Project 10:

DC to DC switch mode converter

Power Electronics (ELPO)
Group K65

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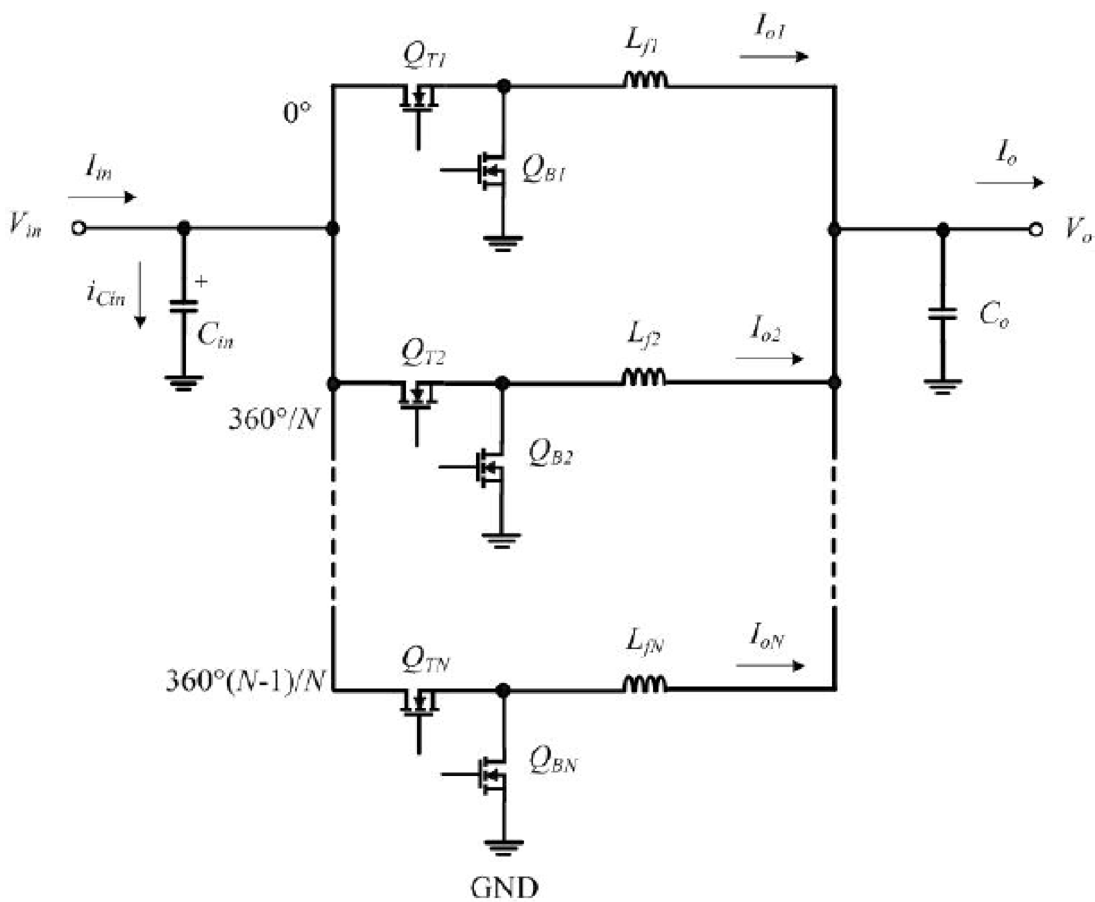
1. INTRODUCTION

It's called DC -DC converter to a device that converts direct current from one voltage to another. Usually switching regulators, giving her a regulated output voltage, and most of the time with current limiting. Frequencies tend to use increasingly higher switching that can reduce the capacity of capacitors, leading to benefits of volume, weight and price.

power electronics can adapt and transform power for different purposes such as a controlled power other equipment, transform electrical energy to alternating or vice versa, and control the speed and performance of electrical machines, etc. Through the use of electronic devices, especially semiconductor. This includes applications in control systems, compensation systems and power factor / harmonic or power supply to industrial consumers or even the interconnection of power systems of different frequency.

The main devices are used by both coils and capacitors and semiconductors working on cutting / saturation (on / off mode

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.

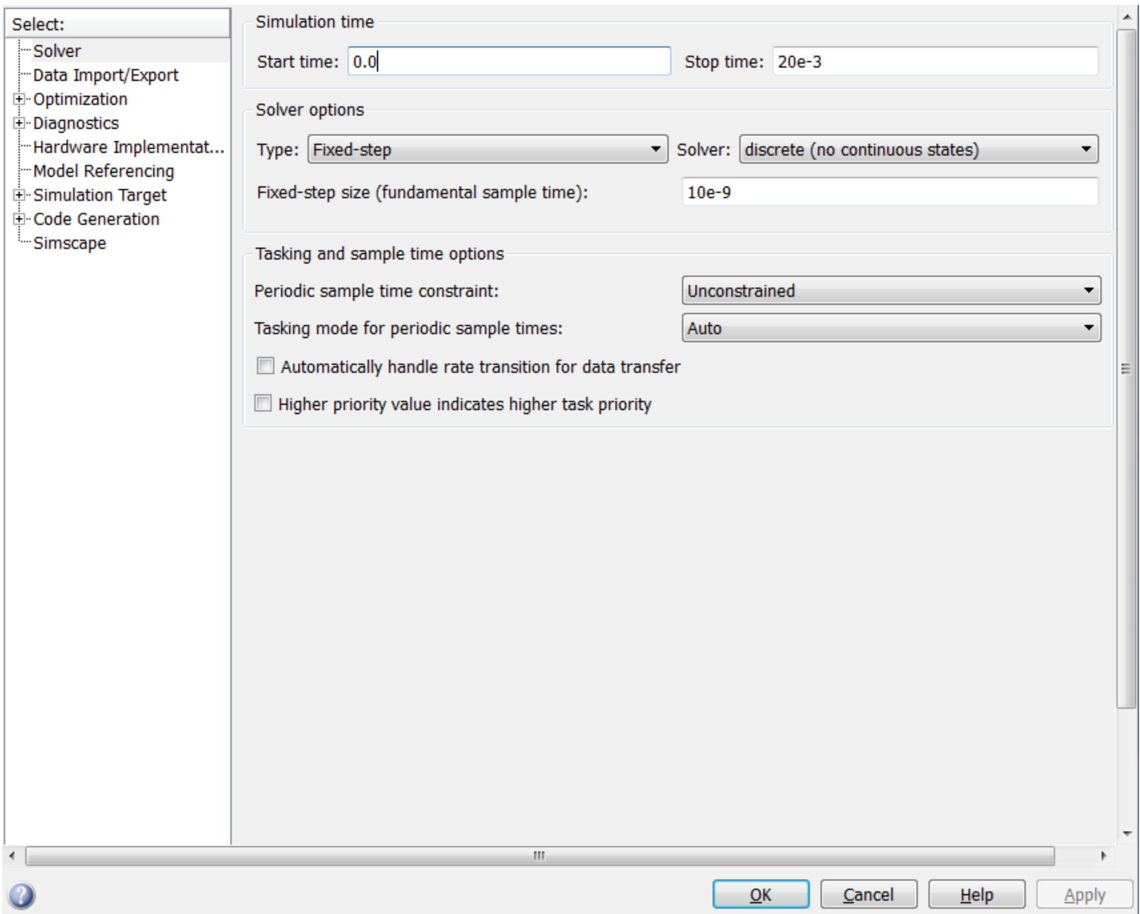


DESIGN ESPECIFICATIONS		
Parameter	**Value**	**Unit**
Input Voltage, V	48	V
Output Voltage,	24	V
Output Power	500	W
Switching Frequency	100	kHz
Inductor Current Ripple	20	%
Capacitor Voltage Ripple	1	%

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

2. MATLAB CONFIGURATION

In this section, through the design specifications, the initial configuration parameters are calculated.



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

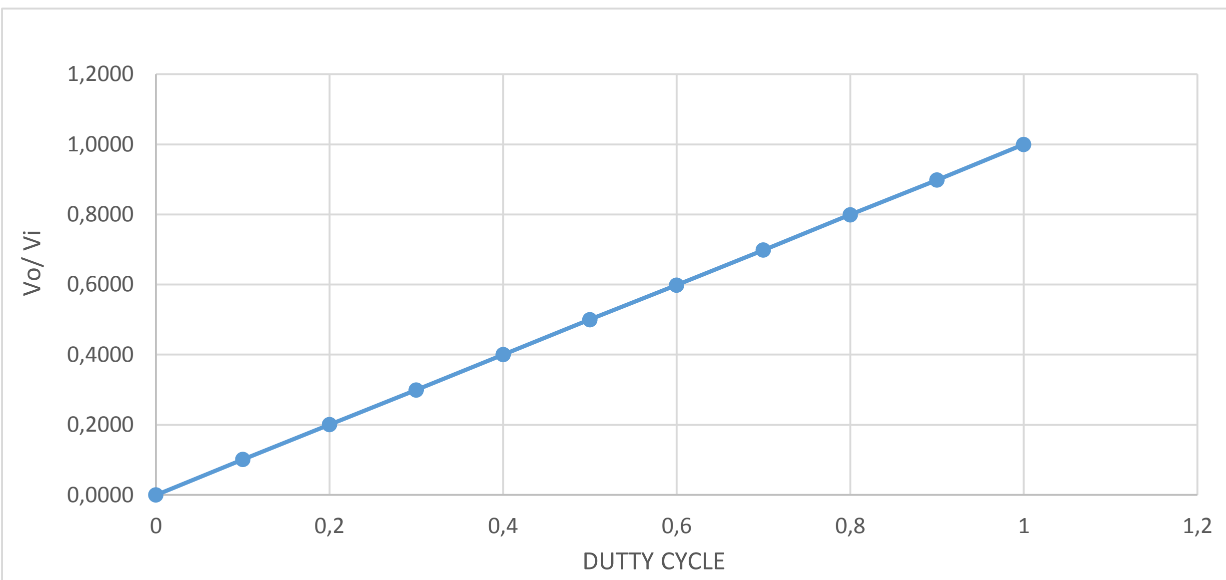
$$\mathbf{R = \frac{(Vout)^2}{P} = \frac{24^2}{500} = 1.152\ \Omega}$$

Duty Cycle

A duty cycle is one period percentage which signal is active. A period is the time that takes signal to complete an on-and-off cycle.For our project, we will need a 50% of duty cycle.

Duty Cycle	Vi	Vo	Vo/Vi
0	48	0	0,0000
0,1	48	4,84	0,1008
0,2	48	9,63	0,2006
0,3	48	14,37	0,2994
0,4	48	19,21	0,4002
0,5	48	24	0,5000
0,6	48	28,74	0,5988
0,7	48	33,53	0,6985
0,8	48	38,37	0,7994
0,9	48	43,12	0,8983
1	48	48	1,0000

$$\mathbf{D_{cycle}} = \frac{\mathbf{Vout}}{\mathbf{Vinput}} = \frac{\mathbf{24}}{\mathbf{48}} = \mathbf{0.5}$$



Inductance

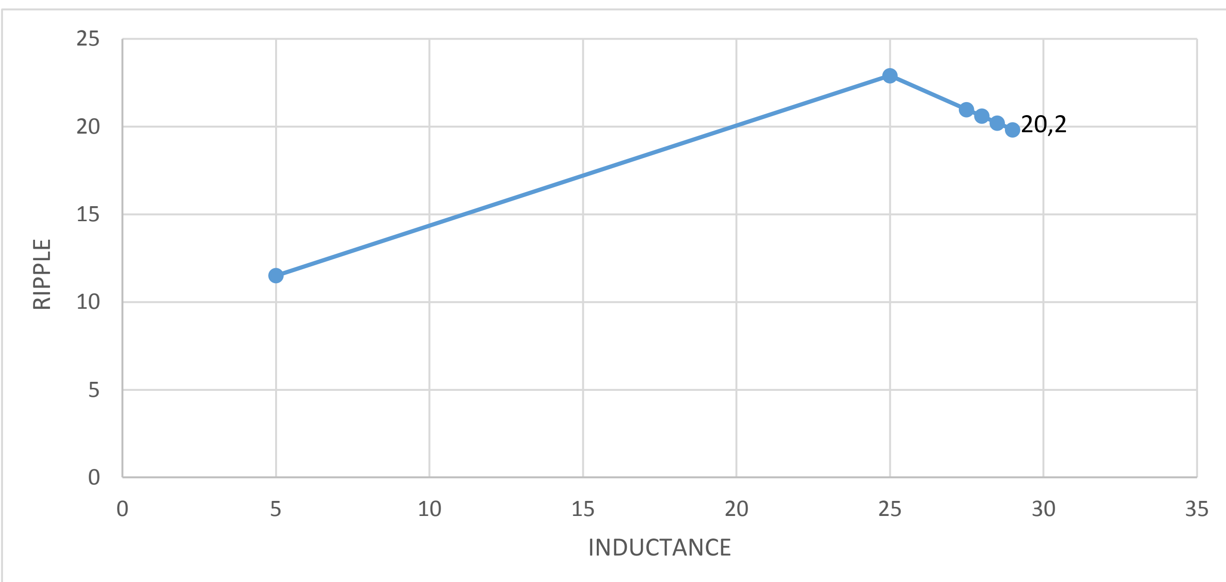
To obtain 20% ripple in the inductors, we have to look the minimum and maximum value of the signal and applying the following equation.

L(µH)	IL max.	IL min.	%ripple
5	32,87	8,79	11,5
25	23,24	18,45	22,9
27,5	23,02	18,65	20,97
28	22,98	18,69	20,59
28,5	22,94	18,73	20,2
29	22,9	18,77	19,82

$$Ripple_{pp} = Imax - Imi$$

$$Iaverage = \frac{Imax - Imin}{2}$$

$$Ripple = \frac{Ripple_{pp}}{Iaverage} * 100$$



To obtain a 20% of inductor current ripple, we need an inductance of 25.5 µH. As we have 3 inductance in parallel, multiply the value obtained for 3. Therefore the final value of each inductor is 85.5 µH.

Capacitor

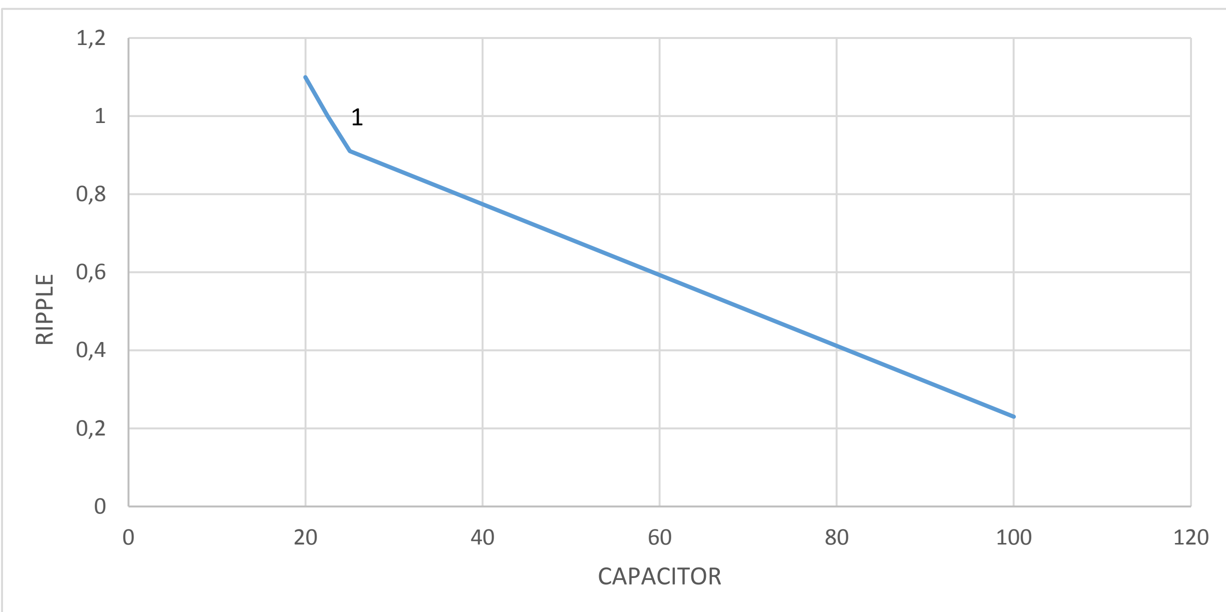
To obtain a 10% ripple in the capacitors, we have to look the minimum and maximum value of the voltage signal and applying the following equation.

C (µF)	V max	V min	%ripple
20	20,95	20,72	1,1
22,5	20,94	20,73	1
25	20,93	20,74	0,91
100	20,86	20,81	0,23

$$Ripple_{pp} = Vmax - Vmin$$

$$Vaverage = \frac{Vmax - Vmin}{2}$$

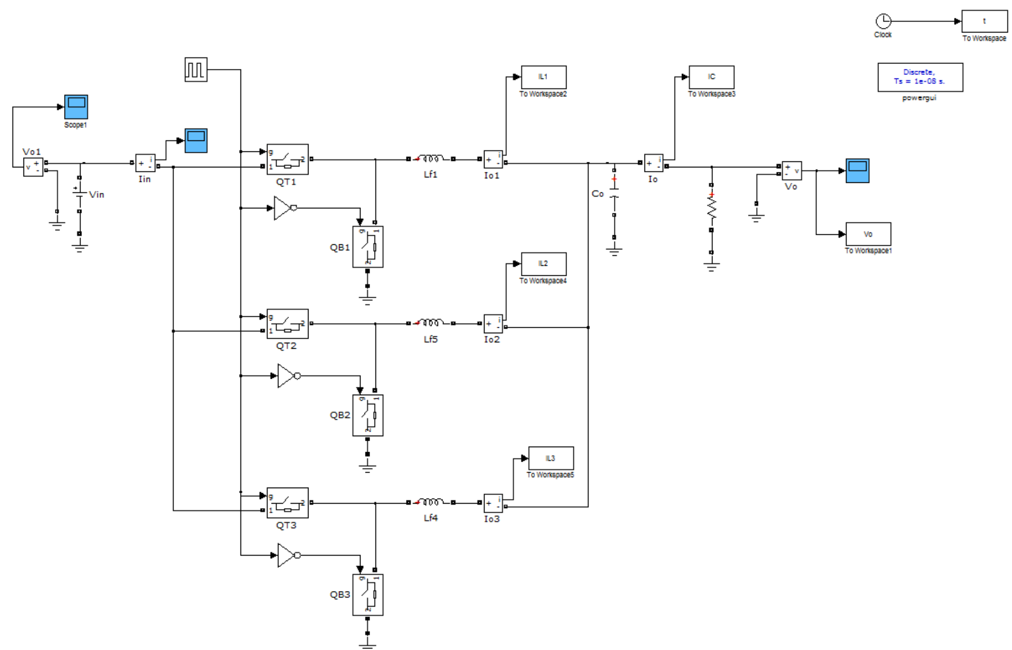
$$Ripple = \frac{Ripple_{pp}}{Vaverage} * 100$$



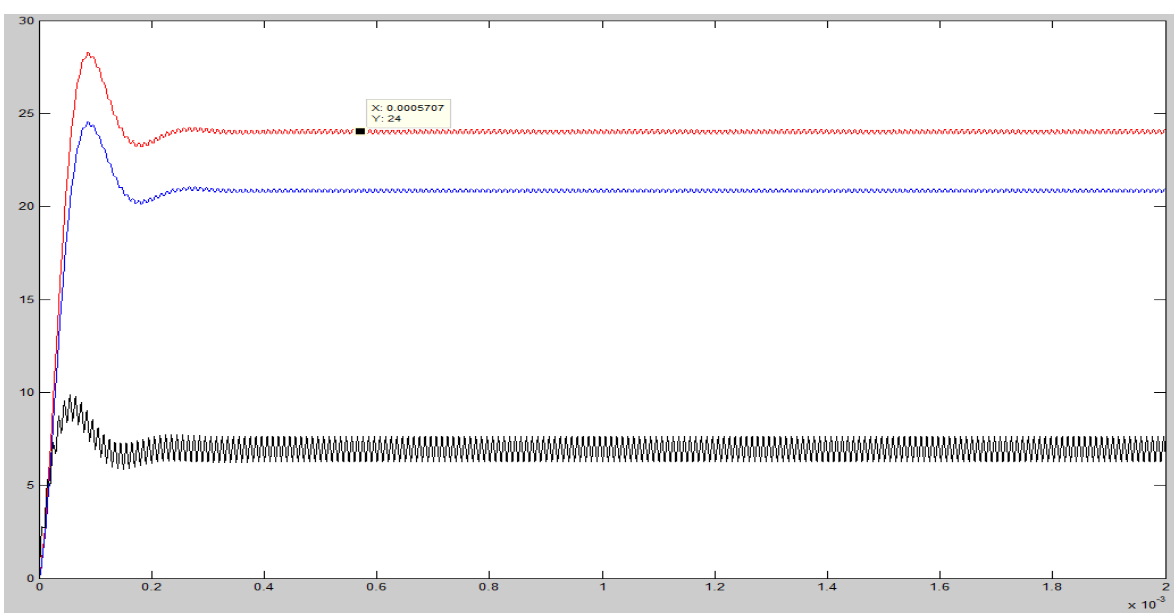
To obtain a 20% of inductor current ripple, we need a capacitor of 22.5 µF.

3. STEADY STATE PERFORMANCE

In this section, we will make the study of DC-DC converter in open loop parameters calculated above.



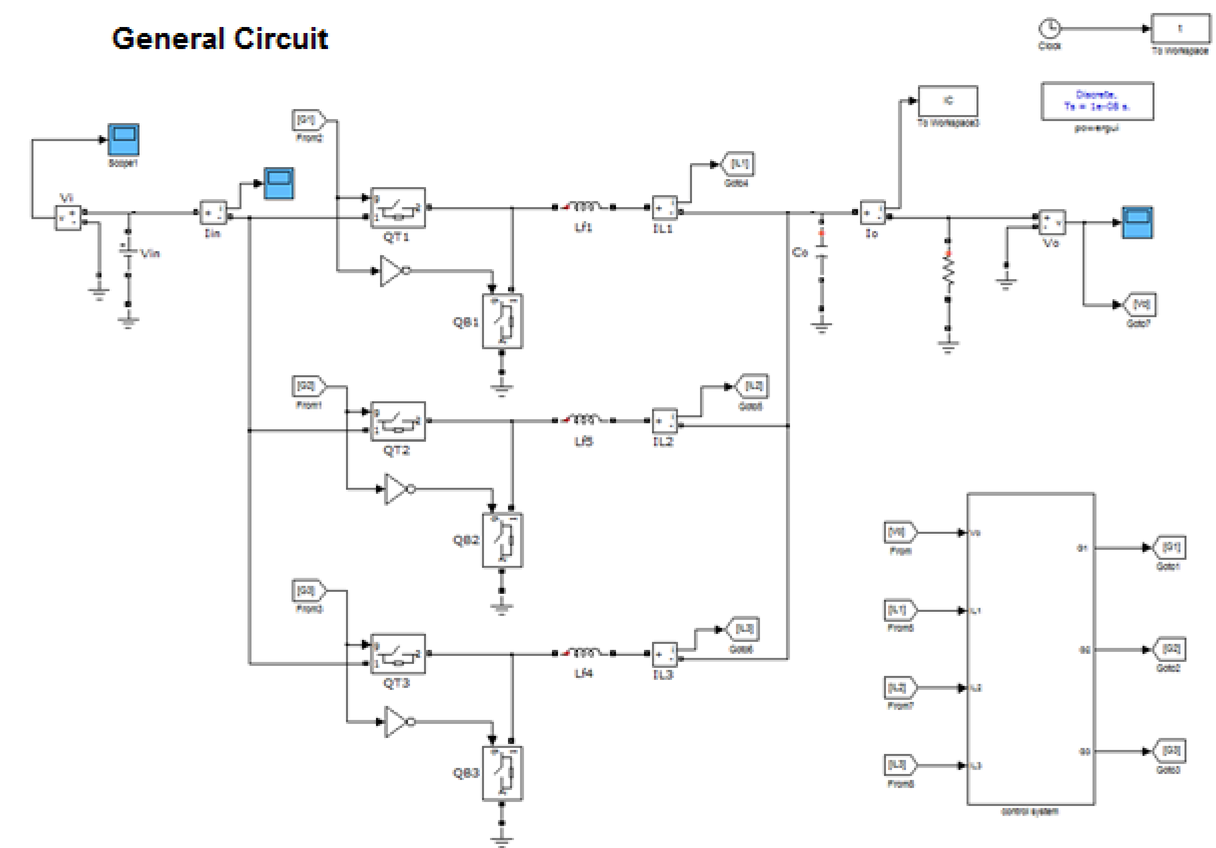

```
>> hold on; grid on
>>plot(t,Vo, 'r');plot(t,IC,'b'); plot(t,IL1,'k')
```

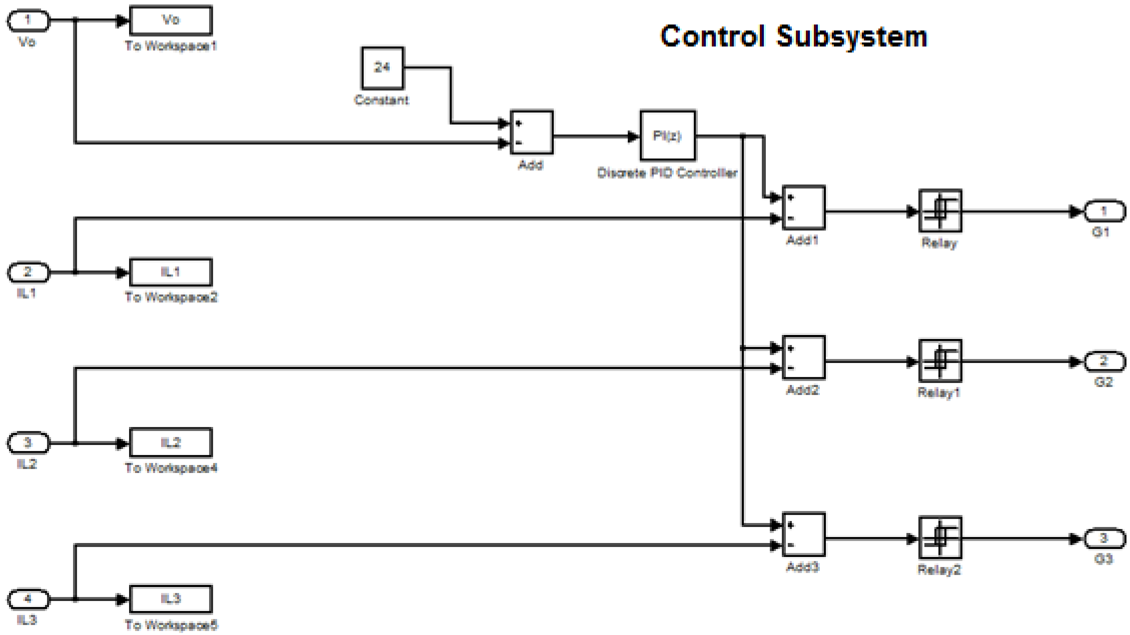


The IL1, IL2, IL3 inductor currents are in phase. The behavior of this circuit can be seen that there is an overshoot at the beginning of the signal which is totally unwanted. In steady state can be observed an average output voltageof24volts which is the goal of the exercise

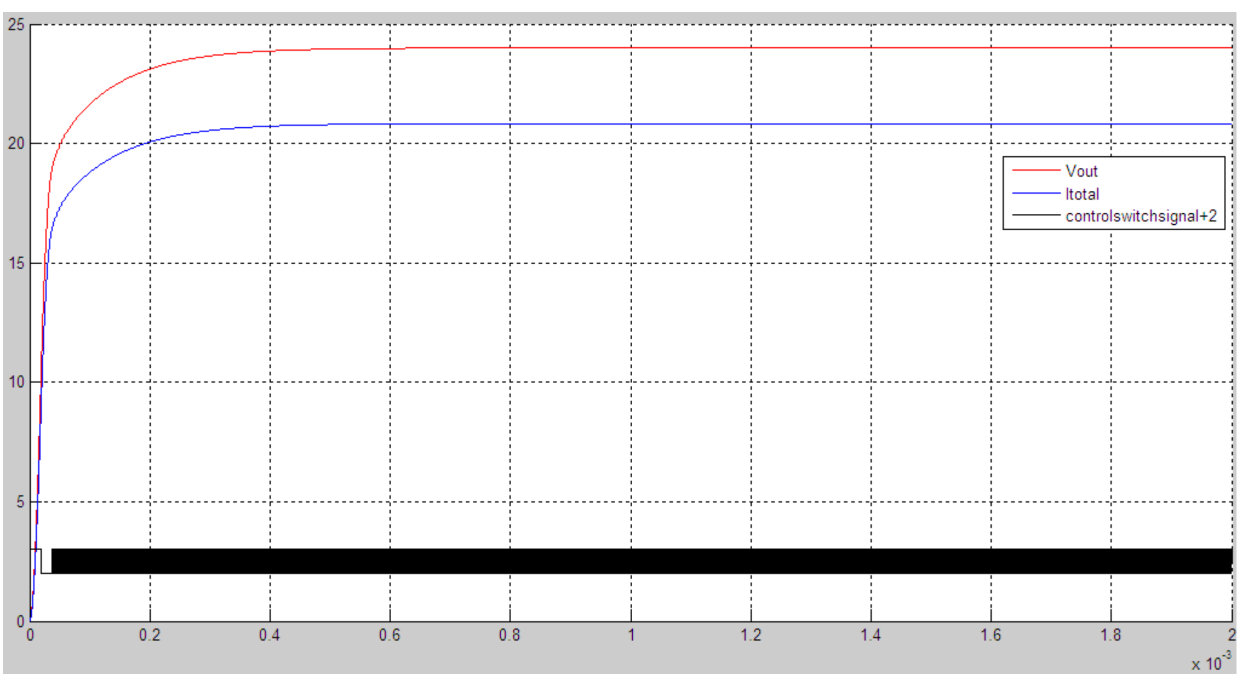
4. PERFORMANCE DURING TRANSIENT OPERATION

To correct the overshoot in the transient state, a control subsystem is added to the schema. This control system is based on the implementation of a PID. To choose correctly KP and KI values we have used trial and error method and the result is a stable signal without overshooting.



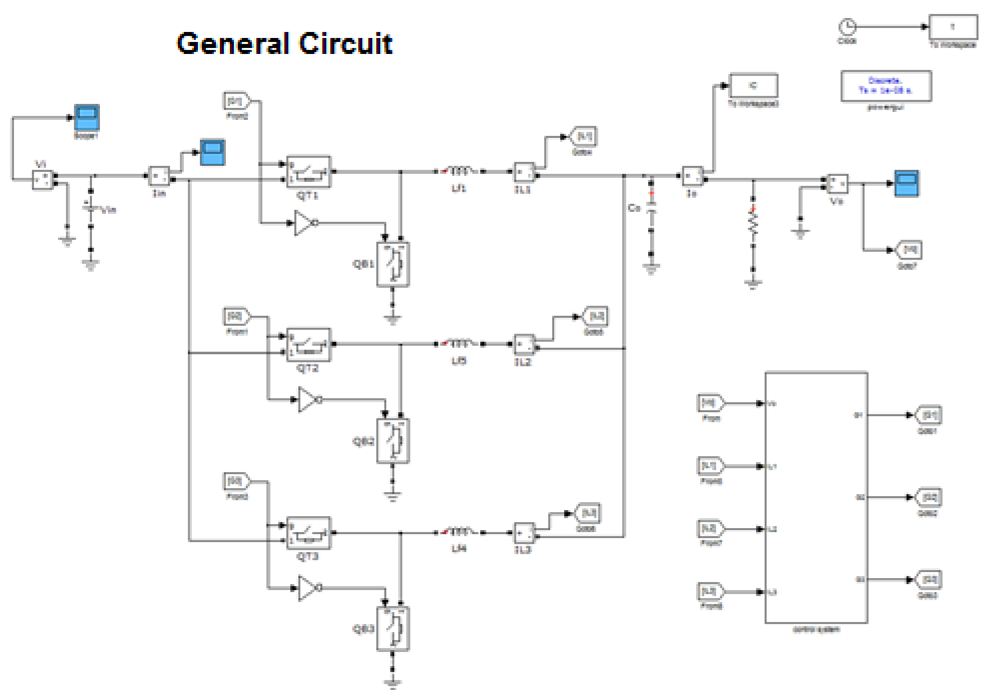


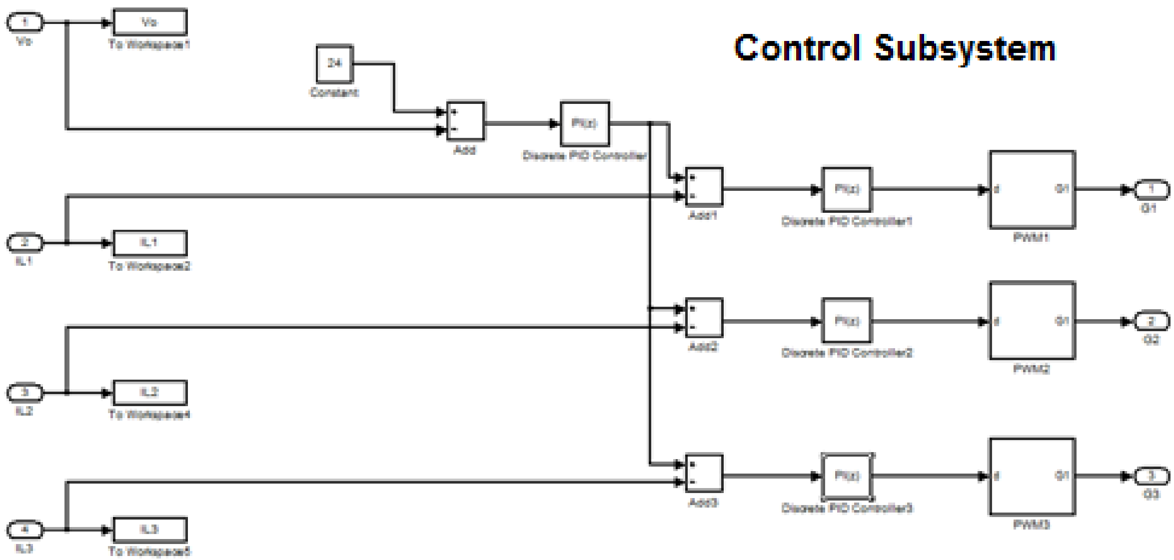

```
>>kp=0.55
>>ki=12000
>>hold on;grid on
>>plot(t,Vo, 'r');plot(t,IC,'b')
```



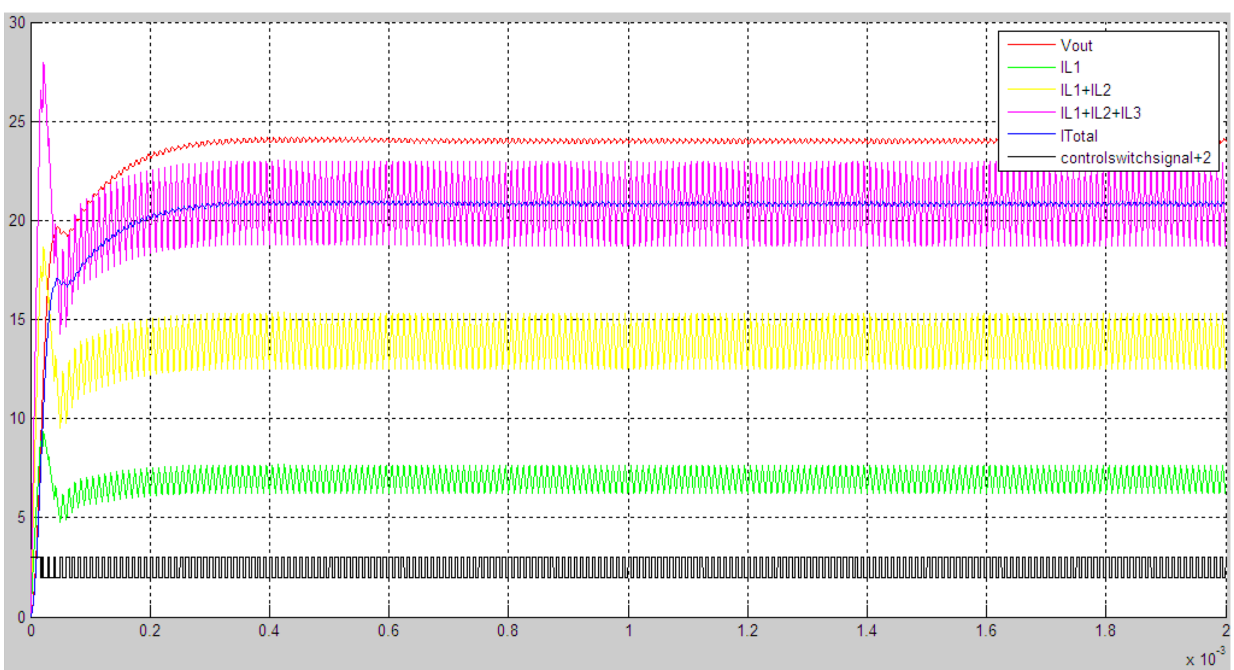
Zoom of control switch signal:

To properly operate the switches and the operation will be more optimal, we need to apply a digital signal to the inputs of the 6 switches. Therefore need to implement three PWM with their respective PID to correct the input value of the switches.





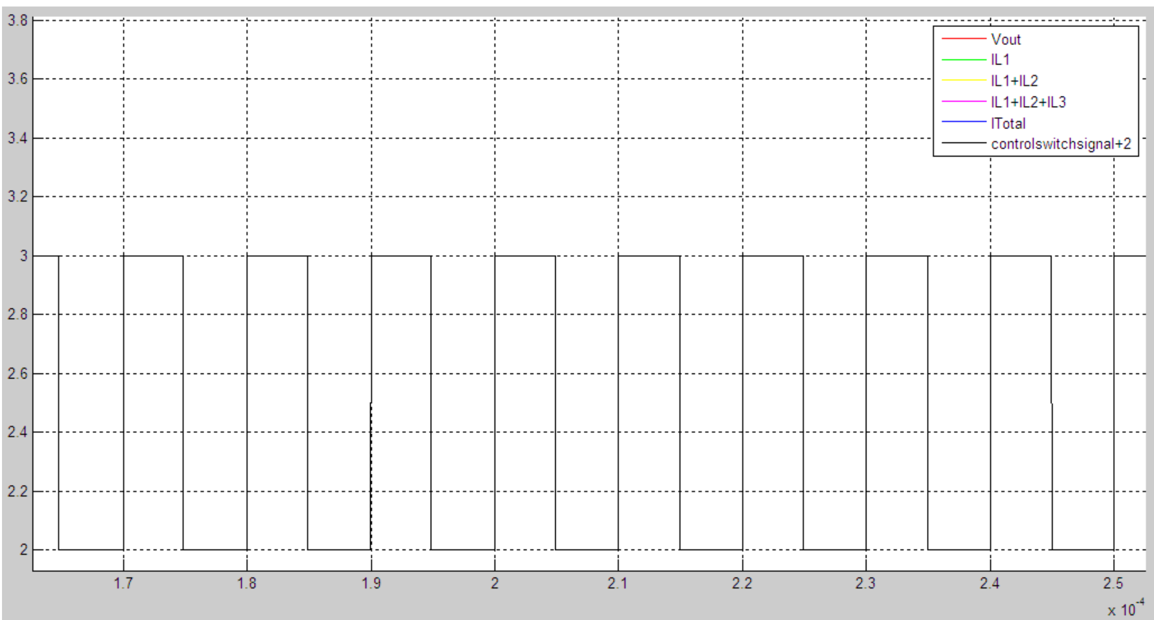

```
>>kpV=0.5
>>kiV=7000
>>kp=0.25
>>ki=2500
>>plot (t, Vo, 'r'); plot (t, IL1, 'g'); plot (t, IL1+IL2, 'y'); plot (t, IL1+IL2+IL3, 'm'); plot (t, IC,
   'b'); plot(t,u1+2,'k')
```



According to the above figure, different values may be observed, such as the output voltage, the current single inductor, the sum of two inductor currents, the sum of the three inductor currents, the total inductor current filtered thanks to capacitor ... a technique called "interleaving" will be used to reduce the ripple in each of the inductor currents, and improving the system for signals with less ripple.

In the next section, this technique will be used and will be able to observe the improved results.

<u>Zoom of control switch signal:</u>

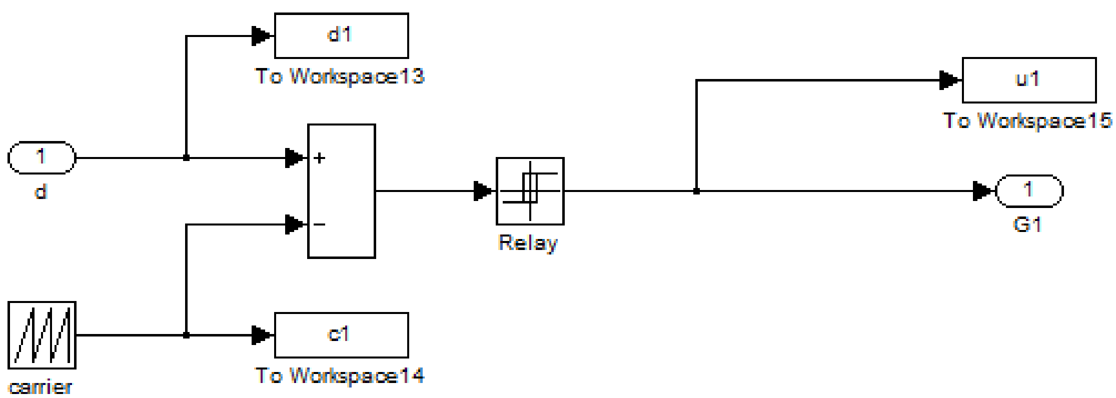


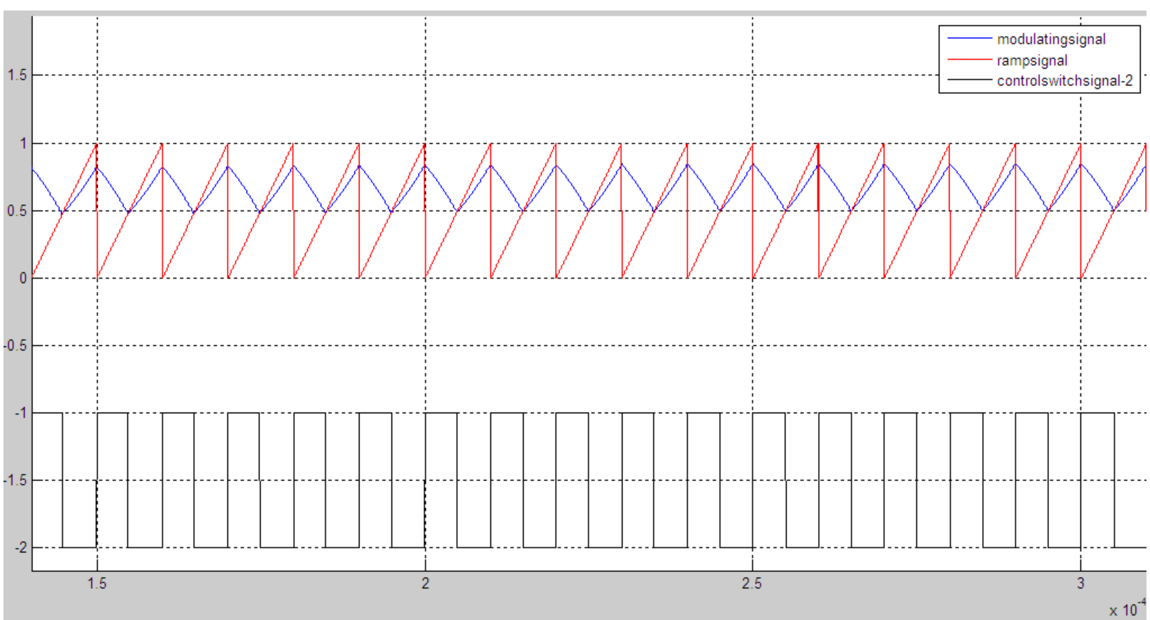
In the last picture, we have the sequence which will be entered into the switches to work correctly.

PWM signal:

```
>> plot (t,d1,'b');plot(t,c1,'r');plot(t,u1-2,'k')
>> legend ('modulatingsignal','rampsignal','controlswitchsignal-2')
```

PWM(Pulse With Modulator)

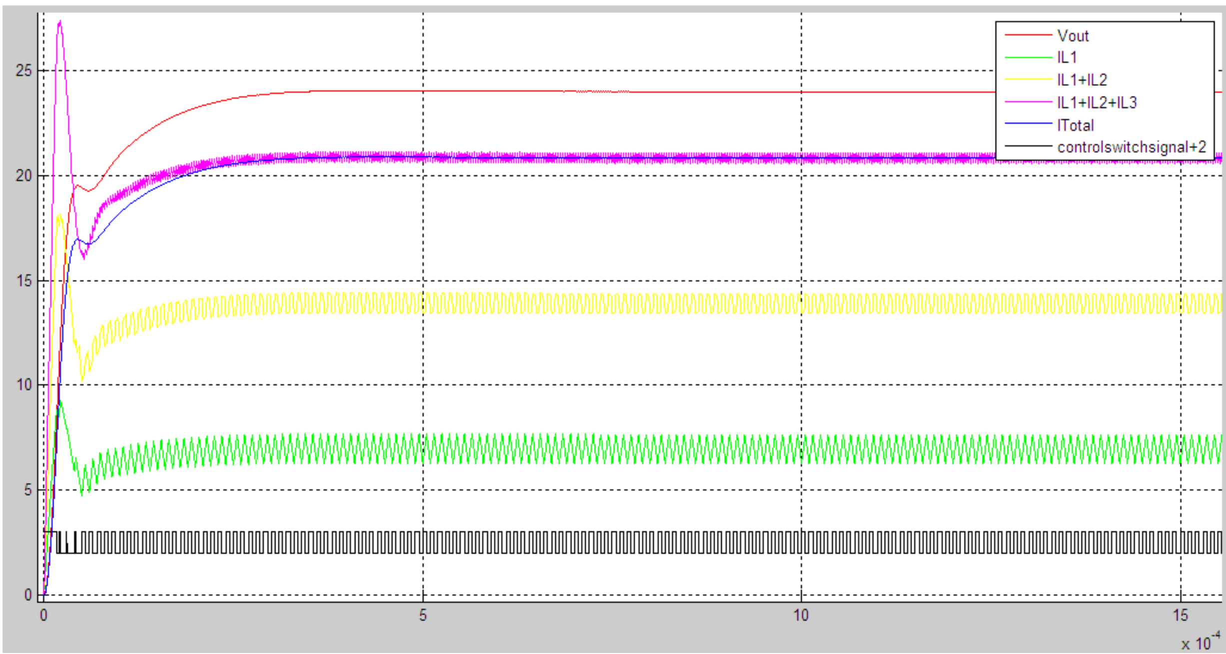




In the last picture, we can see the implementation of the PWM, where we compare the modulated signal with the ramp signal. Then, the signal obtained is a perfect digital signal, which will be introduced in to the switches.

5. REDUCTION OF RIPPLE IN TOTAL CURRENT BY INTERLEAVING

Applying the method of interleaving between the intensities 120º, the noise will decrease approximately 90%. This is because it had a 20% ripple for each intensity (60% in the sum of all three) to 2% or 3% of the total ripple in the sum of the three intensities.



According to the last picture, different values may be observed, such as the output voltage, the current single inductor, the sum of two inductor currents, the sum of the three inductor currents, the total inductor current filtered thanks to capacitor ... a technique called "interleaving" have been used to reduce the ripple in each of the inductor currents, and to improve the system.

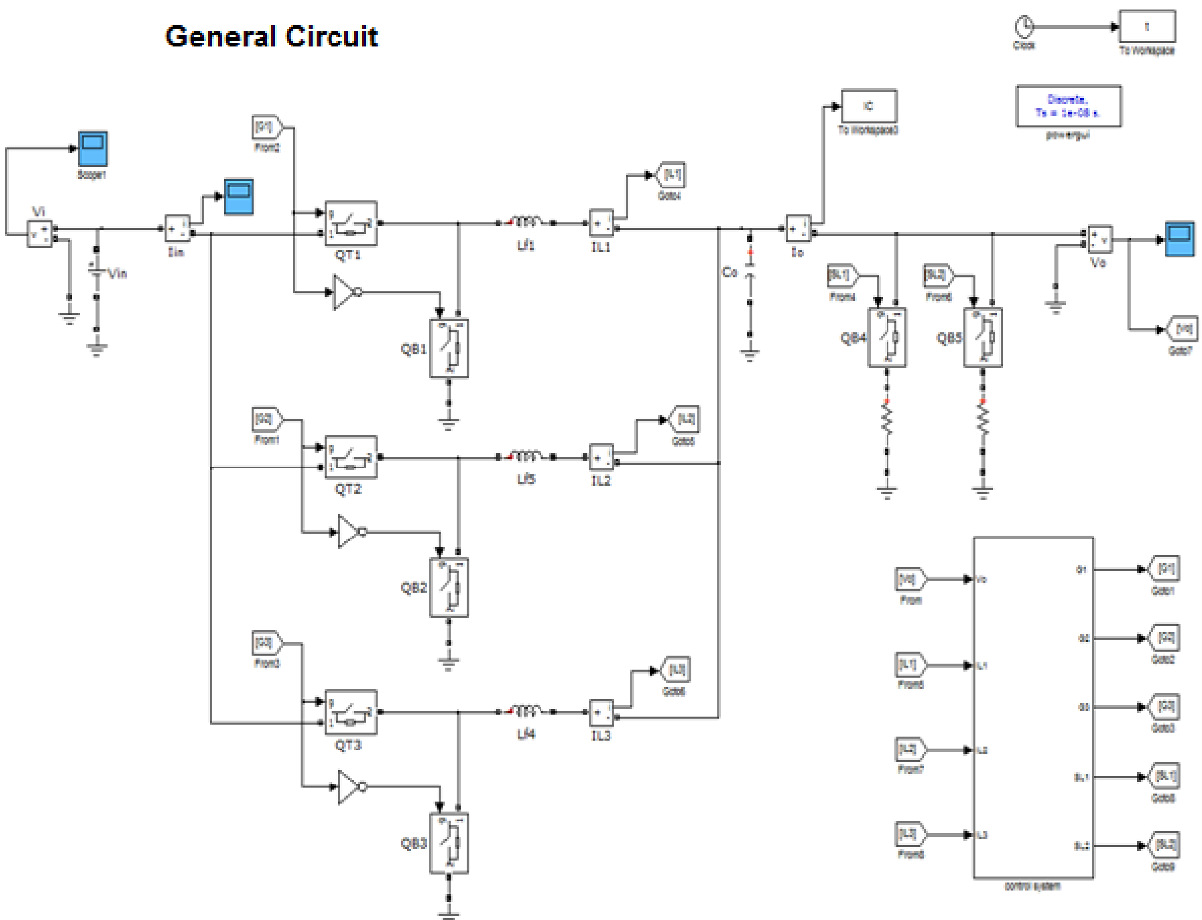
From this point, all simulations will be implemented with this technique, because the results have improved a lot.

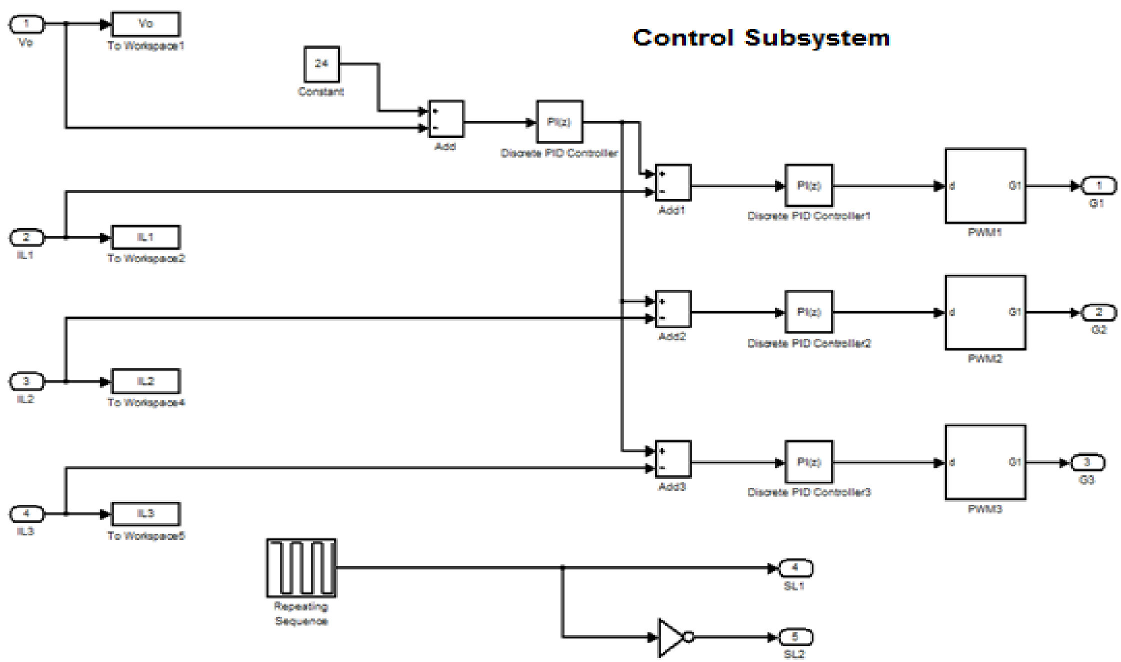
6. RESPONSE TO EXTERNAL DISTURBANCE

6.1. EXTERNAL DISTURBANCE AT THE OUTPUT VOLTAGE

Then, in the next section, the disturbance in the output voltage will be implemented, the constantly changing load resistance in order to visualize the behavior of the electronic circuit.

Three possibilities will be implemented, in which the resistive load that will be added, will be lower, equal, and higher than the original resistive load.

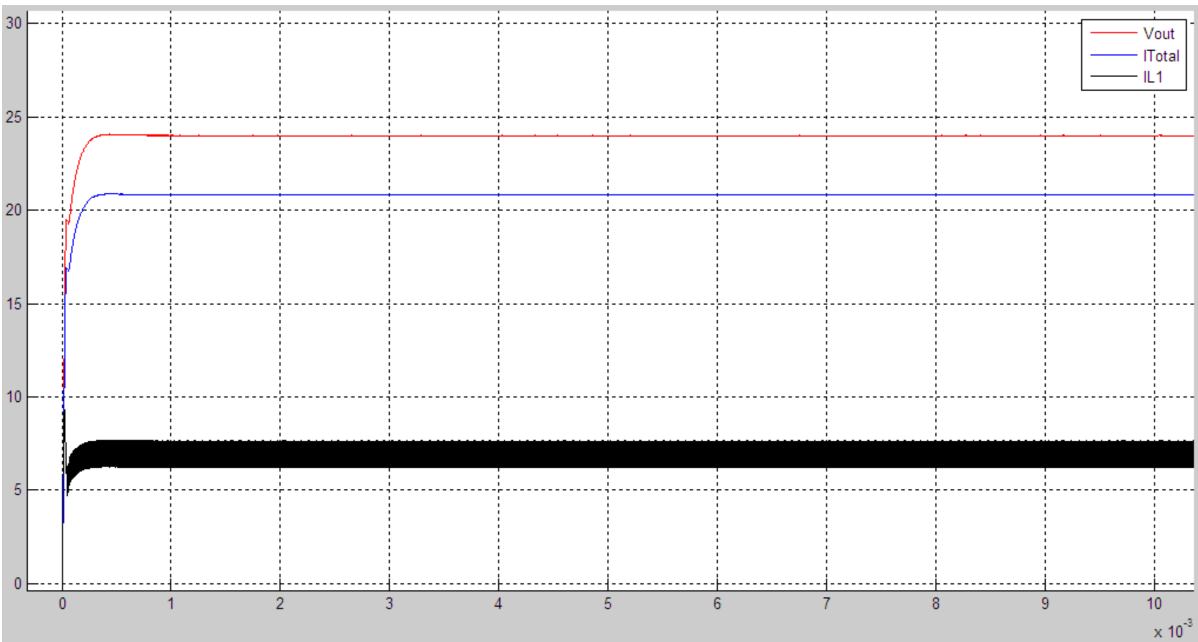



Control Subsystem
1
Vo
Vo
To Workspace1
24
Constant
Add
PI(z)
Discrete PID Controller
Add1
PI(z)
Discrete PID Controller1
d
G1
PWM1
1
G1
2
IL1
IL1
To Workspace2
Add2
PI(z)
Discrete PID Controller2
d
G1
PWM2
2
G2
3
IL2
IL2
To Workspace4
Add3
PI(z)
Discrete PID Controller3
d
G1
PWM3
3
G3
4
IL3
IL3
To Workspace5
Repeating
Sequence
4
SL1
5
SL2

6.1.1.THE SAME R VALUE

>> plot (t, Vo, 'r'); plot (t, IC, 'b'); plot (t, IL1, 'k')
>> legend ('Vout', 'ITotal', 'IL1')

$$R_1 = R_2 = 1.152\ \Omega$$



According to the previous figure, we have this results and we are going to calculate the power

$$P = V * It$$

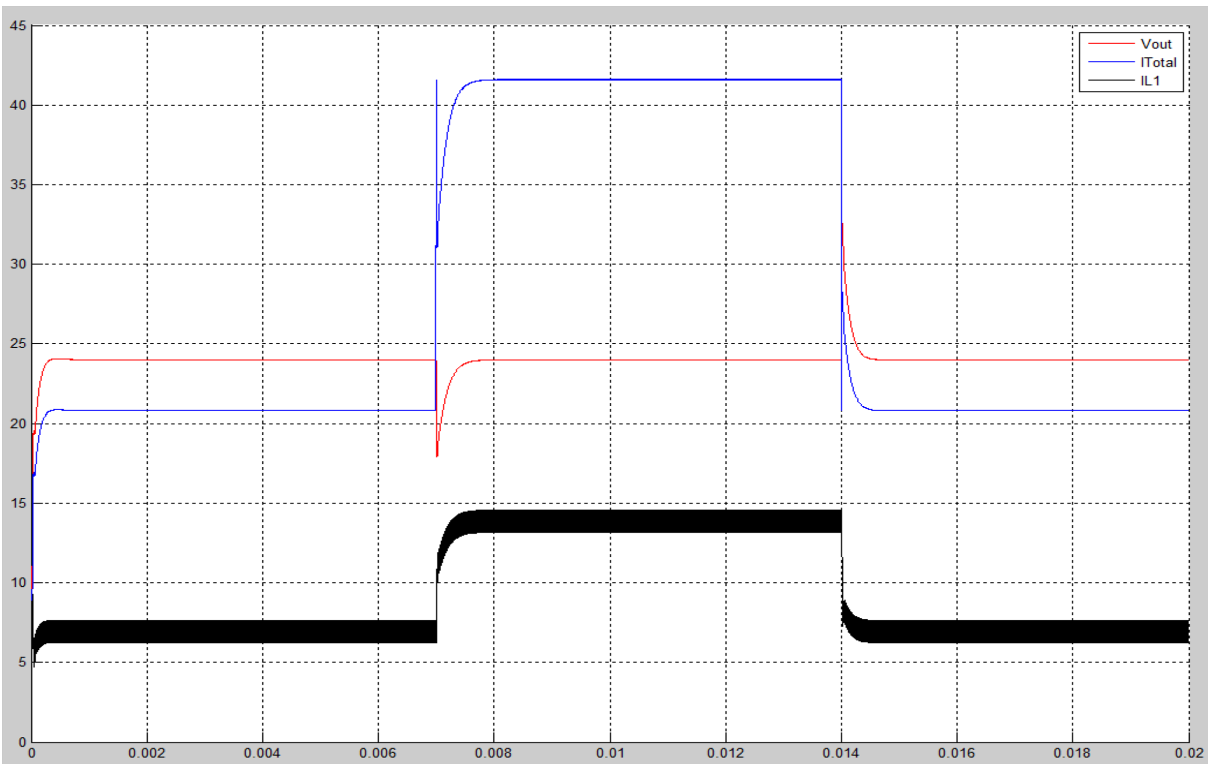
$$P = 24V * 21A = 540W$$

6.1.2.*R1/2 = R2 VALUE*

```
>> plot (t, Vo, 'r'); plot (t, IC, 'b'); plot (t, IL1, 'k')
>> legend ('Vout', 'ITotal', 'IL1')
```

$$\boldsymbol{R_1 = 1.152\ \Omega}$$

$$\boldsymbol{R_2 = 0.576\ \Omega}$$



According to the previous figure, we have this results and we are going to calculate the power. It will be calculated in two points, at the beginning and one after 7ms. We will see the differences in this cases.
During 7ms, we can observe an increase of the output power.

$$P = V * It$$

At the beginning = P = 24V * 21A = 504W

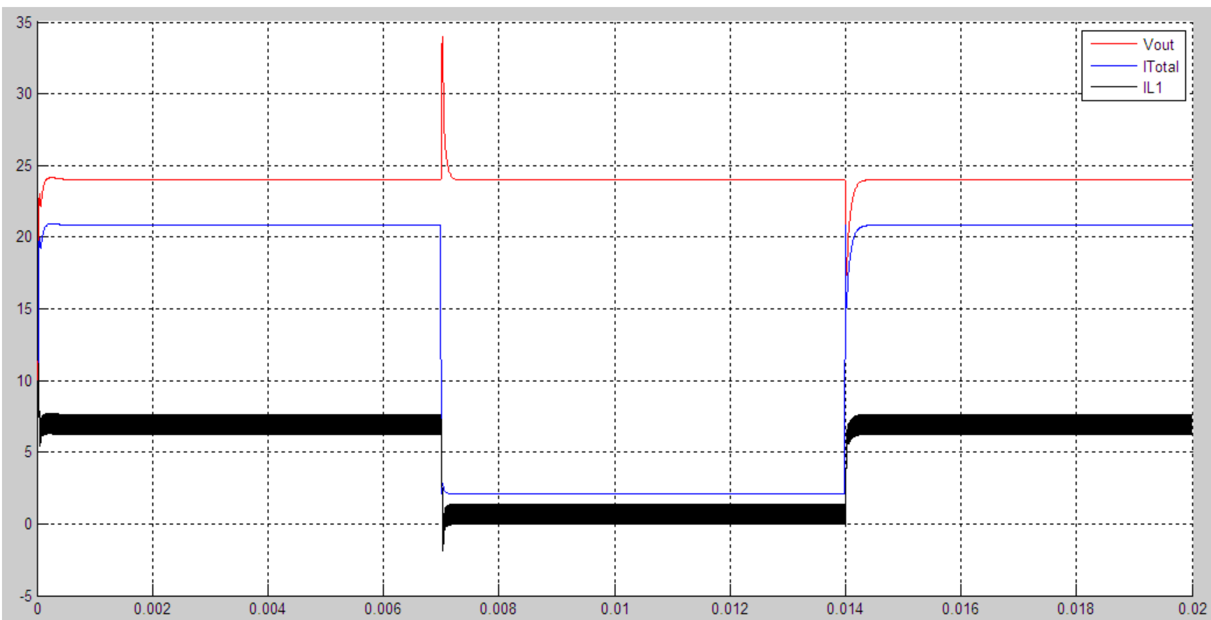
After 7ms = P = 24V * 41A = 984W

6.1.3.10*R1 = R2 VALUE

```
>> plot (t, Vo, 'r'); plot (t, IC, 'b'); plot (t, IL1, 'k')
>> legend ('Vout', 'ITotal', 'IL1')
```

$$R_1 = 1.152\ \Omega$$

$$R_2 = 11.520\ \Omega$$



According to the previous figure, we have this results and we are going to calculate the power. It will be calculated in two points, at the beginning and one after 7ms. We will see the differences in this cases.
During 7ms, we can observe a decrease of the output power.

$$P = V * It$$

At the beginning = P = 24V * 21A = 504W

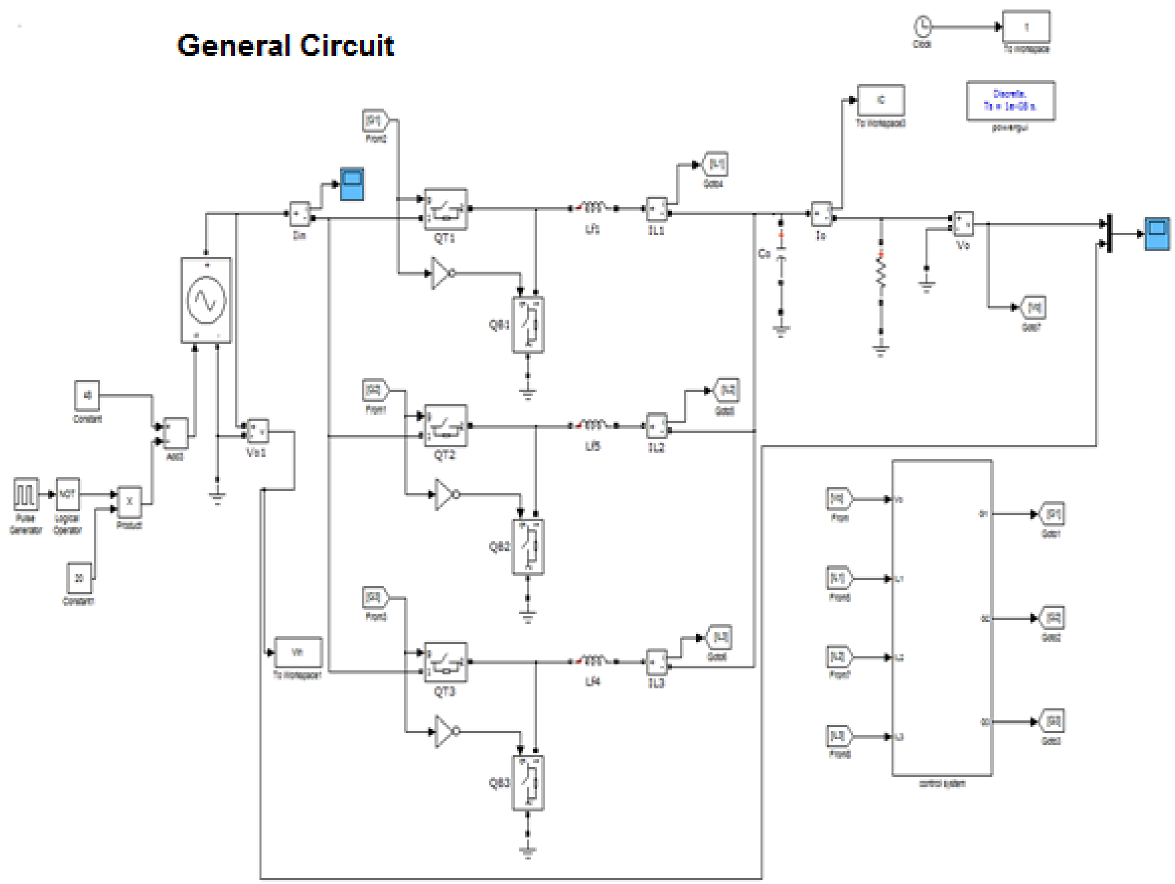
After 7ms = P = 24V * 2.5A = 60W

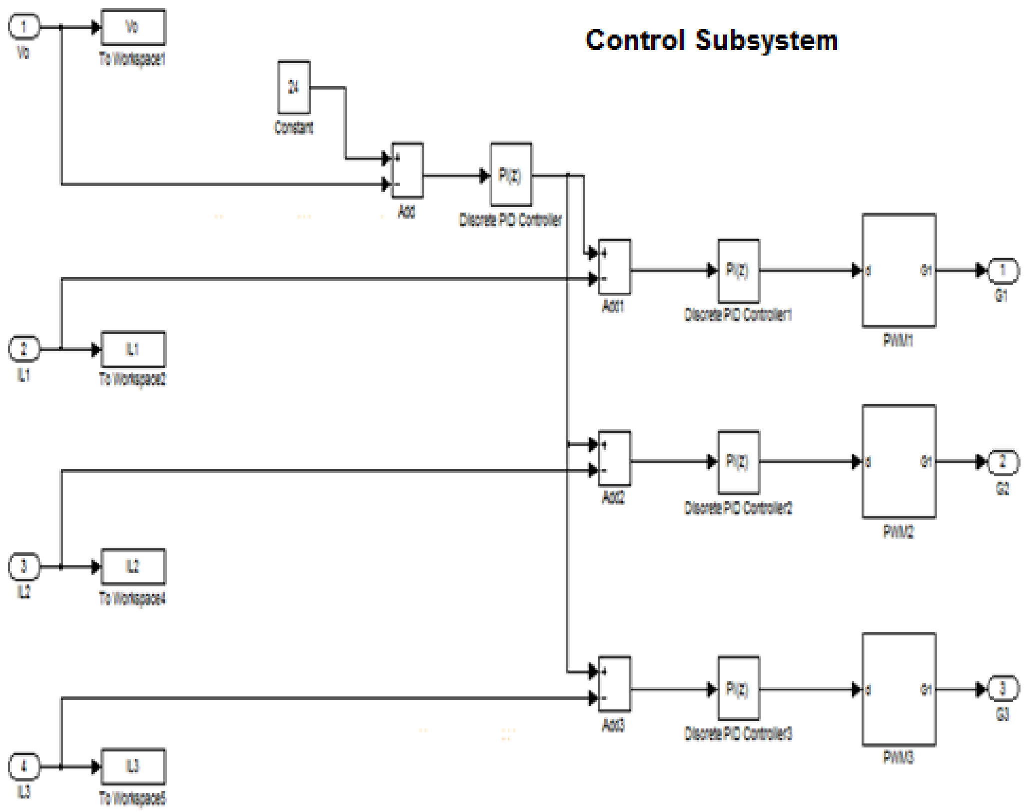
6.2. EXTERNAL DISTURBANCE AT THE INPUT VOLTAGE

Then, in the next section, perturbations to the input DC-DC converter will be implemented.

In the following diagram, it can be seen as a pulse generator implemented between the original voltage (48V) and a constant voltage of different value.
As will be seen below, the original tension go alternating with the specified voltage, generating a square wave.

Three possible cases to observe differences in the behavior of the circuit is implemented.

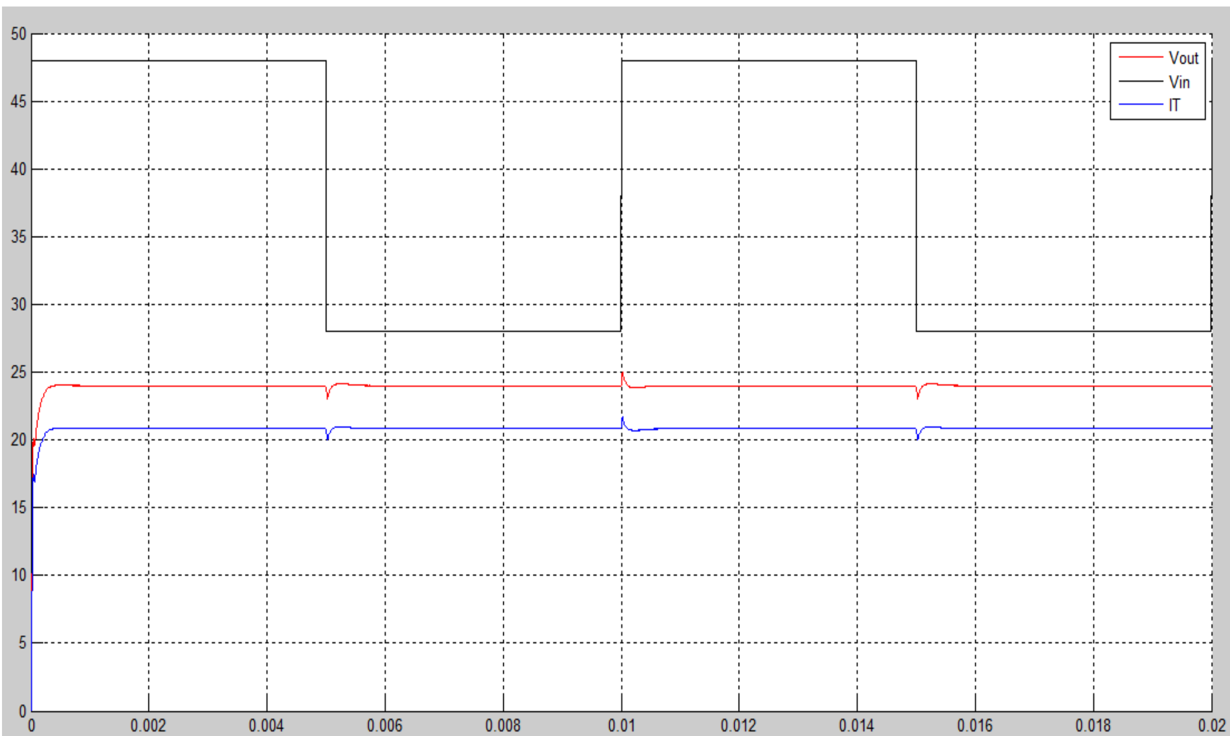



Control Subsystem
Vo
To Workspace1
24
Constant
Add
P(z)
Discrete PID Controller
Add1
Discrete PID Controller1
PWM1
G1
IL1
To Workspace2
Add2
Discrete PID Controller2
PWM2
G2
IL2
To Workspace4
Add3
Discrete PID Controller3
PWM3
G3
IL3
To Workspace5

6.2.1.INPUT CONSTANT = 20V

Input Voltage = 48V
Input Constant = 20V

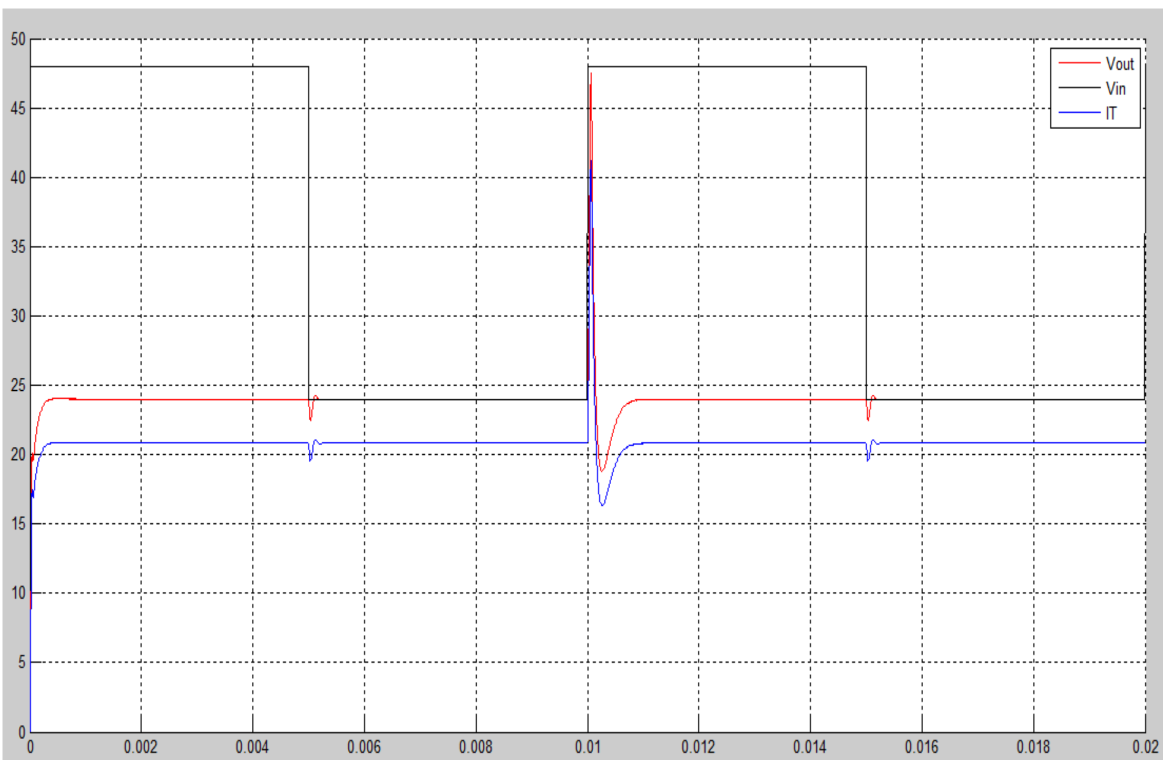
```
>> kp = 0.25
>> ki = 2500
>> hold on
>> grid on
>> plot (t, Vo, 'r'); plot (t, Vin, 'k'); plot (t, IC, 'b')
>> legend ('Vout', 'Vin', 'IT')
```



6.2.2.INPUT CONSTANT = 24V

Input Voltage = 48V
Input Constant = 24V

```
>> kp = 0.25
>> ki = 2500
>> hold on
>> grid on
>> plot (t, Vo, 'r'); plot (t, Vin, 'k'); plot (t, IC, 'b')
>> legend ('Vout', 'Vin', 'IT')
```

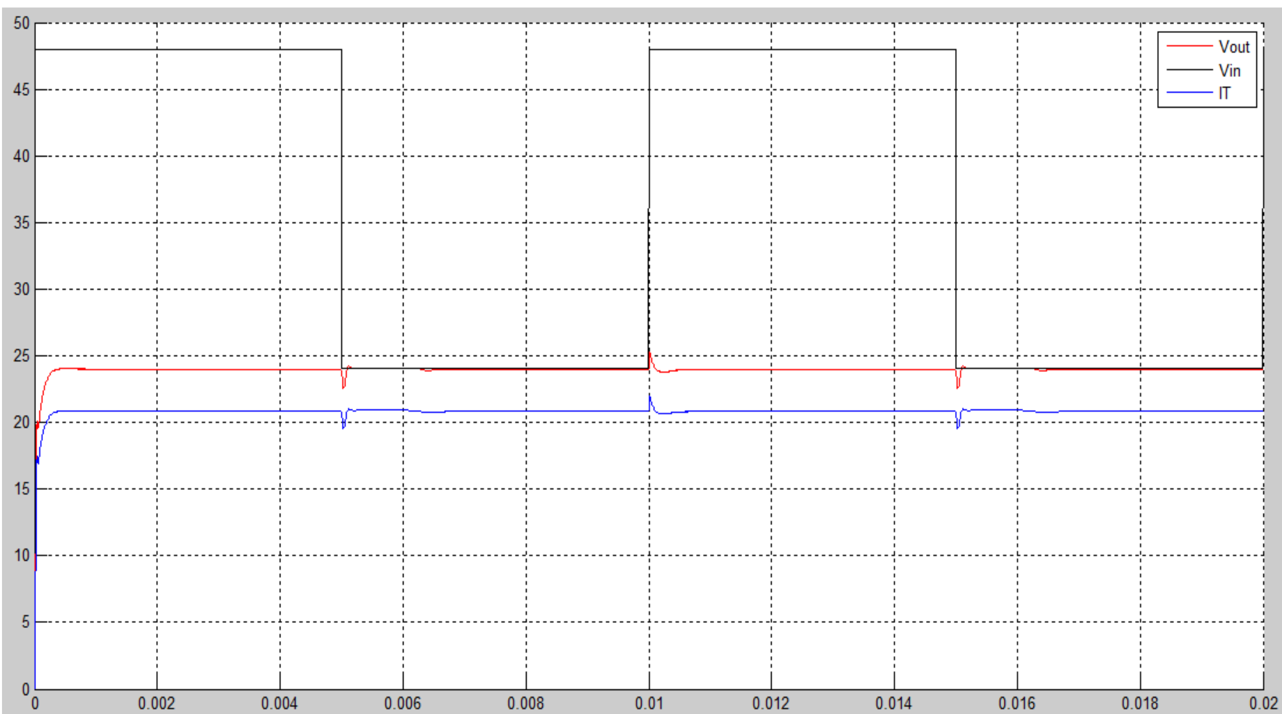


If we alternate the input voltage with a voltage value higher or equal than our output voltage, we can see how the system changes the behavior, causing a small decrease at the output voltage.

6.2.3.INPUT CONSTANT = 23.9V

Input Voltage = 48V
Input Constant = 23.9V

```
>> kp = 0.25
>> ki = 2500
>> hold on
>> grid on
>> plot (t, Vo, 'r'); plot (t, Vin, 'k'); plot (t, IC, 'b')
>> legend ('Vout', 'Vin', 'IT')
```



After viewing the three possible cases, with three different constant, we can reach the conclusion that the system is very robust to perturbations at the input voltage. It is insensitive to changes at the input voltage.

7. CONCLUSIONS

In the first place, we could see how the system was unstable in transient state. To avoid instability, we implemented a PI control system.

Second, the output signal was not optimal to have a stable and robust control system. To solve this problem, we decided to implement three PWM + PI's to obtain a perfect digital signal to send to the switches.

Third, the system was analyzed and it showed that there were a large ripple in the sum of the three inductor currents. Performing an interleaving between three currents will reduce the ripple. Thanks to this method, the capacitor chosen 22.5 µF could be reduced for a faster response without the system was affected their design specifications.

Finally, a high external load at the output voltage was applied, and the results were that we got a reduced consumption of the system. In the other side, the control is robust against the input voltage disturbances.