It is more interesting to express it as a function of the input or output quantities.

The average value of the current in the inductance L being equal to the input current I_e, we can written by:

$$I_K = I_M = I_{IN} + \frac{\Delta I}{2} = \frac{I_{OUT}}{(1-\alpha)} + \frac{\Delta I}{2} \tag{II.11}$$

The average value is written by:

$$I_{Kmoy} = \alpha I_{IN} = \frac{\alpha}{1-\alpha} I_{OUT} \tag{II.12}$$

It is shown that the effective value is given by:

$$I_{Keff} = I_{IN} \sqrt{\alpha \left(1 + \frac{1}{12}\left(\frac{\Delta I}{I_{IN}}\right)^2\right)} \tag{II.13}$$

This expression is in fact little different from the previous formulagiven by:

$$I_{Keff} = I_{IN} \sqrt{\alpha} \tag{II.14}$$

During phase 2, when diode D conducts, switch K is subjected to the output voltage Vs written by:

$$V_{K\,\max} = V_{OUT} \tag{II.15}$$

II.6 Conclusion:

In this chapter, we saw how to determine the ideal values of the elements used for the voltage we need in the realization part. But how it works after the design of the chopper prototype model? We will go to be a big difference between simulation and realization of the boost converter. This is actually what we'll see in the next chapter.

III.1. Introduction:

In the previous chapter, we explained how to determine the appropriate values for each element of the task being performed. In this chapter we will simulate and practically apply what we talked about earlier. As we will compare the results obtained from simulation and experimentation in this part.

III.2. Components of the experiment parts:

We know the boost converter has special ingredients, and in our study, we'll take it as follows:

Coil L: 0.25 mH

Capacitor C: 560 µF

Frequency F: 32 kHz

Mosfet M: IRFP250N

Diode D: BYT30P-1000

III.3.Open Loop:

III.3.1. Simulation results:

We install the circuit in Matlab/Simulink, constantly change the value of the duty cycle **D** and record the results obtained:

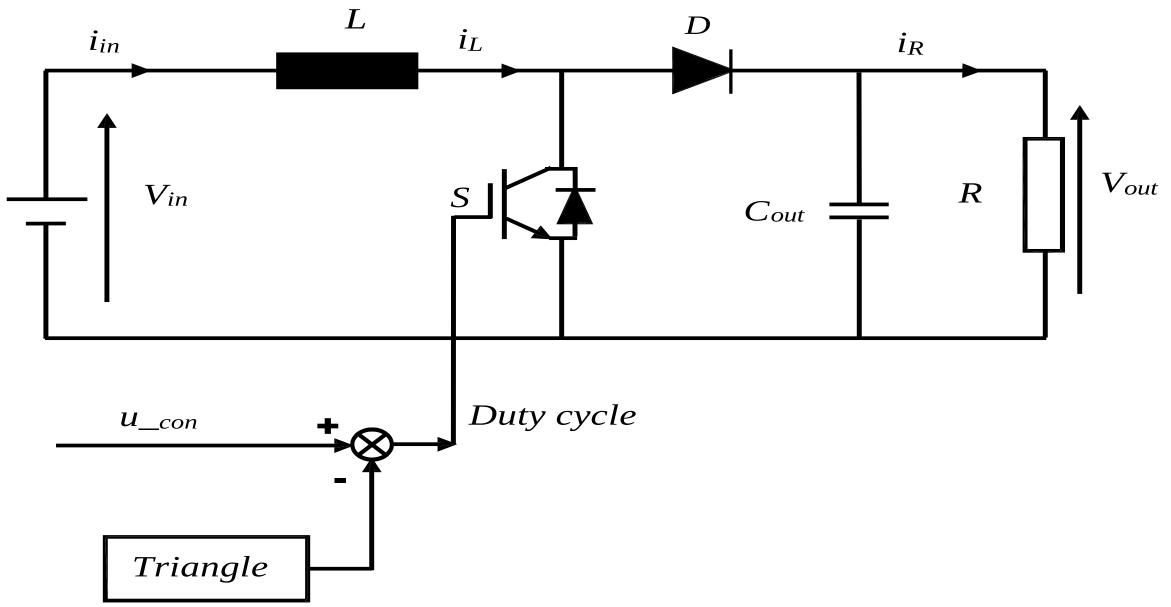


Fig III.1: Open Loop Scheme.

III.3.1.1Open Loop Results:

We launched the simulation in Matlab, and we detailed in all of the following cases :

In first case we choose the duty cycle = 0.8 , the second 0.75,the therd 0.5,and the fourth 0.25 and we recored the following results

***- α = 0.8 :**

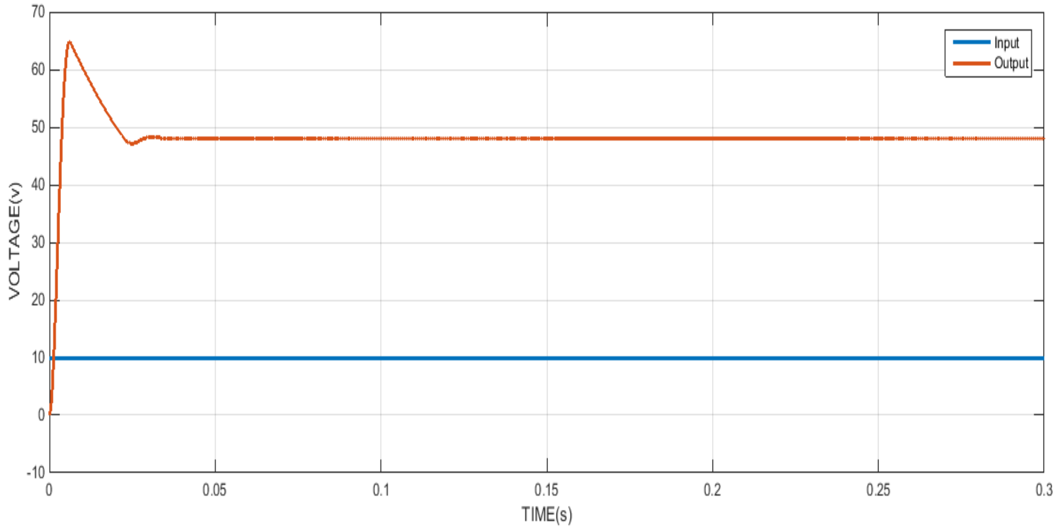


Fig III.2: Voltage In α = 0.8

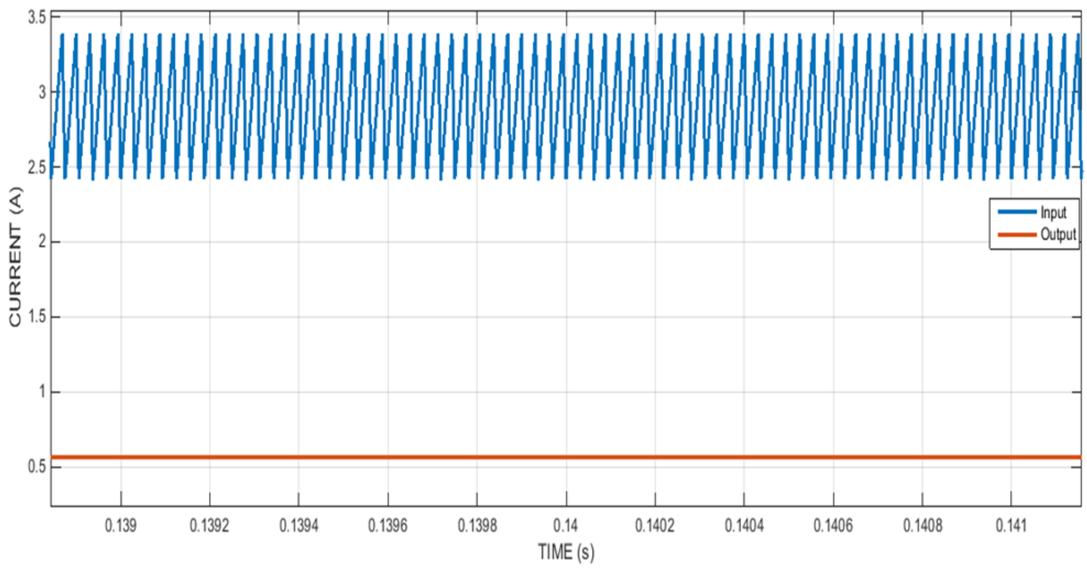


Fig III.3: Current In α = 0.8

***- α = 0.75 :**

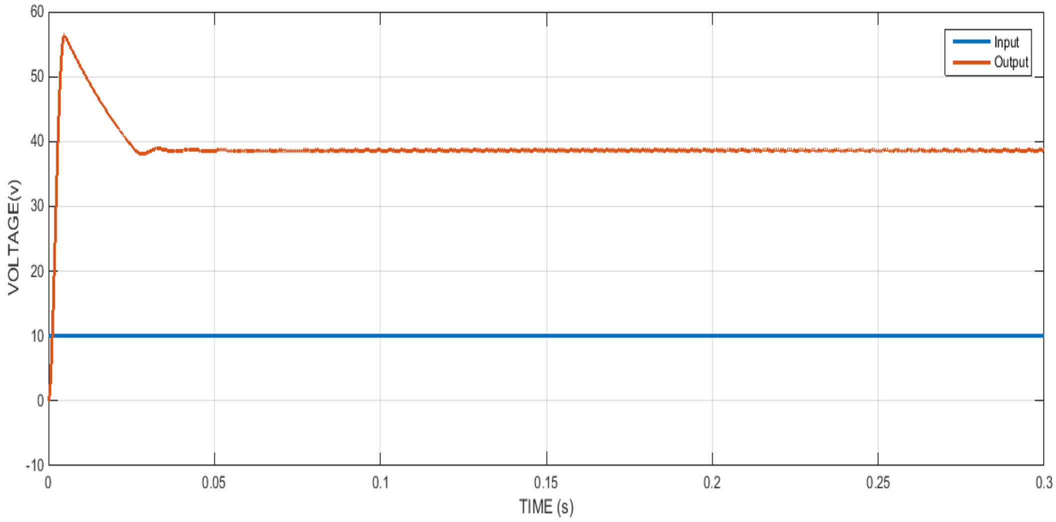


Fig III.4: Voltage In α = 0.75

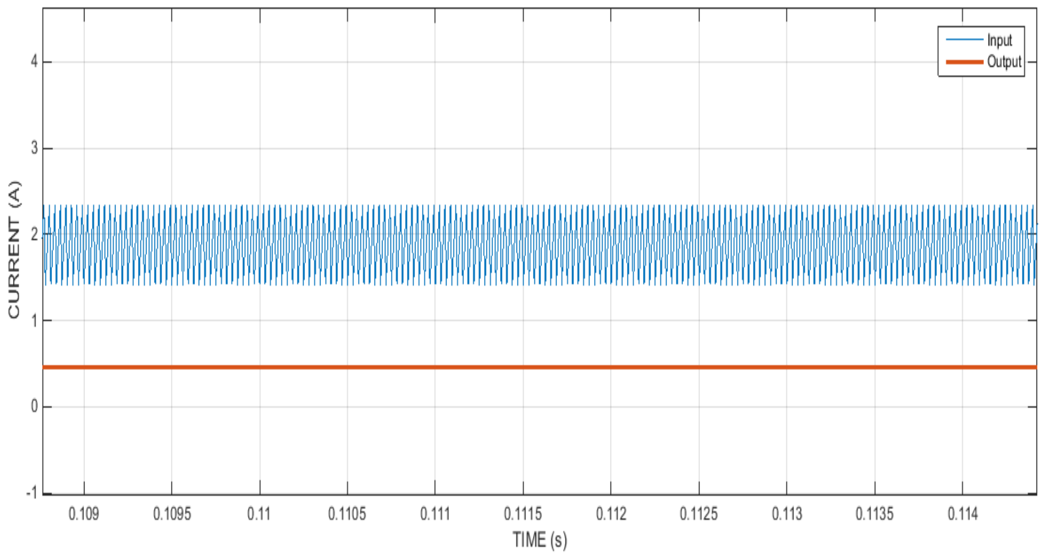


Fig III.5: Current In α = 0.75

We notice in the first and second cases that the input current vibrates between two values and the voltage of the output has a pulse and then stabilize at a certain value

***- α = 0.5 :**

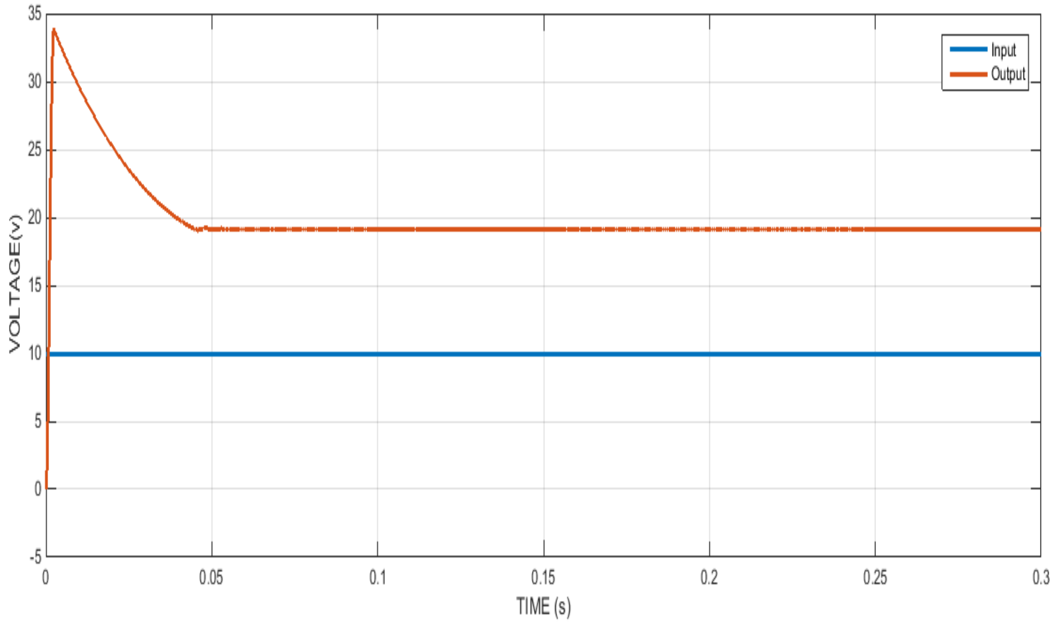


Fig III.6: Voltage In α = 0.5

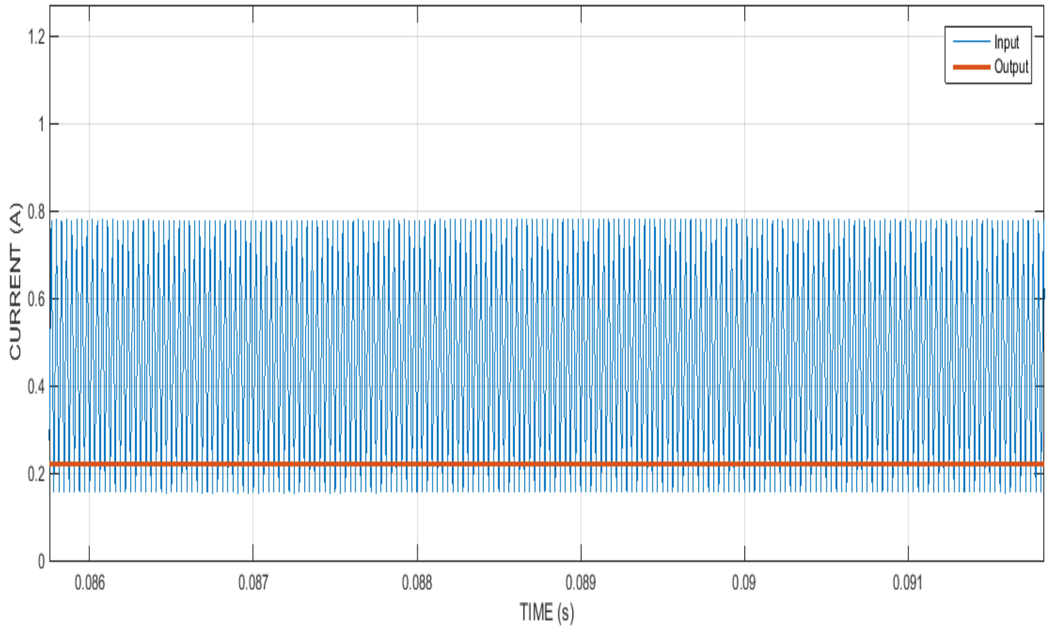


Fig III.7: Current In α = 0.5

***- α = 0.25 :**

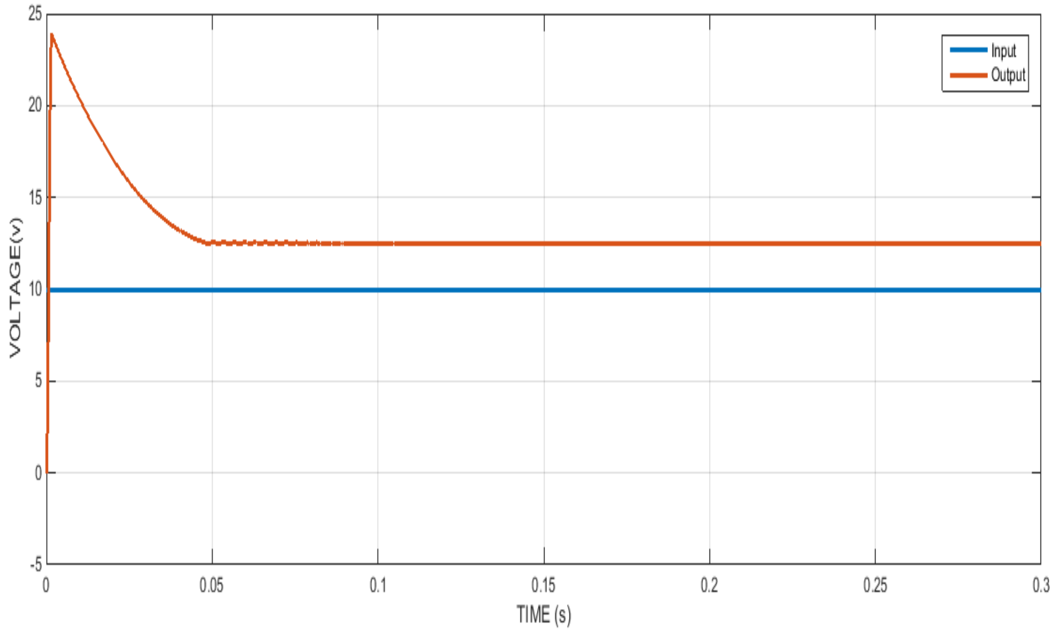


Fig III.8: Voltage In α = 0.25

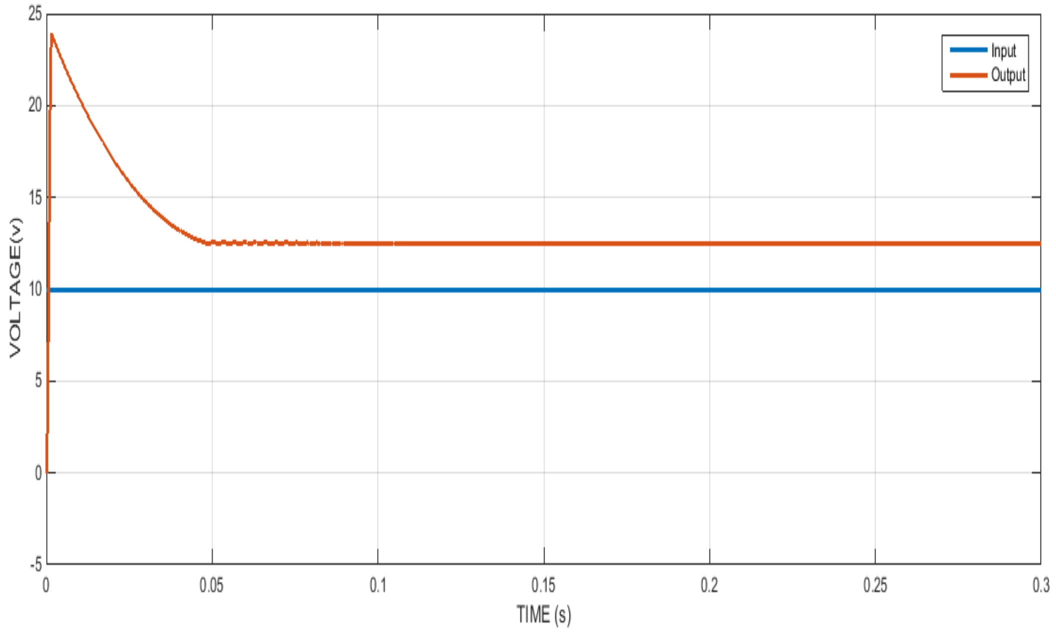


Fig III.9: Current In α = 0.25

We note in the third and fourth cases that the presence of pulse is still with the lack of the voltage value in the permanent system , either for the current we notice the lack of interval in which it vibrates .

And we summarized the results in the following table.

Tab III.1: Open Loop Results

I_{out}	I_{in}	V_{out}	V_{in}	α
0.56	3.38	48.01	10	0.8
0.45	1.95	38.6	10	0.75
0.22	0.65	19.15	10	0.5
0.14	0.31	12.52	10	0.25

III.3.2 Practical results:

This part consists two parts as follow:

III.3.2.1. Power Part:

After we selected the necessary components for the converter, we installed it in the lab as described in the boost structure in the first chapter, we got a model which we will show in two parts, the first part is the power part and it is as follow :

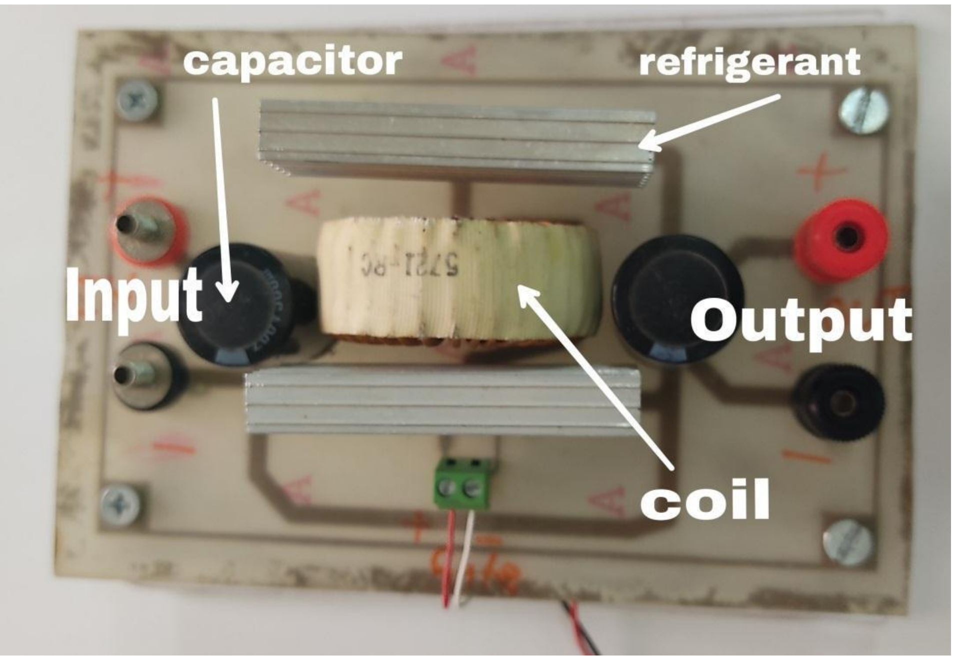


Fig III.10: The power part of the BC

III.3.2.2.Control Part:

The control part consists of Matlab, Arduino and A control circuit [containing DIODE and MOSFET].

We've already known the power part, and we're going to show now the second part, which is the control part which containing Arduino, DIODE and MOSFET :

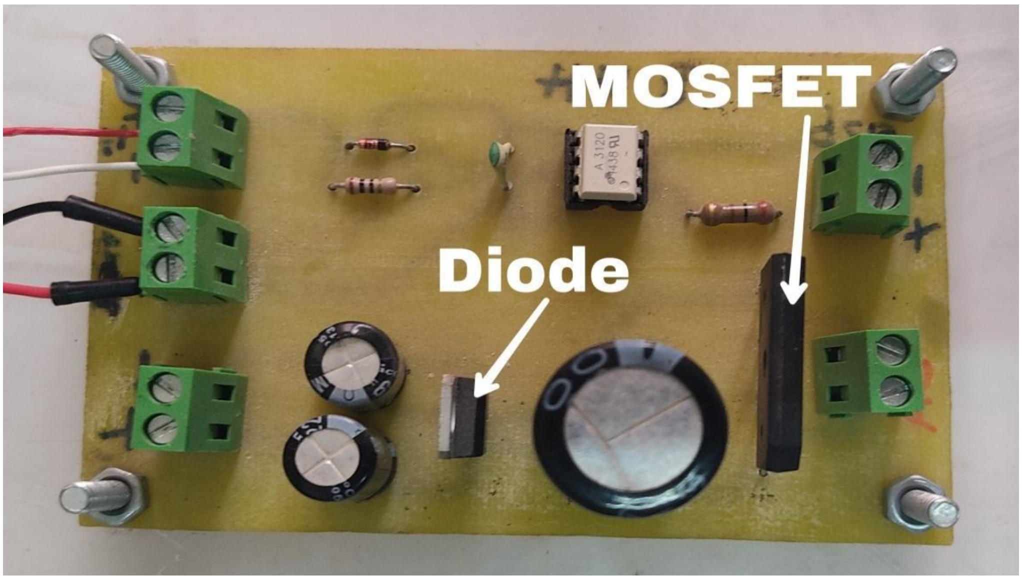


Fig III.11: The control part of the BC.

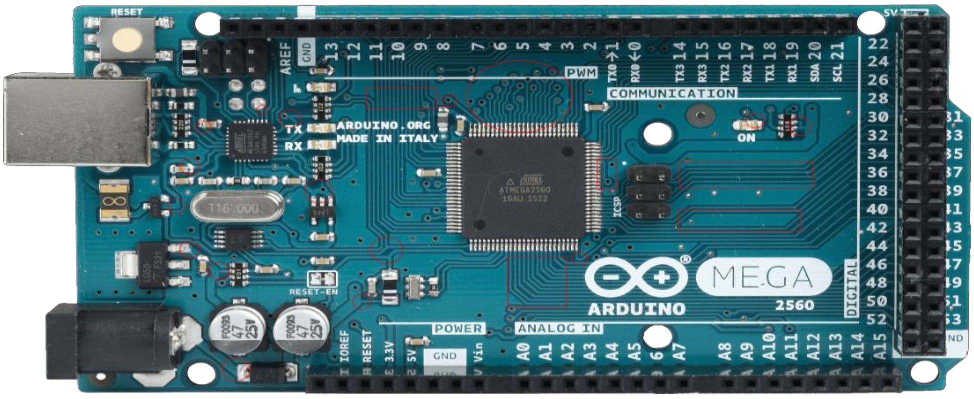


Fig III.12: The Arduino mega

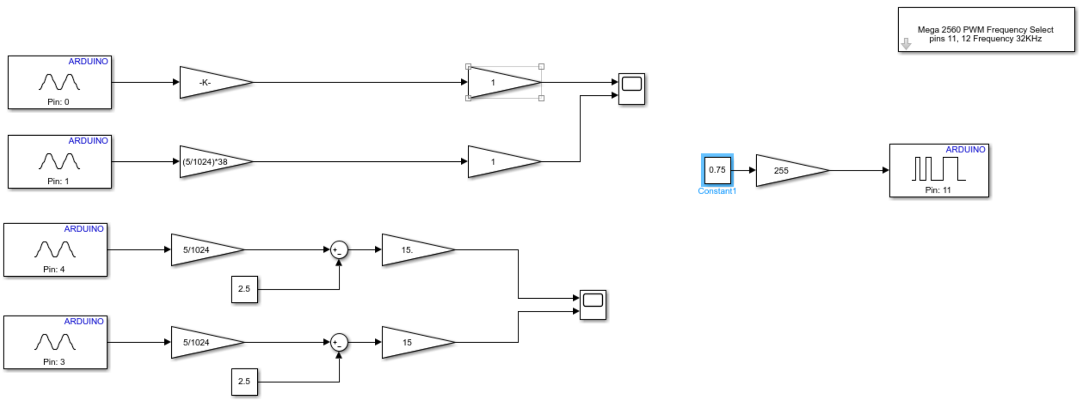


Fig III.13: Open Loop Scheme In Matlab

After collecting the power and control part in the lab, we fed the c, changed the value of the duty cycle , We notice that the converter does its work where it raises the input voltage but for the current it lowers it and we notice that the current and voltage constantly changes as time changes between two values and this changes applies to four cases:

***- α = 0.8 :**

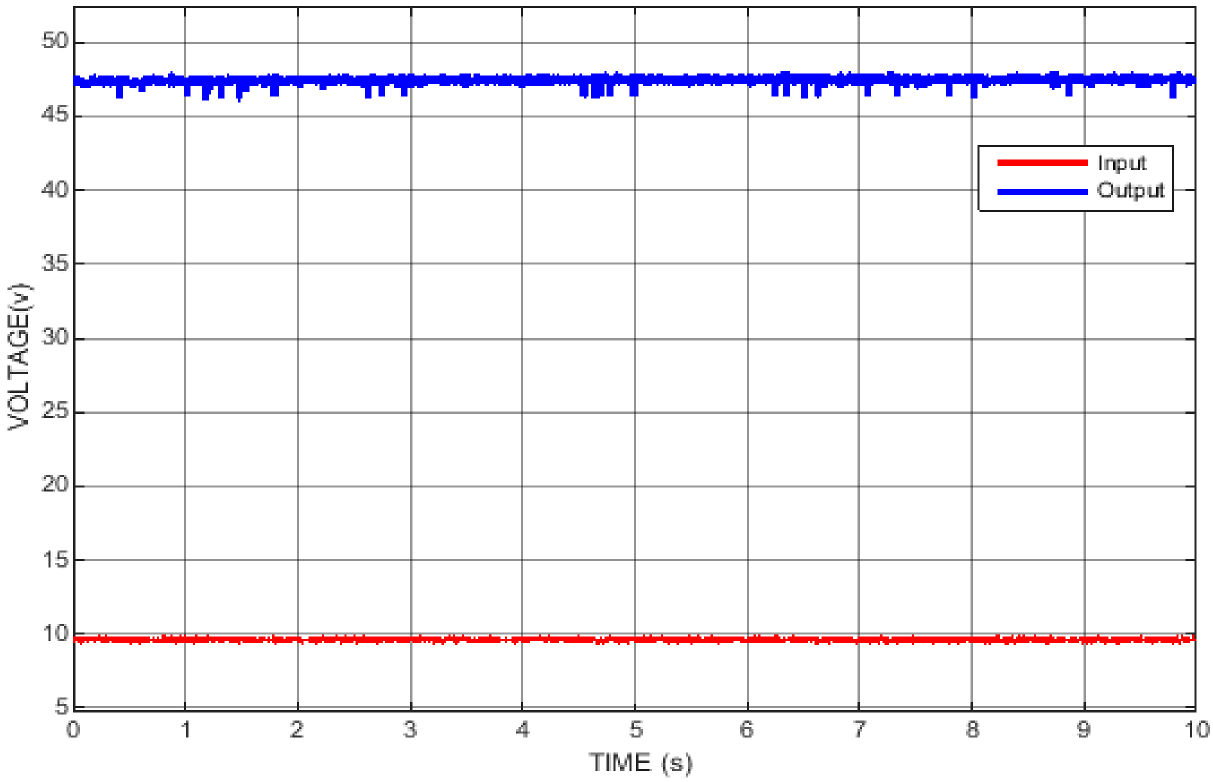


Fig III.14: Voltage In α = 0.8

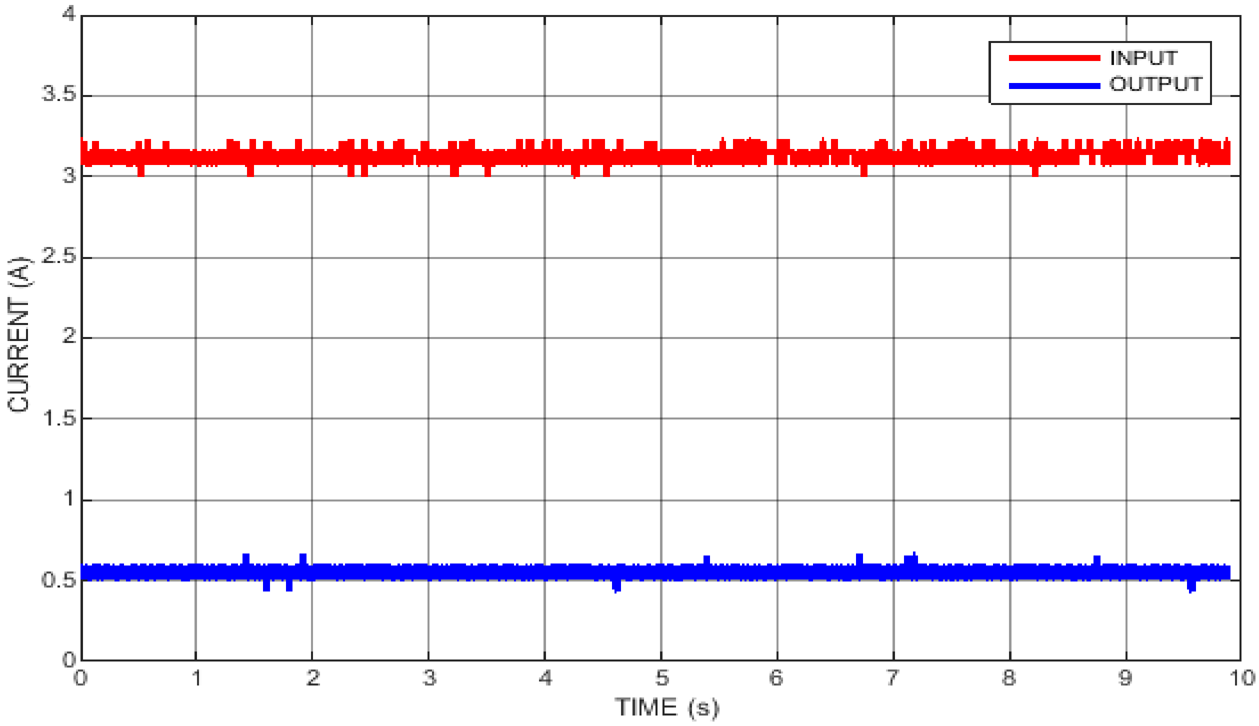
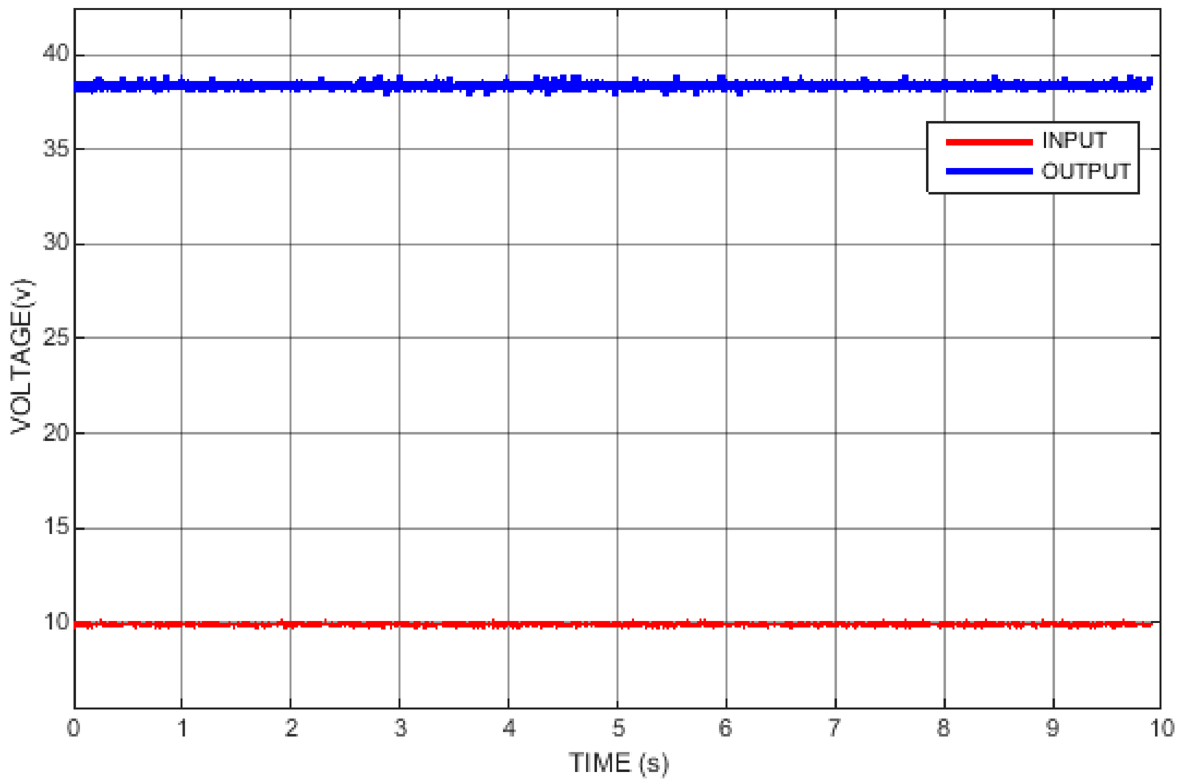
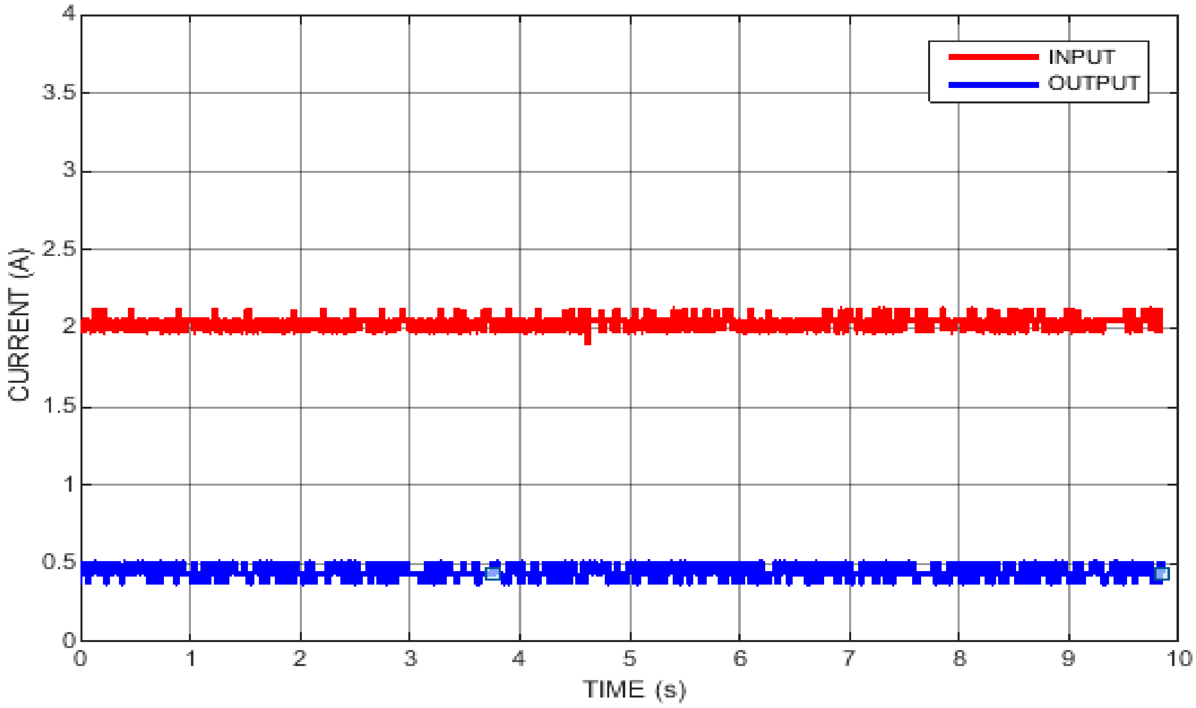


Fig III.15: Current In α = 0.8

***- α = 0.75 :**



FigIII.16: Voltage In α = 0.75



FigIII.17: Current In α = 0.75

***- α = 0.5 :**

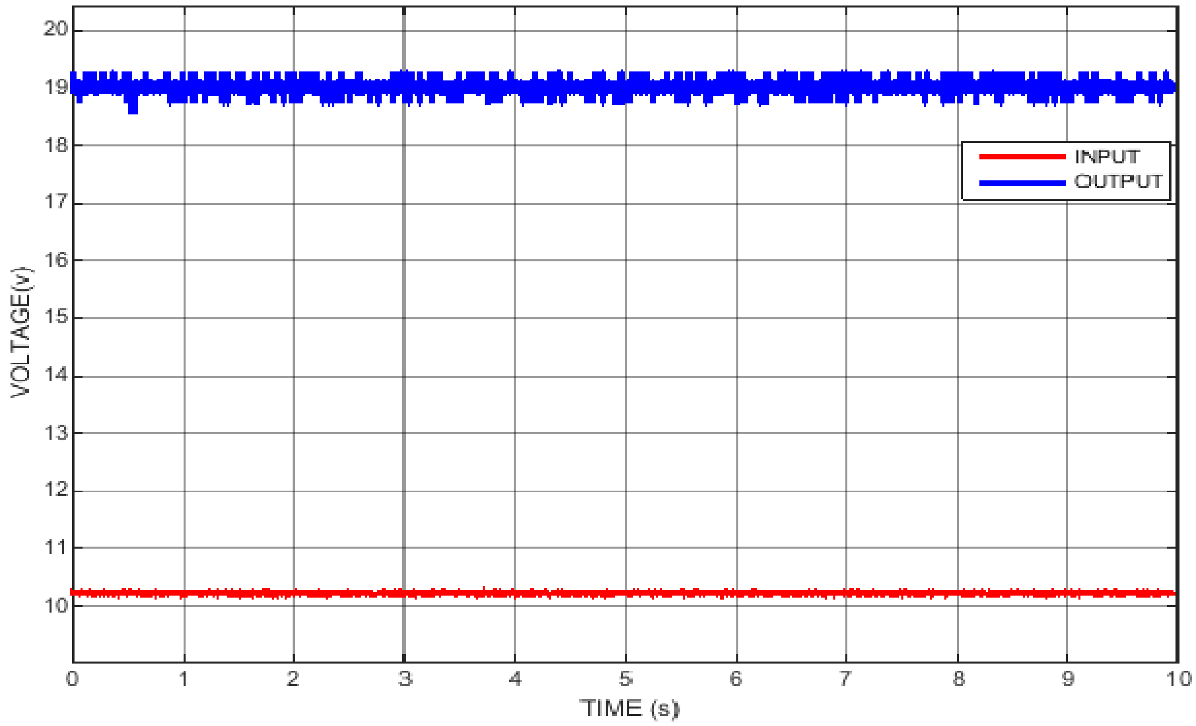
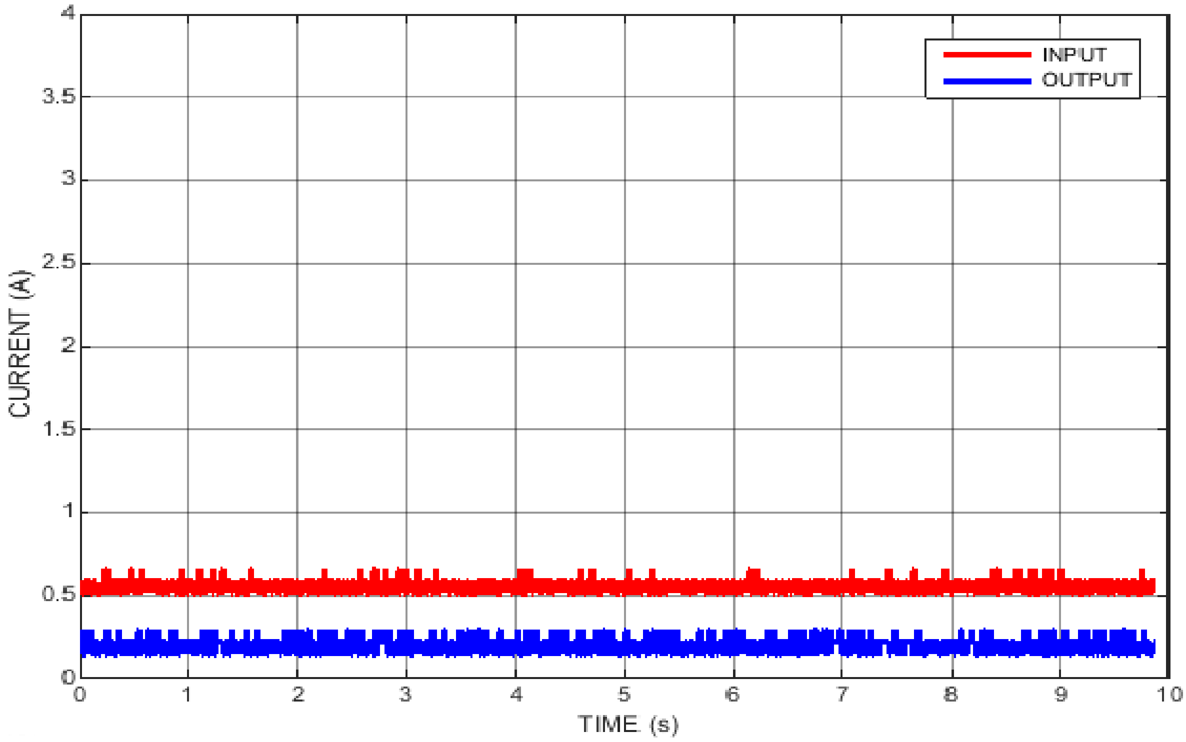
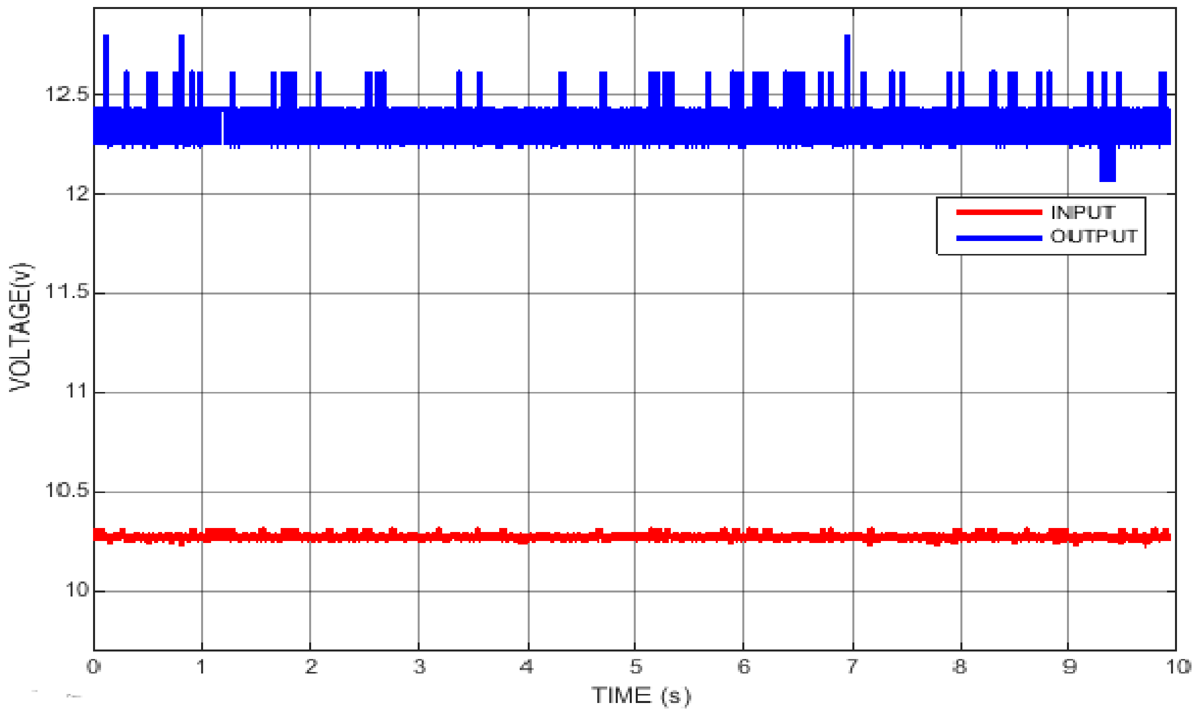


Fig III.18: Voltage In α = 0.5



FigIII.19: Current In α = 0.5

***- α = 0.25 :**



FigIII.20: Voltage In α = 0.25

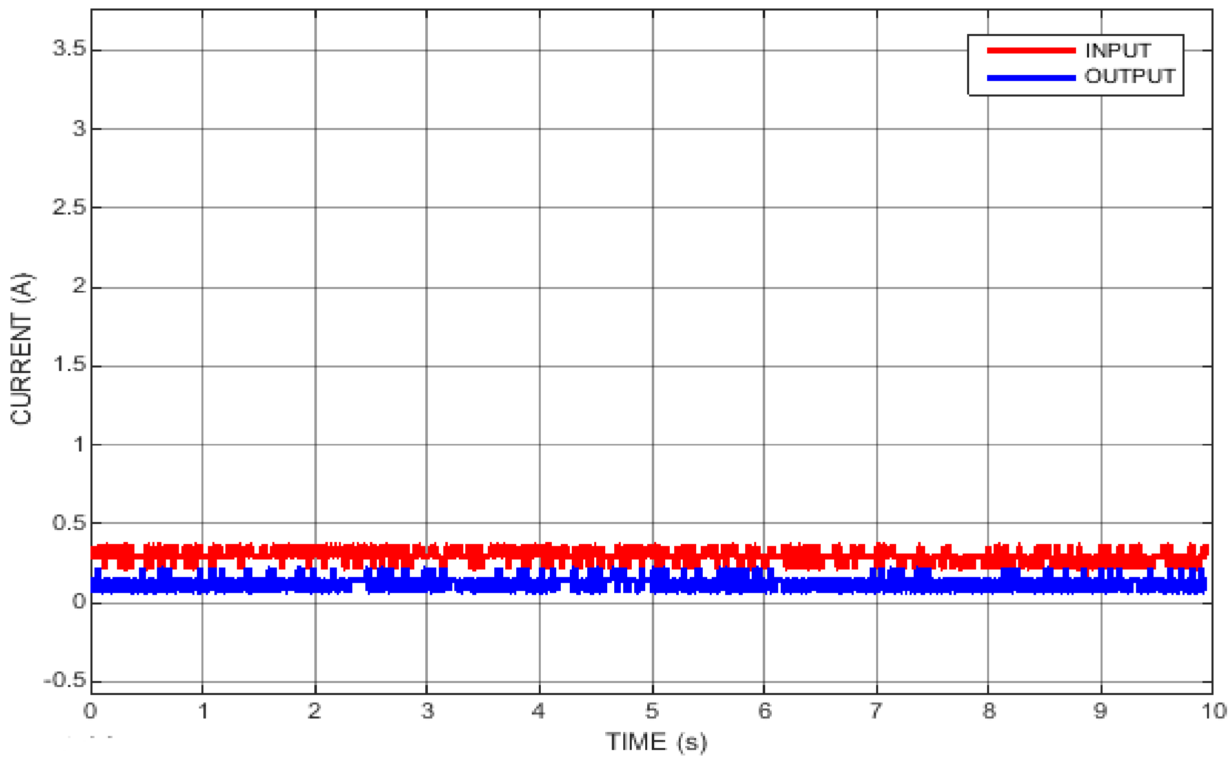


Fig III.21: Current In α = 0.25

This table summarizes the previous results :

Tab III.2: Open Loop Results in Practical

I_{out}	I_{in}	V_{out}	V_{in}	α
0.58	3.1	47.2	10.1	0.8
0.47	2	38.3	10.1	0.75
0.27	0.5	19.37	10.1	0.5
0.1	0.2	12.68	10	0.25

III.3.3. Discussion and Comparison :

We note a great convergence between simulation results and actual experimentation with vibrations in experimentation curves.

III.4.Closed Loop:

III.4.1. Simulation results:

We added **PID** controller on the system and change reference every time and record results:

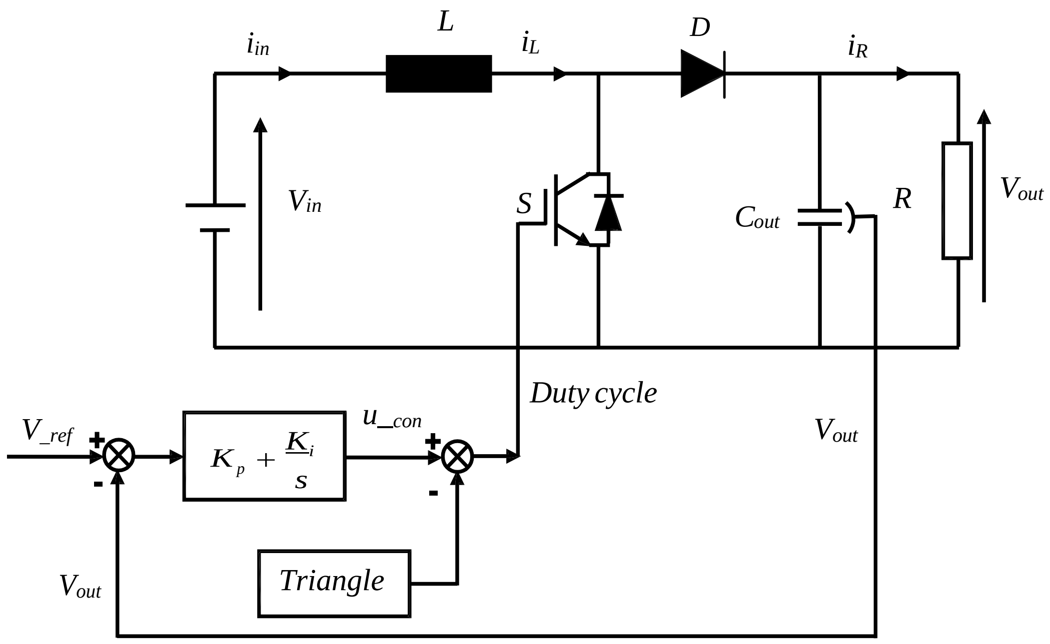


Fig III.22: Closed Loop Scheme

And in this part, we made the duty cycle change automatically using PID controller to track the desired voltage .

We are going to test two case:

***- First case reference =18V**

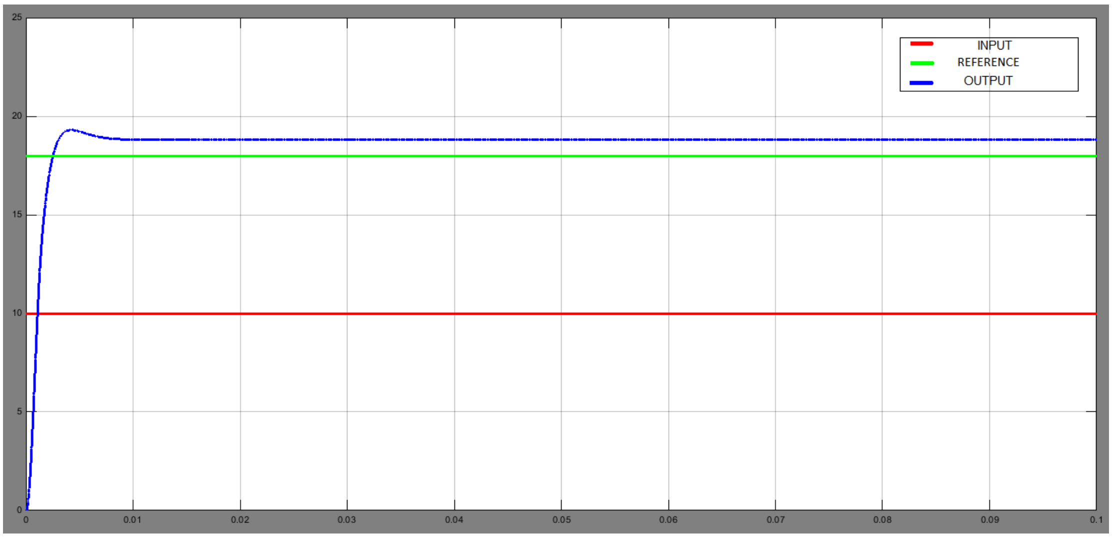


Fig III.23: Reference Voltage = 18V

***- second case reference =25V**

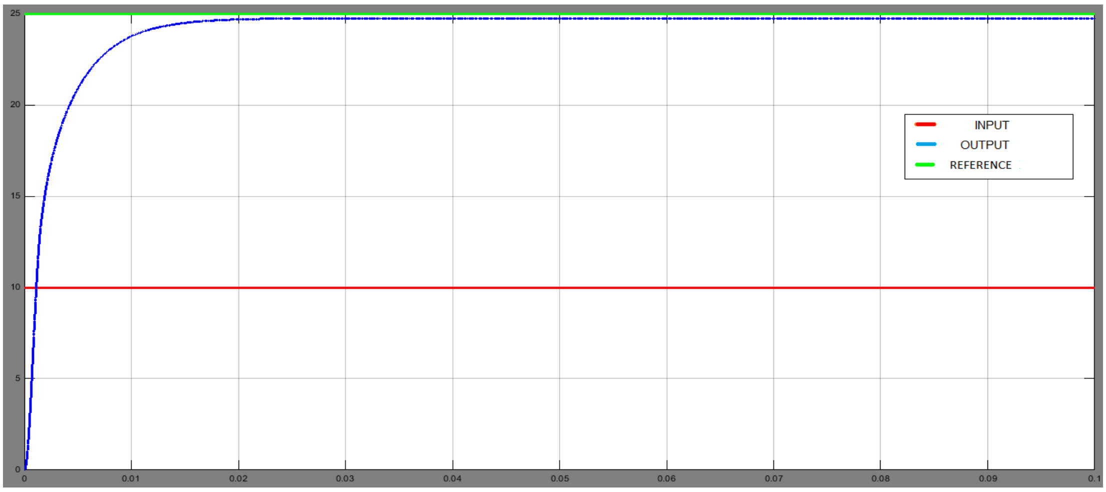


Fig III.24: Reference Voltage = 25V

III.4.2. Practical results:

We combine **ARDUINO** and **PID** controller in matlab, change reference by matlab and record results:

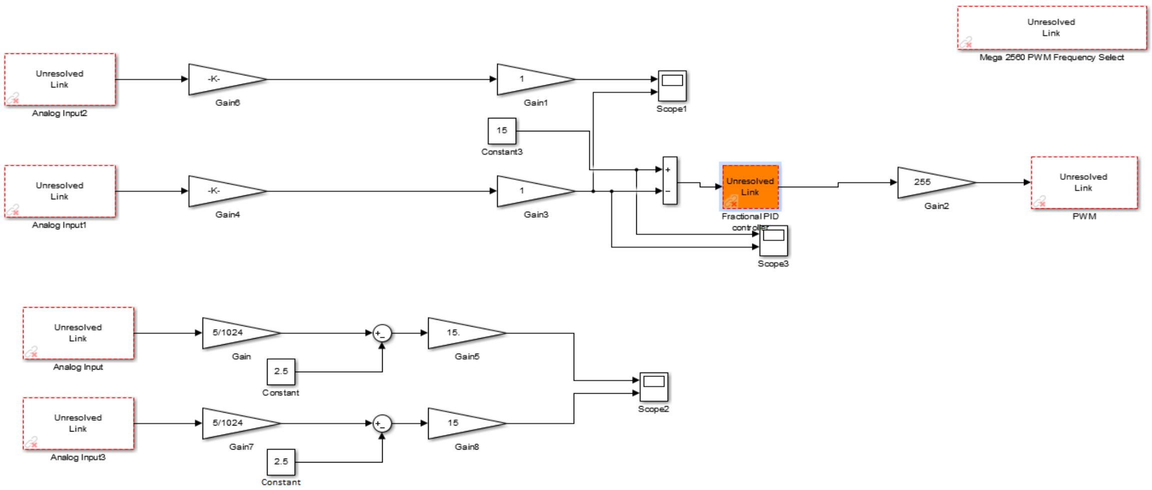


Fig III.25: ClosedLoopSchemeIn Matlab

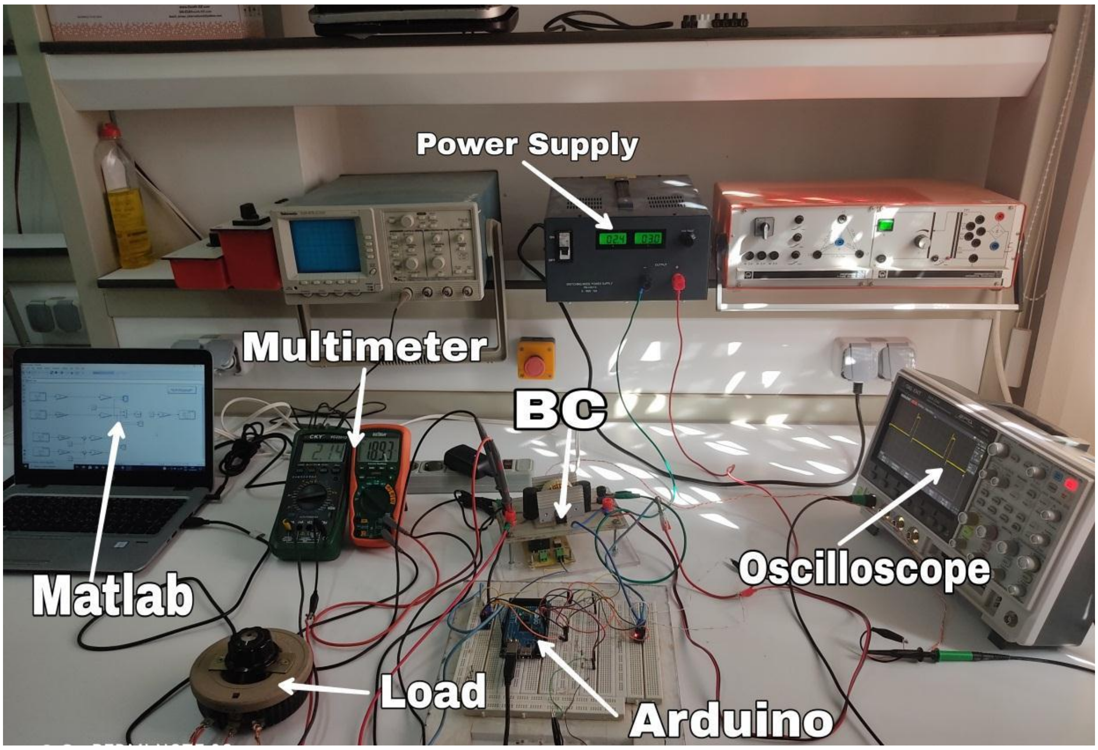


Fig III.26: Closed Loop in Practical.

We'll apply the same procedures as before, but in this case the converter will actually be pid controller in the matlab and connected to the Arduino.

We are going to test two case:

***- First case reference =10_15_7V**

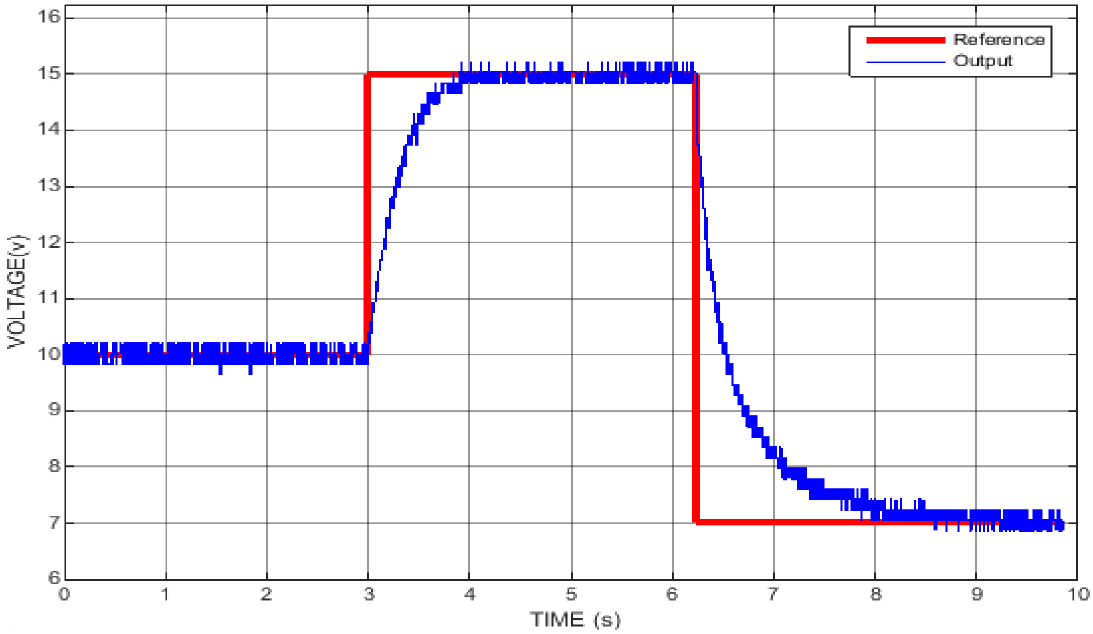


Fig III.27: Reference Voltage = 10_15_7V

*- **second case reference =7_15V**

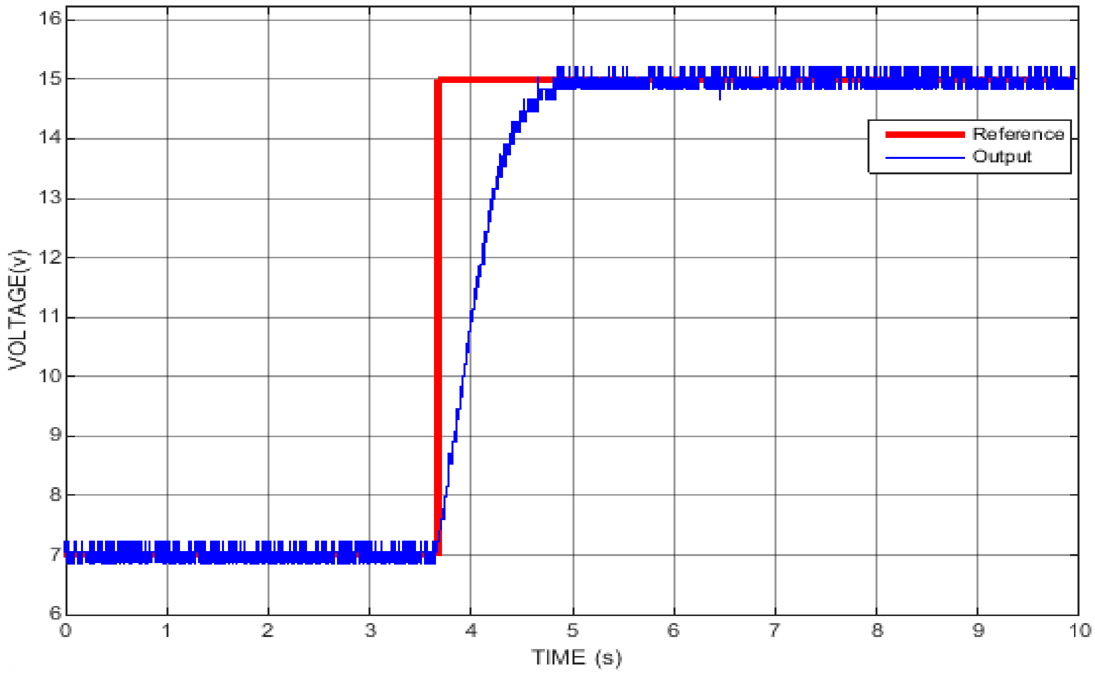


Fig III.28: Reference Voltage = 7_15V

III.4.3. Discussion and Comparison :

We notice that in the first case(simulation) our Boost converter tracks the reference in a short time, giving us a good respond with a low error which means our converter have a good if not un excellent respond .while in the second case we've seen that the respond of the practical boost converter it's similar to the first case with the existence of vibrations at the Output voltage resulting from the charge and discharge of the Inductance. But we can say our practical Boot converter works as expected and give us the results required with a high rate of efficiency.

III.5.Conclusion:

After having the simulation and the experiment done, we found a great correspondence between the results. A small difference in response and stability for simulation, unlike in experimentation, we noticed fluctuation in values with slower response speed. This is due to the nature of the materials used and the purity of the current passing through these elements.

General Conclusion :

The work presented in this Master dissertation aims to realize DC-DC converters. Then, this study presented a single type which is the Boost converter. As we tried to conduct some experiments on the Boost converter and try to study it and get to know the converter more.

In the first chapter, we talked about the DC converters and their many and many types. Then we specialized in the important type of the Boost converter when we learned about its components and its principle operating. In addition, this part presented how the boost converter raises the input voltage and then sends it to the output. We talked also about its uses, advantages and disadvantages.

In the second chapter, we had previously learned about the components of the Boost converter, but we did not know how to choose the appropriate components for each converter according to its use. So we touched on how to define these components and how to calculate each element accurately. In addition, this part tried to verify the choice of the components with extreme accuracy according to the requirement conditions. We defined also the capacitor, the Inductance, the diode and the transistor carefully.

In the third chapter, we collected all that we studied previously when we exploited the theories that we discussed in the first and second chapters. In addition, the theory study dedicated to the experiment and the simulation parts have been well exploited.

The Boost converter is simulated using MATLAB/Simulink tool. Then we went to the Centre de Développement des Energies Renouvelables (CDER) in Ghardaia, Algeria to realize the same Boost converter in the simulation part.

We used the same values of the special components (capacitor, Inductance, diode, and transistor). After that, we recorded the real results and compared them with the simulation results. This study concluded that the studies were very accurate about the BC (Boost converter). In addition, the results were almost completely identical to the simulation results.

Finally, we can say that the Boost converter is an irreplaceable and heavyweight converter in the world of converters. It is present almost in all areas of life and we hope that there will be studies on its development in the near future.

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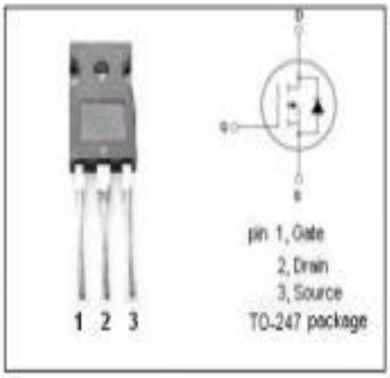
INCHANGE Semiconductor

isc N-Channel MOSFET Transistor IRFP250N，IIRFP250N

• FEATURES

- Static drain-source on-resistance: $R_{DS(on)} \leq 75m\Omega$
- Enhancement mode:
- 100% avalanche tested
- Minimum Lot-to-Lot variations for robust device performance and reliable operation



• DESCRITION

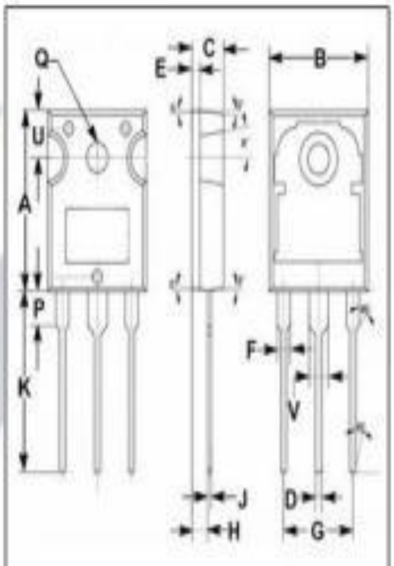
- Fast switching

• ABSOLUTE MAXIMUM RATINGS(T_a=25℃)

SYMBOL	PARAMETER	VALUE	UNIT
V_{DSS}	Drain-Source Voltage	200	V
V_{GS}	Gate-Source Voltage	±20	V
I_D	Drain Current-Continuous	30	A
I_{DM}	Drain Current-Single Pulsed	120	A
P_D	Total Dissipation @T_C=25℃	214	W
T_j	Max. Operating Junction Temperature	175	℃
T_{stg}	Storage Temperature	-55~175	℃

• THERMAL CHARACTERISTICS

SYMBOL	PARAMETER	MAX	UNIT
Rth(j-c)	Channel-to-case thermal resistance	0.7	℃/W
Rth(j-a)	Channel-to-ambient thermal resistance	40	℃/W



	mm	
DIM	MIN	MAX
A	19.80	20.20
B	15.40	15.80
C	4.90	5.10
D	0.90	1.10
E	1.40	1.60
F	1.90	2.10
G	10.80	11.00
H	2.40	2.60
J	0.50	0.70
K	19.50	20.50
P	3.90	4.10
Q	3.30	3.50
U	5.20	5.40
V	2.90	3.10

INCHANGE Semiconductor

isc N-Channel MOSFET Transistor IRFP250N，IIRFP250N

ELECTRICAL CHARACTERISTICS

T_C=25℃ unless otherwise specified

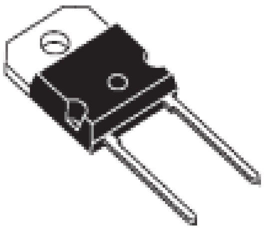
SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
BV_{DSS}	Drain-Source Breakdown Voltage	V_{GS}=0V; I_D=250 μA	200			V
$V_{GS(th)}$	Gate Threshold Voltage	V_{DS}=V_{GS}; I_D=250 μA	2.0		4.0	V
$R_{DS(on)}$	Drain-Source On-Resistance	V_{GS}=10V; I_D=18A			75	mΩ
I_{GSS}	Gate-Source Leakage Current	V_{GS}= ±20V			±0.1	μA
I_{DSS}	Drain-Source Leakage Current	V_{DS}=200V; V_{GS}= 0V			25	μA
V_{SD}	Diode forward voltage	I_S=18A, V_{GS} = 0V			1.3	V

BYT 30P-1000

FAST RECOVERY RECTIFIER DIODE

- VERY HIGH REVERSE VOLTAGE CAPABILITY
- VERY LOW REVERSE RECOVERY TIME
- VERY LOW SWITCHING LOSSES
- LOW NOISE TURN-OFF SWITCHING

Cathode connected to case



SOD93
(Plastic)

SUITABLE APPLICATIONS

- FREE WHEELING DIODE IN CONVERTERS AND MOTOR CONTROL CIRCUITS
- RECTIFIER IN S.M.P.S.

ABSOLUTE MAXIMUM RATINGS

Symbol	Parameter		Value	Unit
V_{RRM}	Repetitive Peak Reverse Voltage		1000	V
V_{RSM}	Non Repetitive Peak Reverse Voltage		1000	V
I_{FRM}	Repetive Peak Forward Current	$t_p \leq 10\mu s$	375	A
$I_{F(RMS)}$	RMS Forward Current		70	A
$I_{F(AV)}$	Average Forward Current	$T_c = 85°C$ $\delta = 0.5$	30	A
I_{FSM}	Surge non Repetitive Forward Current	$t_p = 10ms$ Sinusoidal	200	A
P	Power Dissipation	$T_c = 85°C$	60	W
T_{stg} T_j	Storage and Junction Temperature Range		- 40 to + 150 - 40 to + 150	°C

THERMAL RESISTANCE

Symbol	Parameter	Value	Unit
$R_{th(j-c)}$	Junction-case	1	°C/W

BYT 30P-1000

ELECTRICAL CHARACTERISTICS

STATIC CHARACTERISTICS

Symbol	Test Conditions		Min.	Typ.	Max.	Unit
I_R	$T_j = 25°C$	$V_R = V_{RRM}$			100	µA
	$T_j = 100°C$				5	mA
V_F	$T_j = 25°C$	$I_F = 30A$			1.9	V
	$T_j = 100°C$				1.8	

RECOVERY CHARACTERISTICS

Symbol	Test Conditions		Min.	Typ.	Max.	Unit
t_{rr}	$T_j = 25°C$	$I_F = 1A$ $dI_F/dt = -15A/\mu s$ $V_R = 30V$			165	ns
		$I_F = 0.5A$ $I_R = 1A$ $I_{rr} = 0.25A$			70	

TURN-OFF SWITCHING CHARACTERISTICS (Without Series Inductance)

Symbol	Test Conditions		Min.	Typ.	Max.	Unit
t_{IRM}	$dI_F/dt = -120A/\mu s$	$V_{CC} = 200V$ $I_F = 30A$ $L_p \leq 0.05\mu H$ $T_j = 100°C$ See figure 11			200	ns
	$dI_F/dt = -240A/\mu s$			120		
I_{RM}	$dI_F/dt = -120A/\mu s$				19.5	A
	$dI_F/dt = -240A/\mu s$			22		

TURN-OFF OVERVOLTAGE COEFFICIENT (With Series Inductance)

Symbol	Test Conditions	Min.	Typ.	Max.	Unit
$C = \frac{V_{RP}}{V_{CC}}$	$T_j = 100°C$ $V_{CC} = 200V$ $I_F = I_{F(AV)}$ $dI_F/dt = -30A/\mu s$ $L_p = 5\mu H$ See figure 12			4.5	

To evaluate the conduction losses use the following equation:

$V_F = 1.47 + 0.010\, I_F$ $\qquad P = 1.47 \times I_{F(AV)} + 0.010\, I_F{}^2{}_{(RMS)}$

Figure 1. Low frequency power losses versus average current

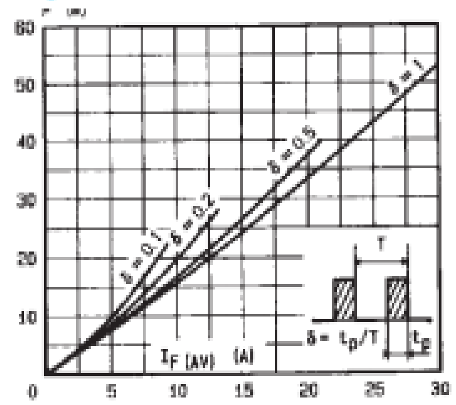


Figure 2. Peak current versus form factor

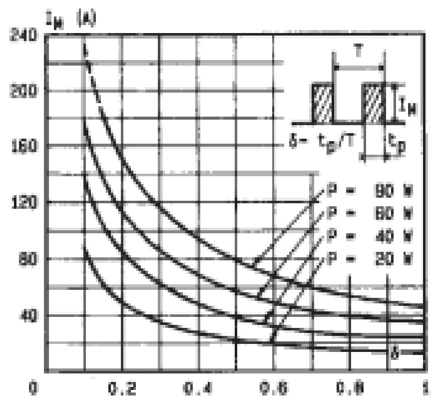


Figure 3. Non repetitive peak surge current versus overload duration

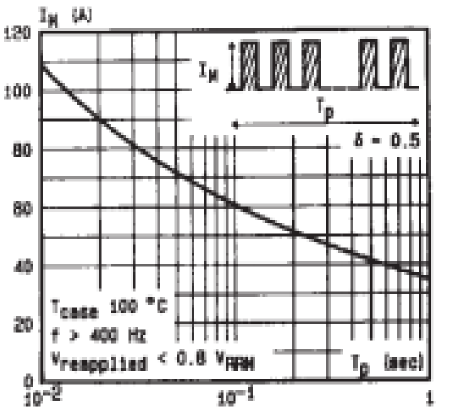


Figure 4. Thermal impedance versus pulse width

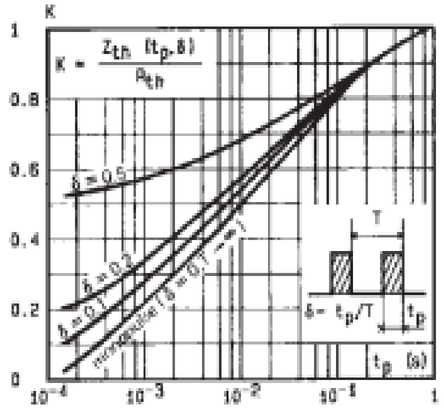


Figure 5. Voltage drop versus forward current

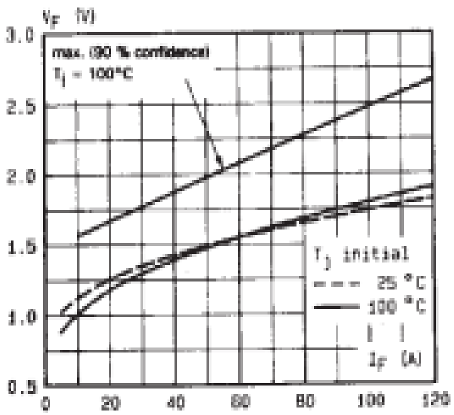


Figure 6. Recovery charge versus di_F/dt.

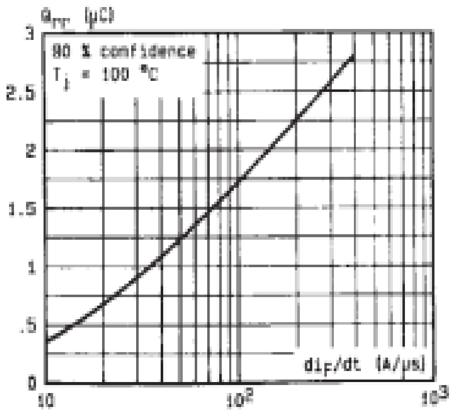


Figure 7. Recovery time versus di_F/dt.

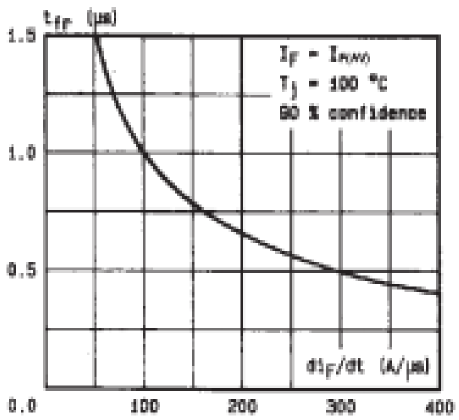
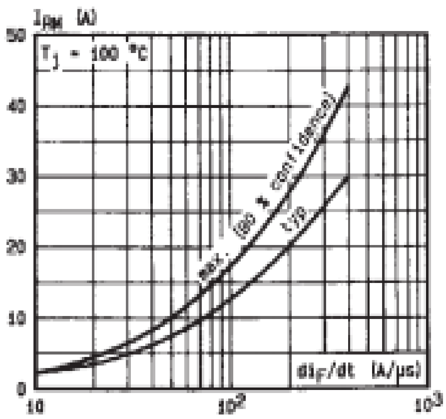


Figure 8. Peak reverse current versus di_F/dt.



BYT 30P-1000

Figure 9. Peak forward voltage versus dI_F/dt.

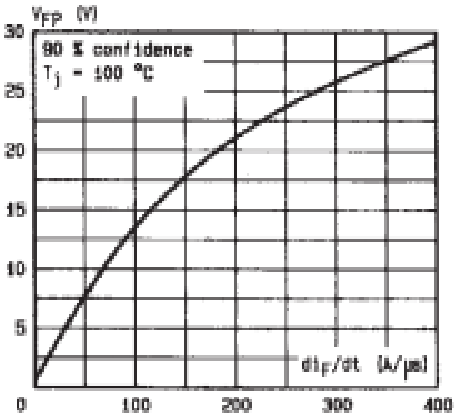


Figure 10. Dynamic parameters versus junction temperature.

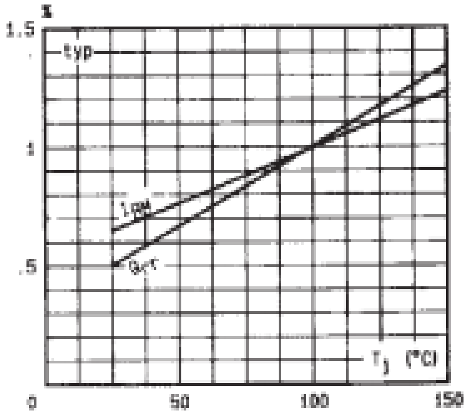


Figure 11. Turn-off switching characteristics (without series inductance).

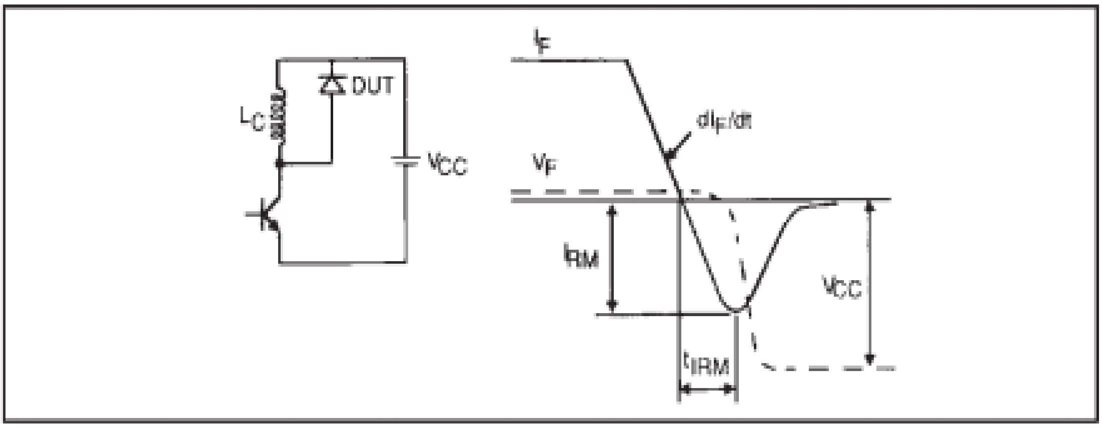
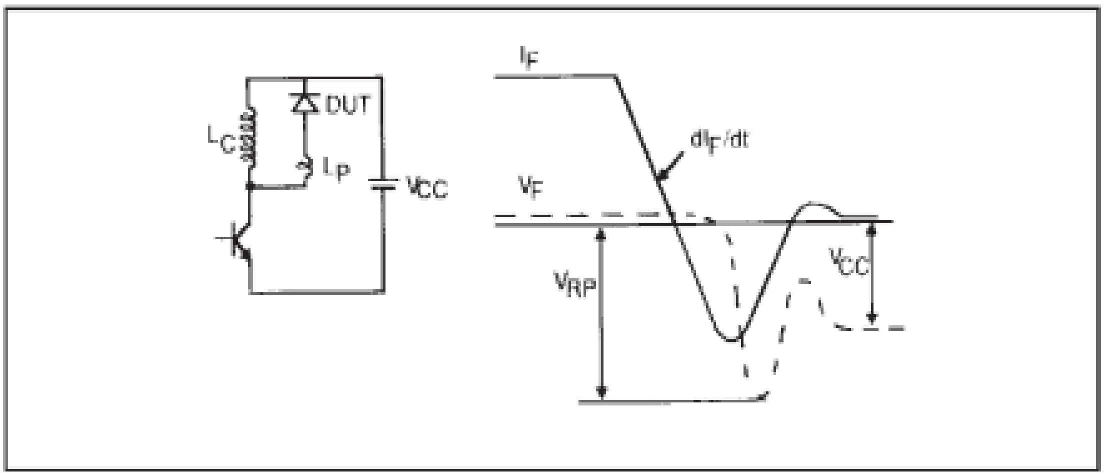
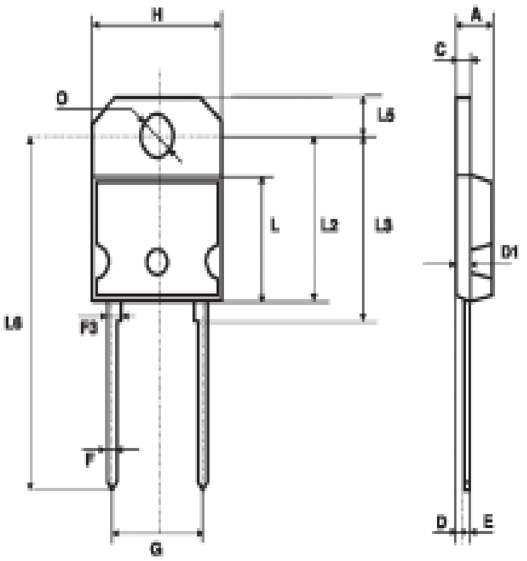


Figure 12. Turn-off switching characteristics (with series inductance)



PACKAGE MECHANICAL DATA
SOD93 Plastic



REF.	DIMENSIONS					
	Millimeters			Inches		
	Min.	Typ.	Max.	Min.	Typ.	Max.
A	4.70		4.90	0.185		0.193
C	1.17		1.37	0.046		0.054
D		2.50			0.098	
D1		1.27			0.050	
E	0.50		0.78	0.020		0.031
F	1.10		1.30	0.043		0.051
F3		1.75			0.069	
G	10.80		11.10	0.425		0.437
H	14.70		15.20	0.578		0.598
L			12.20			0.480
L2			16.20			0.638
L3		18.0			0.709	
L5	3.95		4.15	0.156		0.163
L6		31.00			1.220	
O	4.00		4.10	0.157		0.161

Cooling method: by conduction (method C)
Marking: type number
Weight: 4.3g
Recommended torque value: 80cm. N
Maximum torque value: 100cm. N

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http://www.st.com

Schematic: arduino-mega2560-schematic.pdf

Summary

Microcontroller	ATmega2560
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	54 (of which 14 provide PWM output)
Analog Input Pins	16
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	256 KB of which 8 KB used by bootloader
SRAM	8 KB
EEPROM	4 KB
Clock Speed	16 MHz

Power

The Arduino Mega can be powered via the USB connection or with an external power supply. The power source is selected automatically.

External (non-USB) power can come either from an AC-to-DC adapter (wall-wart) or battery. The adapter can be connected by plugging a 2.1mm center-positive plug into the board's power jack. Leads from a battery can be inserted in the Gnd and Vin pin headers of the POWER connector.

The board can operate on an external supply of 6 to 20 volts. If supplied with less than 7V, however, the 5V pin may supply less than five volts and the board may be unstable. If using more than 12V, the voltage regulator may overheat and damage the board. The recommended range is 7 to 12 volts.

The Mega2560 differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the Atmega8U2 programmed as a USB-to-serial converter.

value, the LED is on, when the pin is LOW, it's off.

- **I2C: 20 (SDA) and 21 (SCL).** Support I2C (TWI) communication using the Wire library (documentation on the Wiring website). Note that these pins are not in the same location as the I2C pins on the Duemilanove or Diecimila.

The Mega2560 has 16 analog inputs, each of which provide 10 bits of resolution (i.e. 1024 different values). By default they measure from ground to 5 volts, though is it possible to change the upper end of their range using the AREF pin and analogReference() function.

There are a couple of other pins on the board:

- **AREF.** Reference voltage for the analog inputs. Used with analogReference().
- **Reset.** Bring this line LOW to reset the microcontroller. Typically used to add a reset button to shields which block the one on the board.

Communication

The Arduino Mega2560 has a number of facilities for communicating with a computer, another Arduino, or other microcontrollers. The ATmega2560 provides four hardware UARTs for TTL (5V) serial communication. An ATmega8U2 on the board channels one of these over USB and provides a virtual com port to software on the computer (Windows machines will need a .inf file, but OSX and Linux machines will recognize the board as a COM port automatically. The Arduino software includes a serial monitor which allows simple textual data to be sent to and from the board. The RX and TX LEDs on the board will flash when data is being transmitted via the ATmega8U2 chip and USB connection to the computer (but not for serial communication on pins 0 and 1).
A SoftwareSerial library allows for serial communication on any of the Mega2560's digital pins.
The ATmega2560 also supports I2C (TWI) and SPI communication. The Arduino software includes a Wire library to simplify use of the I2C bus; see the documentation on the Wiring website for details. For SPI communication, use the SPI library.

Programming

The Arduino Mega can be programmed with the Arduino software (download). For details, see the reference and tutorials.
The ATmega2560 on the Arduino Mega comes preburned with a bootloader that allows you to upload new code to it without the use of an external hardware programmer. It

The power pins are as follows:

- **VIN.** The input voltage to the Arduino board when it's using an external power source (as opposed to 5 volts from the USB connection or other regulated power source). You can supply voltage through this pin, or, if supplying voltage via the power jack, access it through this pin.
- **5V.** The regulated power supply used to power the microcontroller and other components on the board. This can come either from VIN via an on-board regulator, or be supplied by USB or another regulated 5V supply.
- **3V3.** A 3.3 volt supply generated by the on-board regulator. Maximum current draw is 50 mA.
- **GND.** Ground pins.

Memory

The ATmega2560 has 256 KB of flash memory for storing code (of which 8 KB is used for the bootloader), 8 KB of SRAM and 4 KB of EEPROM (which can be read and written with the EEPROM library).

Input and Output

Each of the 54 digital pins on the Mega can be used as an input or output, using pinMode() , digitalWrite(), and digitalRead() functions. They operate at 5 volts. Each pin can provide or receive a maximum of 40 mA and has an internal pull-up resistor (disconnected by default) of 20-50 kOhms. In addition, some pins have specialized functions:

- **Serial: 0 (RX) and 1 (TX); Serial 1: 19 (RX) and 18 (TX); Serial 2: 17 (RX) and 16 (TX); Serial 3: 15 (RX) and 14 (TX).** Used to receive (RX) and transmit (TX) TTL serial data. Pins 0 and 1 are also connected to the corresponding pins of the ATmega8U2 USB-to-TTL Serial chip.
- **External Interrupts: 2 (interrupt 0), 3 (interrupt 1), 18 (interrupt 5), 19 (interrupt 4), 20 (interrupt 3), and 21 (interrupt 2).** These pins can be configured to trigger an interrupt on a low value, a rising or falling edge, or a change in value. See the attachInterrupt() function for details.
- **PWM: 0 to 13.** Provide 8-bit PWM output with the analogWrite() function.
- **SPI: 50 (MISO), 51 (MOSI), 52 (SCK), 53 (SS).** These pins support SPI communication using the SPI library. The SPI pins are also broken out on the ICSP header, which is physically compatible with the Uno, Duemilanove and Diecimila.
- **LED: 13.** There is a built-in LED connected to digital pin 13. When the pin is HIGH

communicates using the original STK500 protocol (reference, C header files).
You can also bypass the bootloader and program the microcontroller through the ICSP (In-Circuit Serial Programming) header; see these instructions for details.

Automatic (Software) Reset

Rather then requiring a physical press of the reset button before an upload, the Arduino Mega2560 is designed in a way that allows it to be reset by software running on a connected computer. One of the hardware flow control lines (DTR) of the ATmega8U2 is connected to the reset line of the ATmega2560 via a 100 nanofarad capacitor. When this line is asserted (taken low), the reset line drops long enough to reset the chip. The Arduino software uses this capability to allow you to upload code by simply pressing the upload button in the Arduino environment. This means that the bootloader can have a shorter timeout, as the lowering of DTR can be well-coordinated with the start of the upload.
This setup has other implications. When the Mega2560 is connected to either a computer running Mac OS X or Linux, it resets each time a connection is made to it from software (via USB). For the following half-second or so, the bootloader is running on the Mega2560. While it is programmed to ignore malformed data (i.e. anything besides an upload of new code), it will intercept the first few bytes of data sent to the board after a connection is opened.
If a sketch running on the board receives one-time configuration or other data when it first starts, make sure that the software with which it communicates waits a second after opening the connection and before sending this data.
The Mega2560 contains a trace that can be cut to disable the auto-reset. The pads on either side of the trace can be soldered together to re-enable it. It's labeled "RESET-EN". You may also be able to disable the auto-reset by connecting a 110 ohm resistor from 5V to the reset line; see this forum thread for details.

USB Overcurrent Protection

The Arduino Mega2560 has a resettable polyfuse that protects your computer's USB ports from shorts and overcurrent. Although most computers provide their own internal protection, the fuse provides an extra layer of protection. If more than 500 mA is applied to the USB port, the fuse will automatically break the connection until the short or overload is removed.

Physical Characteristics and Shield Compatibility

The maximum length and width of the Mega2560 PCB are 4 and 2.1 inches respectively, with the USB connector and power jack extending beyond the former dimension. Three screw holes allow the board to be attached to a surface or case. Note that the distance between digital pins 7 and 8 is 160 mil (0.16"), not an even multiple of the 100 mil spacing of the other pins.

The Mega2560 is designed to be compatible with most shields designed for the Uno, Diecimila or Duemilanove. Digital pins 0 to 13 (and the adjacent AREF and GND pins), analog inputs 0 to 5, the power header, and ICSP header are all in equivalent locations. Further the main UART (serial port) is located on the same pins (0 and 1), as are external interrupts 0 and 1 (pins 2 and 3 respectively). SPI is available through the ICSP header on both the Mega2560 and Duemilanove / Diecimila. *Please note that I_2C is not located on the same pins on the Mega (20 and 21) as the Duemilanove / Diecimila (analog inputs 4 and 5).*