DC TO DC SWITCH MODE CONVERTER

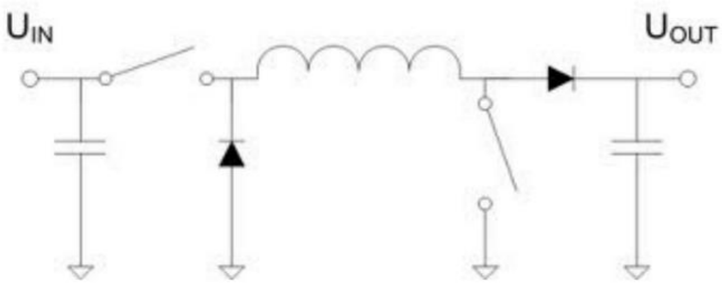
POWER ELECTRONICS

6 of june of 2014

Content

1. Introduction

The following circuit is a DC to DC switch mode converter. The goal of this project is to design the circuit in steady state and to evaluate the performance during transient operation including the system start-up and the response to external disturbances.



DESIGN SPECIFICATIONS		
PARAMETER	VALUE	UNIT
Input voltage, Vin	24	V
Output voltage, Vout	48	V
Output power	500	W
Switching frequency	100	KHz
Inductor current ripple	20	%
Capacitor voltage ripple	1	%

Table 1: project specifications

Note: Ripples are defined as (max value – min value)/average value

2. Circuit features

The proposed project is a Buck-Boost Converter; this circuit is composed by two switches, two diodes, two capacitors and an inductor. The first capacitor is only useful with AC current; by the way we don't use this capacitor.

To reach our goals we have three different topologies:

-Buck Converter

-Boost Converter

-And Buck-Boost Converter

2.1 Buck converter

The first topology is a buck converter. To implement the circuit as a buck converter we must set ON state to the second switch, this circuit is a step down and it works like this:

When the first switch is in on state the input voltage feeds the circuit and the current flows through the inductor, the diode, and a part of the current charge the capacitor and the other part flows through the load.

In the other hand, when the first switch is in off state the polarity of the inductor changes. And the inductor becomes the main source. And now the current of the inductor, added to the capacitor current, flows through the 2 diodes and the Load.

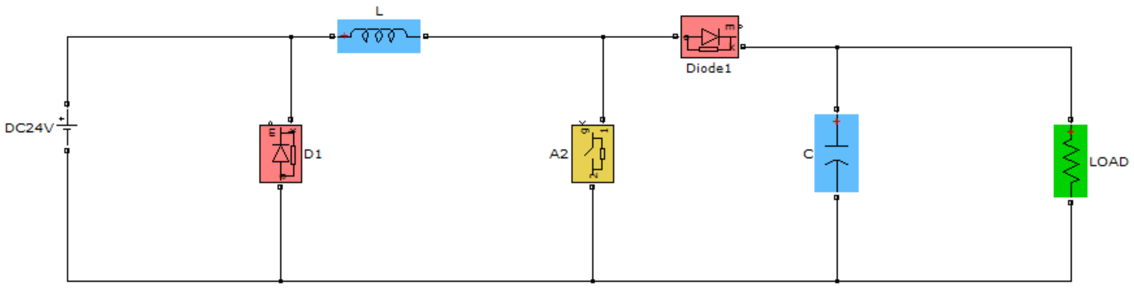


Figure 1: Buck converter plot

2.2 Boost converter

The second topology is a boost converter, this circuit is a step up, and it works like this:

The first switch is always in on state, and the second one is switching on to off state. When the second switch is in off state, the current flows to the inductor, the diode, charge the capacitor and feeding the load. When the second switch is in on state the inductors is discharging thought the switch and the capacitor feeds the load.

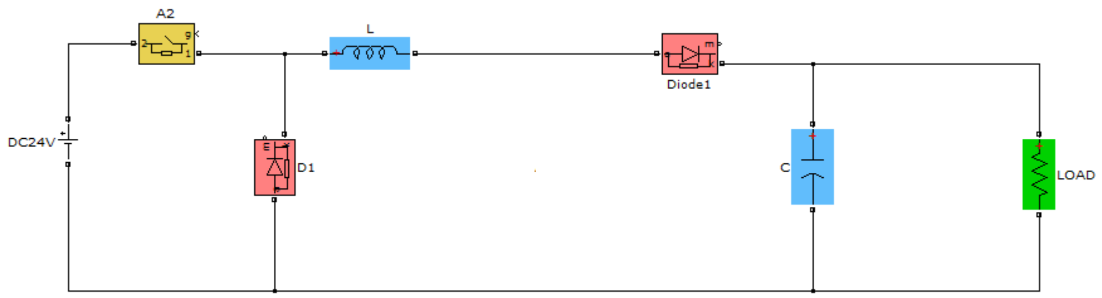


Figure 2: Boost converter plot

2.3 Buck-boost converter

The third topology is a buck-boost converter. It works by the 2 switches commutation and it's a mix of the buck converter with the boost converter.

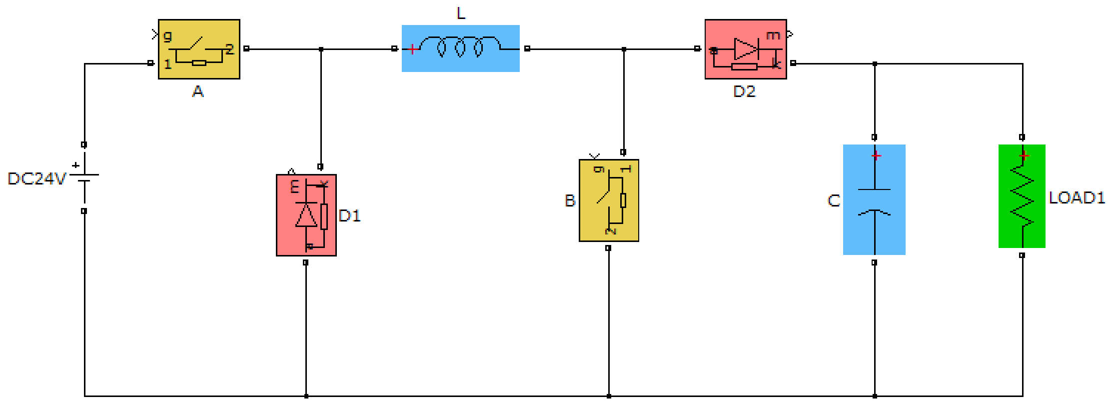


Figure 3: Buck-boost converter

3. Matlab configuration

We have configured Matlab with the aim of getting the best possible performance, and we obtained the next results:

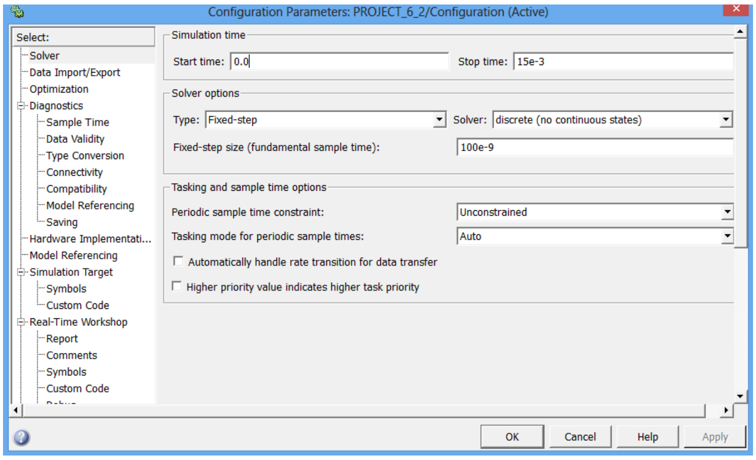


Figure 4: Matlab configuration

$$\mathbf{T_s = \frac{1}{f_s} = \frac{1}{100\ kHz} = 10\ \mu s}$$

3.1 Duty cycle

Duty cycle is the proportion of time during which a component, device, or system is operated. The duty cycle can be expressed as a ratio or as a percentage.

We can calculate the duty cycle with the next formula:

D= $\frac{T}{P} * 100$

Where D is Duty cycle, T is the time signal is active and P is the period of the signal.

In our close loop design the duty cycle changes in time in order of the difference between the output and the goal that we define for every control system.

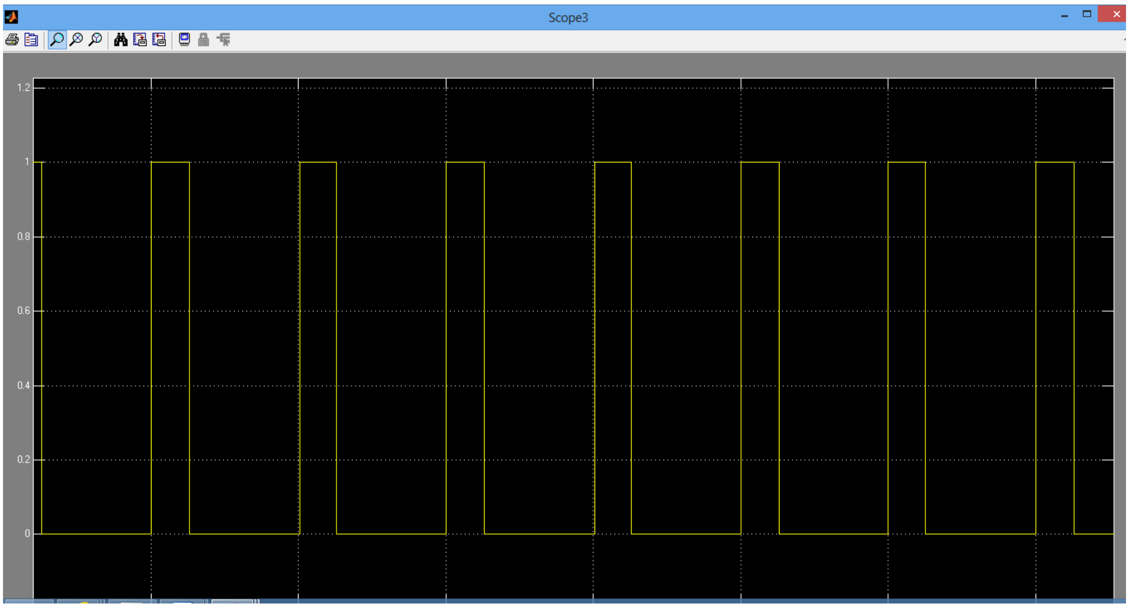


Figure 5: Current PWM

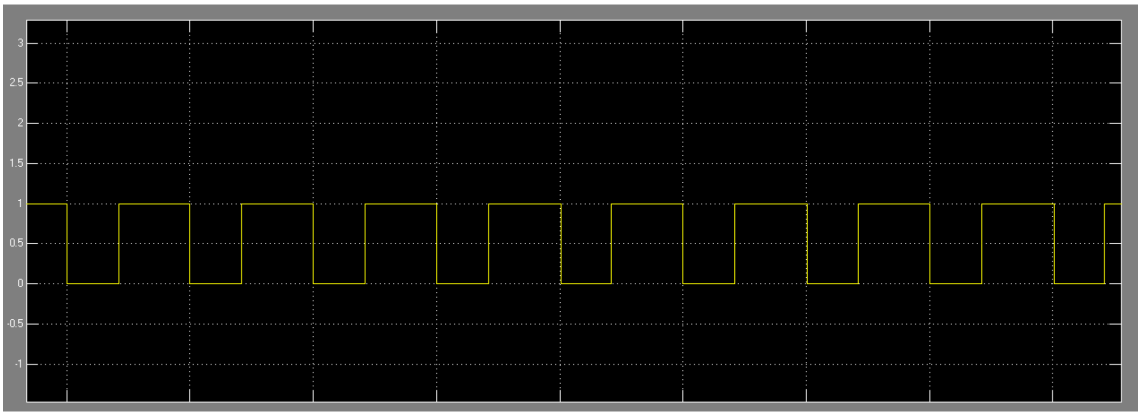
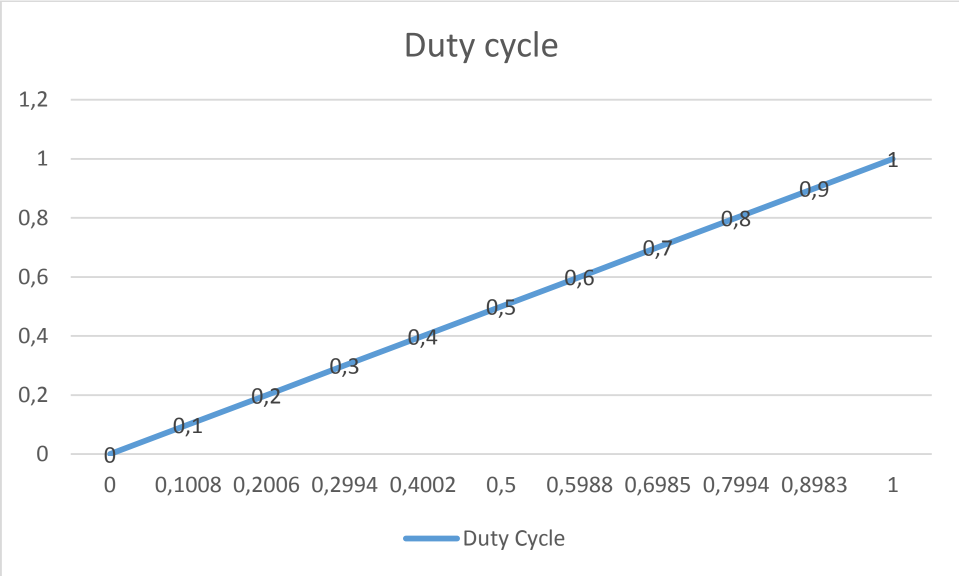


Figure 6: Voltage PWM

DUTY CYCLE	VIN	VOUT	VOUT/VIN
0	24	0	0,0000
0,1	24	2.42	0,1008
0,2	24	4.82	0,2006
0,3	24	7.18	0,2994
0,4	24	9.60	0,4002
0,5	24	12	0,5000
0,6	24	14.37	0,5988
0,7	24	16.76	0,6985
0,8	24	19.18	0,7994
0,9	24	21.56	0,8983
1.0	24	24	1.0000

Table 2: Duty cycle results

$$\mathbf{D_{cycle}} = \frac{\mathbf{Vout}}{\mathbf{Vinput}} = \frac{\mathbf{12}}{\mathbf{24}} = \mathbf{0.5}$$



Graphic 1: Duty cycle trend

4. Circuit design

4.1 Open loop design

We decide to choose boost converter, because it's a step up converter, and we want to design a step up voltage. At first, we design and test our circuit in open loop mode, and we reach our goals. To reach the component values we use the Ohm law, how we only knew the output voltage and power, we had calculated the current and load value. We use the next formulas:

P=V*I → 500 = 48 * I → I=500/48=**10.41 A**

P=R*I^2 → 500 = R *10.41^2 → R=**4.608 Ω**

We use a sample time of 0.01 s.

4.2 Ripple measurement

To calculate the inductor and capacitor ripple values, we use the experience and we tried some different values, analyzing the response of the circuit. Finally, we get the optimal values for the component and we fixed it at 25 μH to the inductor and 28 μF to the capacitor. We have designed the next Matlab program in order to get inductor and capacitor ripple measurements:

```
%% Calculating the Ripples value of Capacitor
figure;
plot(Vo,'r');
Cmax=max(Vo(0.5*size(Vo):size(Vo)));
Cmin=min(Vo(0.5*size(Vo):size(Vo)));

RippleCapacitor=(Cmax-Cmin)*100/AVo

%% Calculating the Ripples value of Inductor Current
figure;
plot(iL);
Imax=max(iL(0.5*size(iL):size(iL)));
Imin=min(iL(0.5*size(iL):size(iL)));

RippleInductor=(Imax-Imin)*100/AiL
```

The Cmax, Cmin, Imax and Imin variables are defined to calculate the max and the min value of the capacitor and inductor. We use the formula in the next way:

We use max and min Matlab commands and we define the ranges from the half of the period until the end of the period. We do this because in the half period the circuit behavior is in steady state and the ripple values are the real ones.

4.3 Close loop design

When open loop design works, we try to design the close loop design. We create a parallel resistor to the load, with the same load value. This is to simulate disturbances. We implement a Step too. This is activated at 0.01 s.

We try to define the values to control the circuit. The response of the circuit is quite different from open loop design. In close loop design, the output voltage of 48V is never reached.

We have divided the circuit to test it. The first part of the circuit has a response of a current source. We analyzed its behavior and we controlled it. We it Works well proceed to do the same in the other part. We change the first circuit by an ideal current source. We control this part and we decide to paste the two single circuits and its behavior wasn't the desired behavior, because it works well when the output was less than 24 V. By this reason we decided to implement a step down system

4.4 Step down design

In this topology, we have reached the desired goals. In the new close loop system configuration, we have added two PID's. In the left circuit we are controlling the current of the circuit and in the right one, we control the voltage. This configuration makes the circuit able to reach the desired output power and ripples of the capacitor and inductor.

We have to redesign component values and our new goals:

NEW DESIGN SPECIFICATIONS		
PARAMETER	VALUE	UNIT
Input voltage, Vin	24	V
Output voltage, Vout	12	V
Output power	500	W
Switching frequency	100	KHz
Inductor current ripple	20	%
Capacitor voltage ripple	1	%

Table 3: New design specifications

Note: Ripples are defined as (max value – min value)/average value

We have calculated component values like in the first one design:

P=V*I $\longrightarrow$ 500 = 48 * I $\longrightarrow$ I=500/12=**41.666 A**

P=R*I^2 $\longrightarrow$ 500 = R *41.666^2 $\longrightarrow$ R=**0.288 Ω**

We use a sample time of 0.0015 s.

5. Results

In this chapter we are going to talk about our circuit results. Finally, we have to design a Buck-boost converter that decreases the input voltage to a half of its value. The rest of specifications can be the same as the beginning specifications.

We have calculated the load that the circuit needs and the current using the Ohm law. Our values of current and load are the next ones:

Current: 41.666 A

Load: 0.288 Ω

We have implemented a resistor in parallel to simulate disturbances on the load. This resistor starts at 0.01 s.

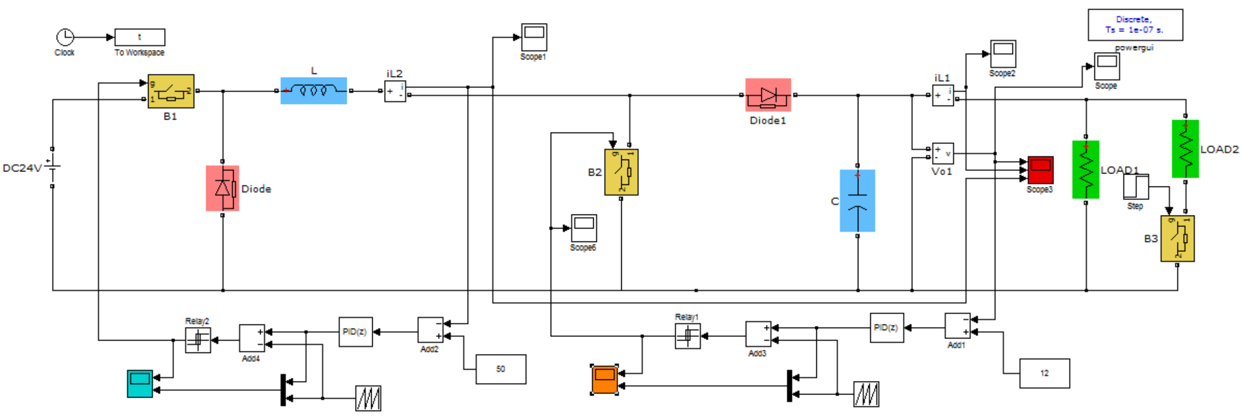


Figure 7: Final circuit design

We get the figure 7 circuit and we have to calculate the PID's values. We decided to implement a PID because it reduces the error in comparison to proportional and integrator separately. We begin to design the PID values. The integrator value must be higher than proportional value. We decided to fix the next values for the first PID:

-Proportional: 0.03

-Integrator: 50

-Derivative: 0

This values are shown at figure 8.

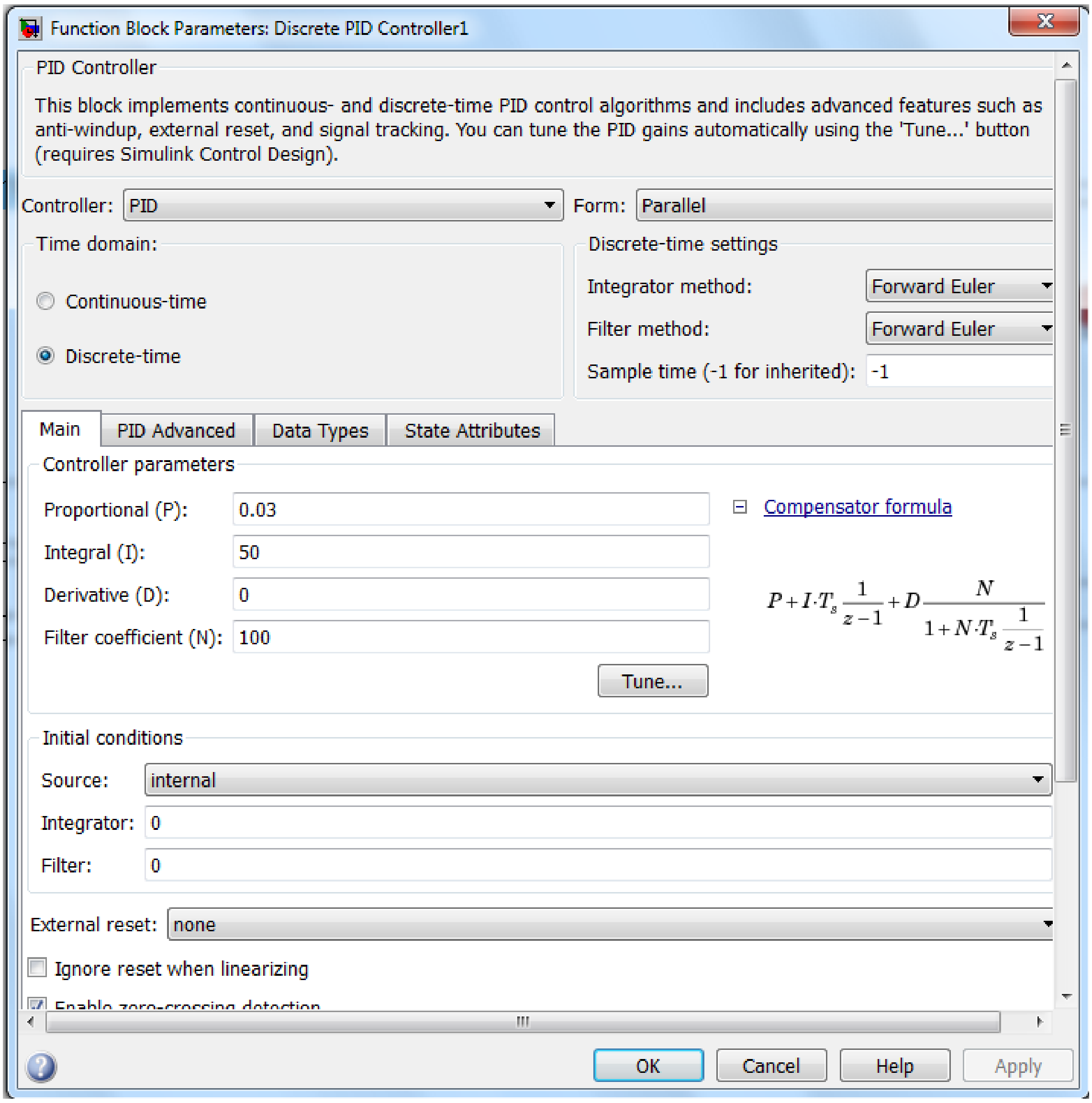


Figure 8: PID values of current control side

We implement the second side control with the next PID values:

-Proportional: 1

-Integrator: 500

-Derivative: 0

This values are shown at figure 9.

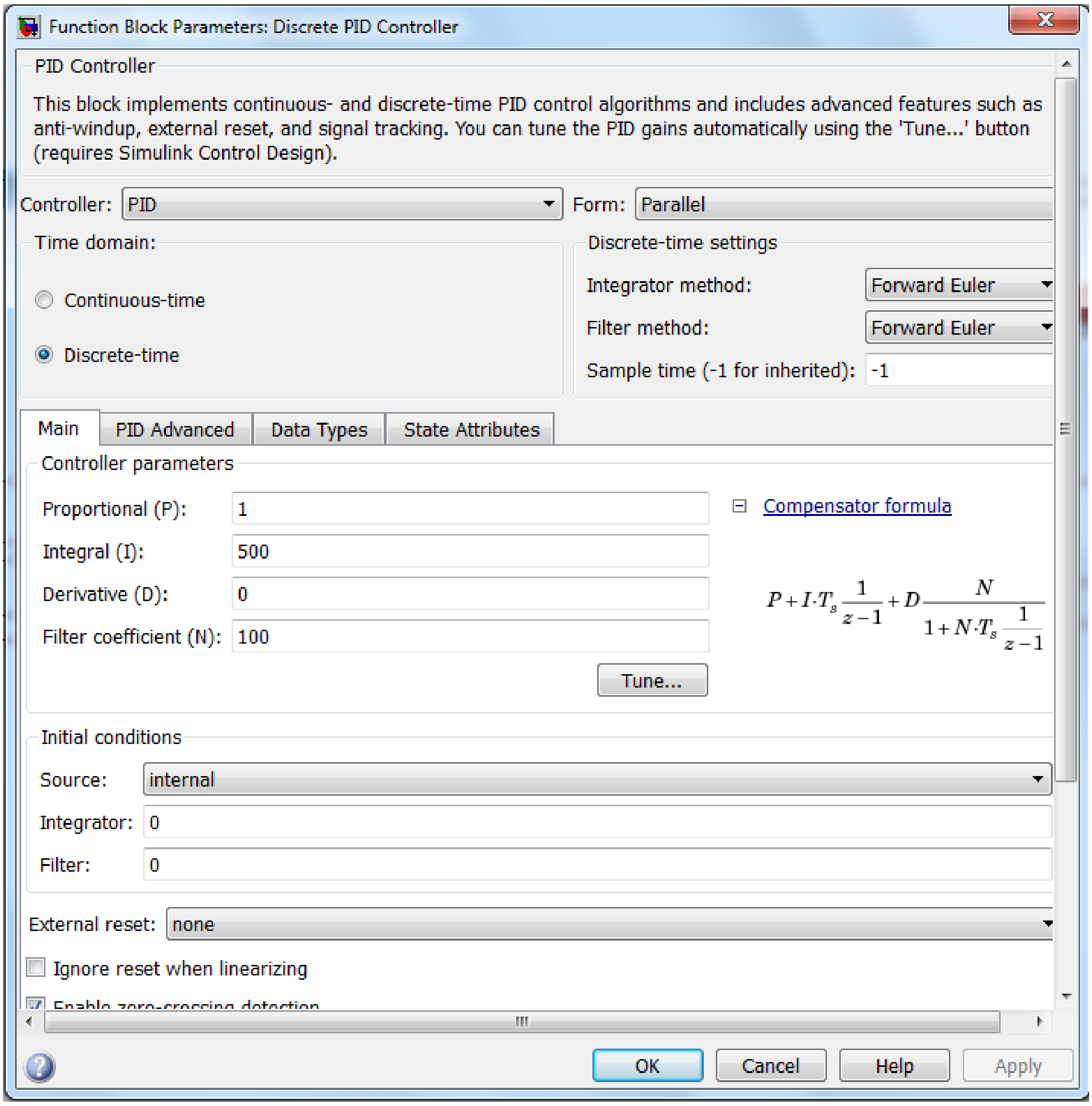


Figure 9: PID values of voltage control side

When we program the PID with the optimal values we have the next results.

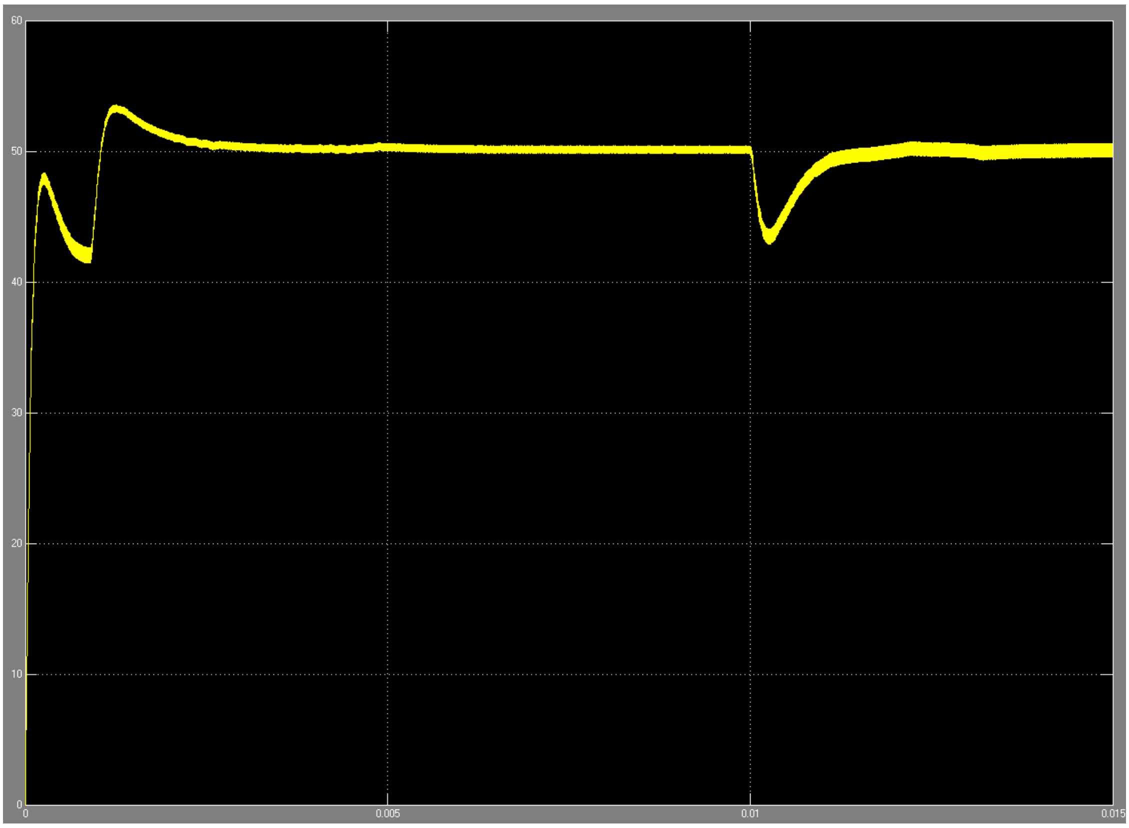


Figure 10: Output current value at first part circuit

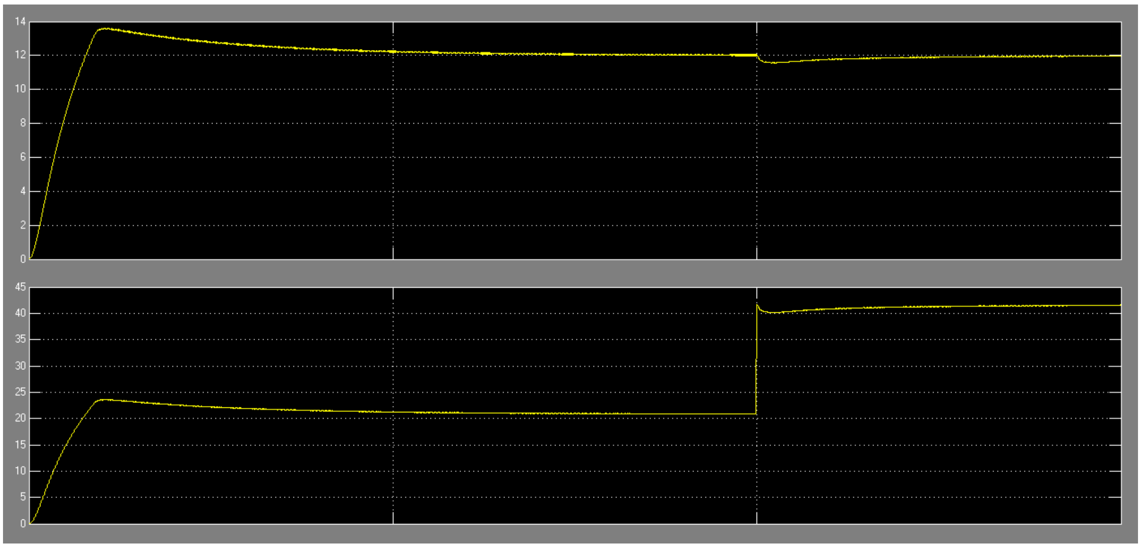


Figure 11: Output voltage value on top and output current value at output of the circuit

In the other hand, we have the pulse width modulator of the two PID. We can show it in the figure 12 for the current control end in the figure 13 for the voltage control.

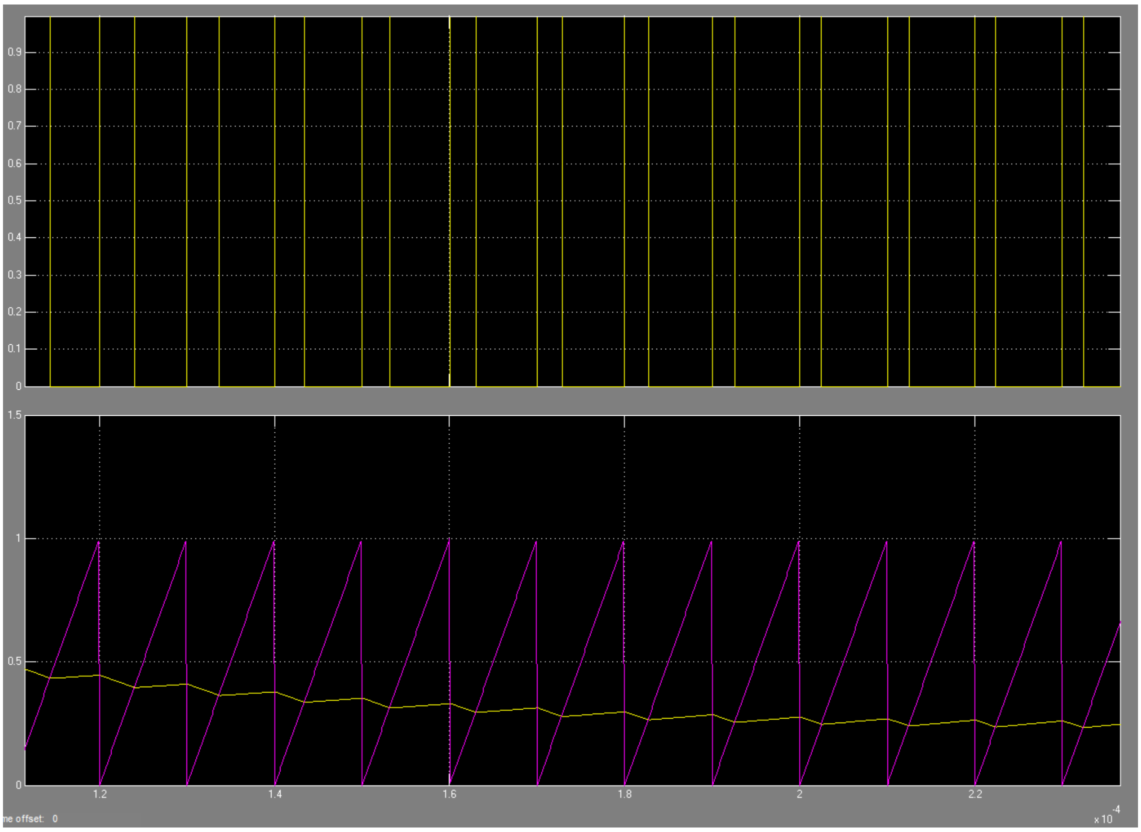


Figure 12: Current side pulse width modulator

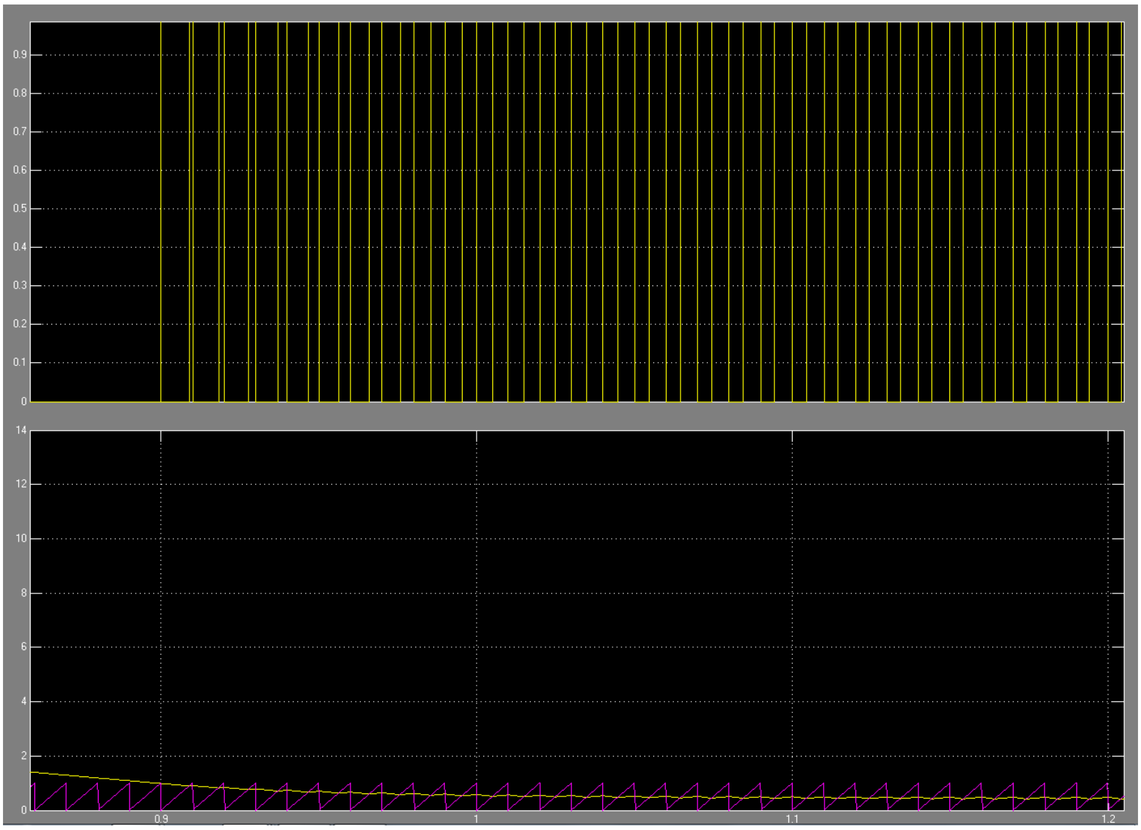


Figure 13: Voltage side pulse width modulator

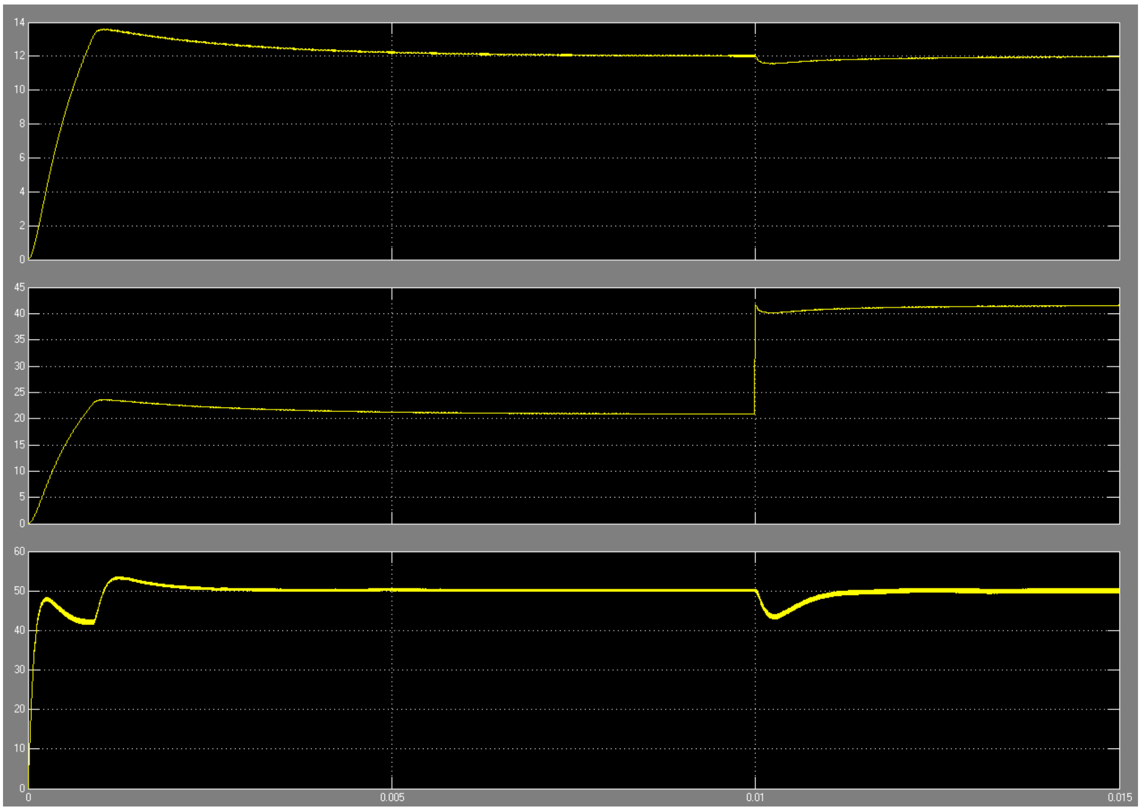


Figure 14: Final result

In the figure 14 we can observe in the top the output voltage is 12 V. In the middle, we have the output current, it increases when the disturbances starts to get the output voltage at the same value. The third plot is the inductor output current that is, more or less, 50 A.

5. Conclusions

As a conclusion of this performance, we can say we reach our second goal and we think power electronics is a very interesting subject, but a 4 months course isn’t enough to learn as much as we want about this theme. But, in the other hand, we have learn some of the converters behavior and how it works, and what we have to do to improve current, voltage, ripples, etc…

The difficulty of this converter becomes fundamental to improve our knowledge in analogic electronic, and it makes us to analyze the circuit from other points of view. This is because we have three different topologies in the same circuit. The way to get one or other different is about the switch position. Finally, we have tried a buck-boost converter, step down.