smart ctrl
control design for power electronics

Single Control Loop Design

Tutorial –December 2018-

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General index

Figure index

1. Introduction

This tutorial is intended to guide you, step by step, to design a DC/DC converter with a single control loop. The selected converter for this example is the buck converter included in Figure 1.

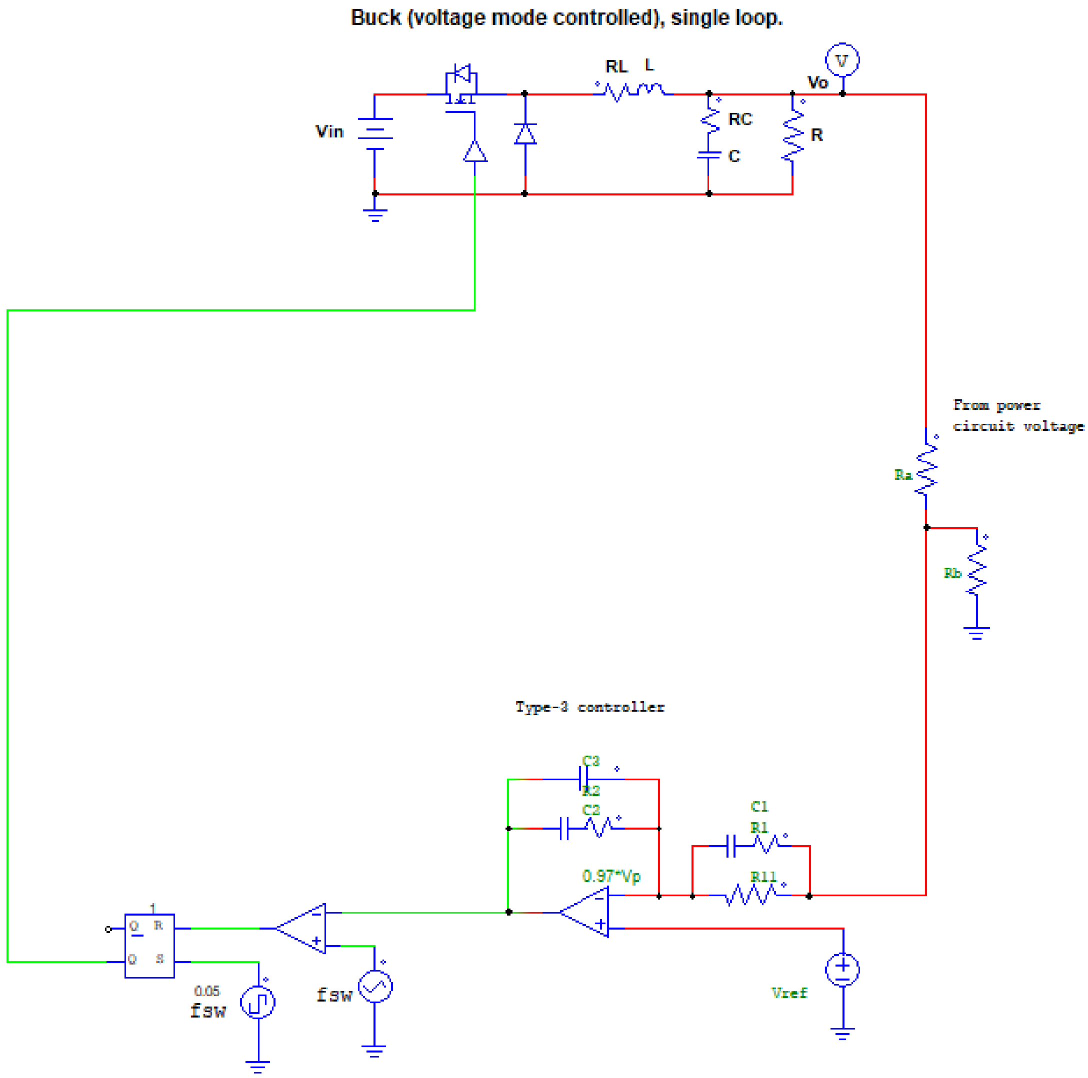


Figure 1: Desired system

2. Buck converter design

1. Open your SmartCtrl Software.
2. To begin the design of a single control loop DC/DC converter click on *DC-DC converter – single loop Voltage Mode Control or ACMC*. See Figure 2.

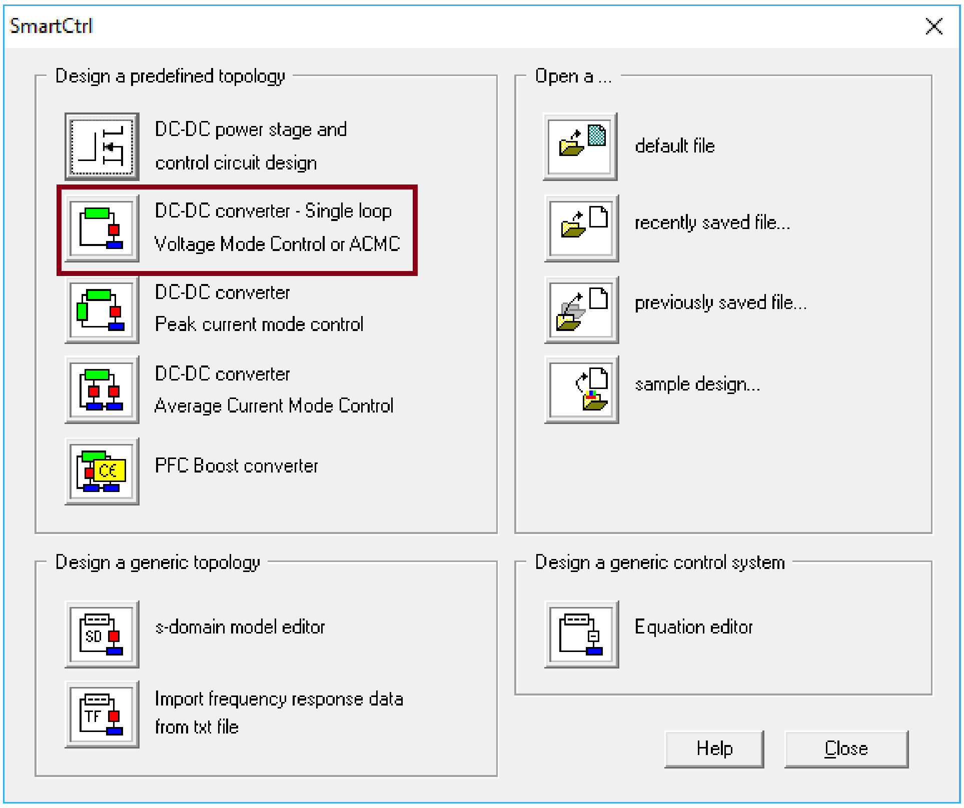


Figure 2: SmartCtrl initial window

It can also be accessed with:

a) Button 
b) Select the corresponding option within the Design menu. See Figure 3.

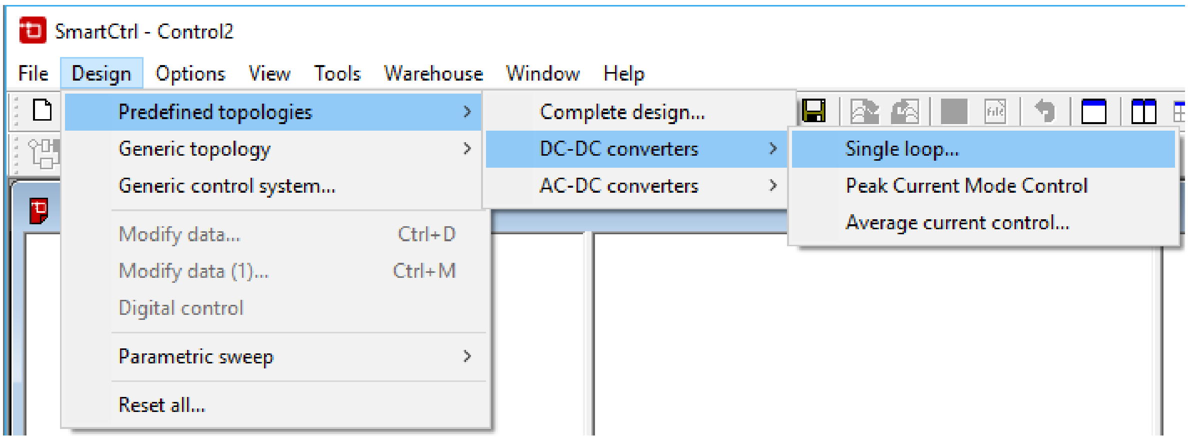


Figure 3: Alternative access to design a Voltage controlled DC-DC converter

3. Select a buck converter and parametrize it as follows. See Figure 4 and Figure 5.

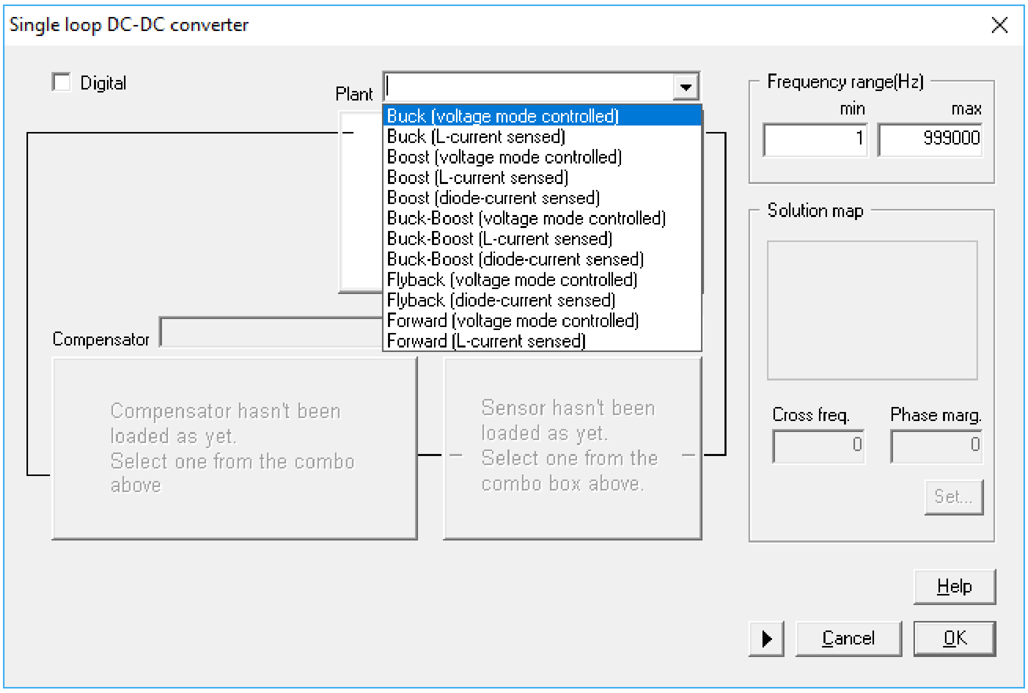


Figure 4: Defining the converter analog topology

As the design is controlled in an analog way, the checkbox "Digital" should be left unchecked. In case the design were digital controlled, it should be checked at this stage or further changes will be lost.

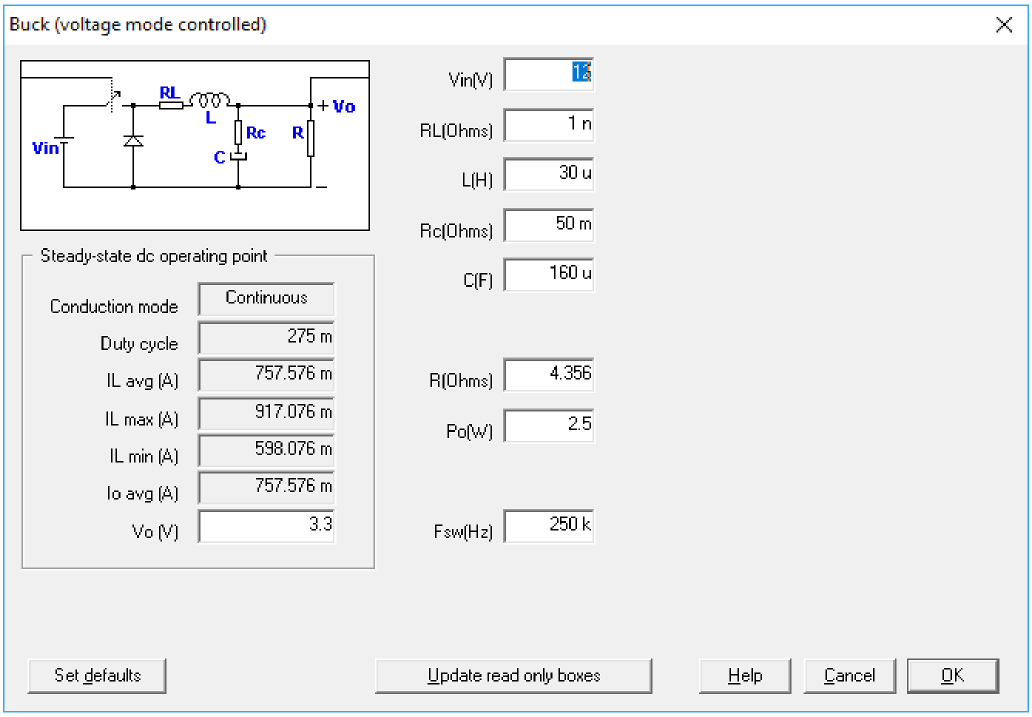


Figure 5: Plant parameters

4. Configure the sensor. See Figure 6 and Figure 7.

   Once the plant has been selected, depending on which magnitude is going to be controlled, the program will display the appropriate type of sensors.

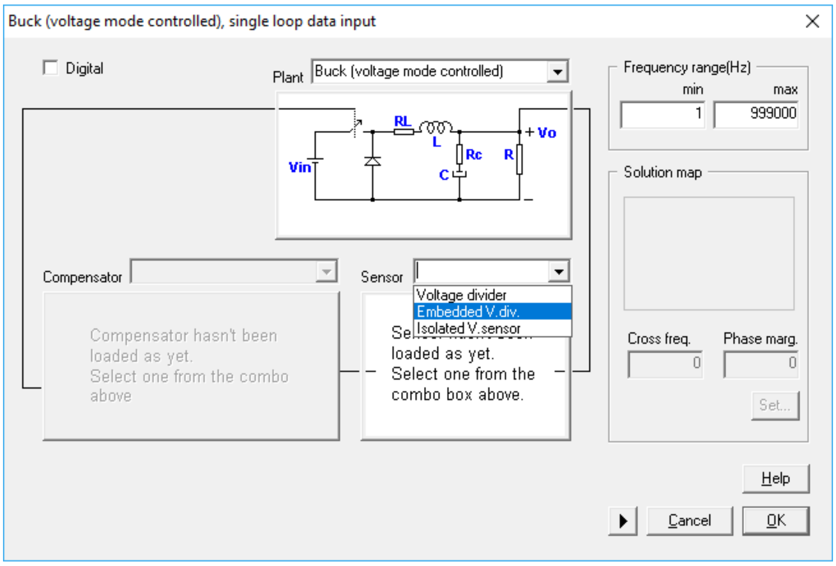


Figure 6: choosing the sensor

In the case of the voltage divider, the user should introduce the reference voltage and the program will automatically calculate the sensor gain. The sensor input data window is the following:

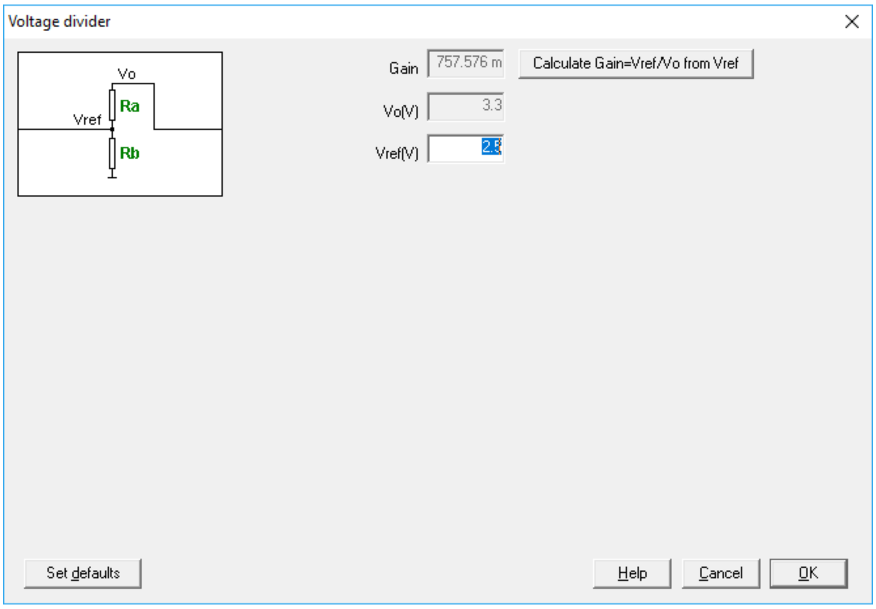


Figure 7: Defining the sensor

Click OK to continue.

Please, note that all the design process will be carried out using this gain, and the resistor values to implement the voltage divider will be provided by the program together with the regulator components.

5. Select and configure the compensator. See Figure 8.

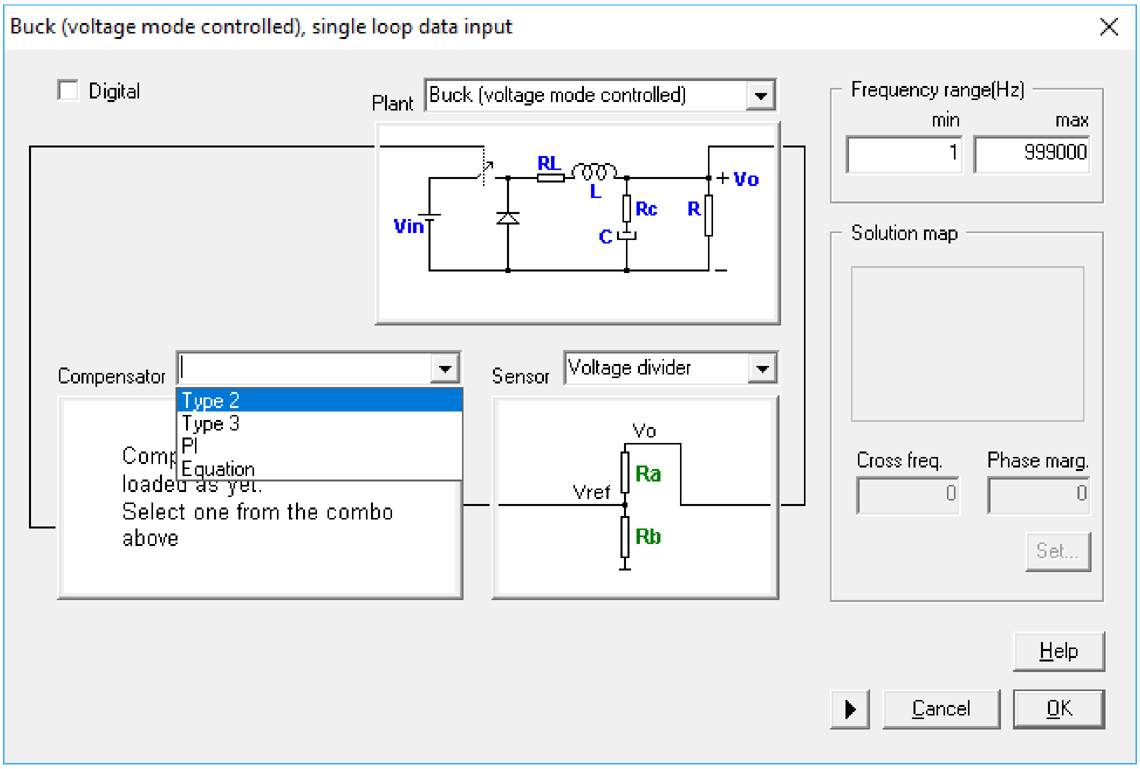


Figure 8: Choosing the compensator

As the design is analog controlled, only analog topologies are listed. To clarify this aspect a little bit a comparison between Type 2 and Type 3 compensators has been done. This comparison is made by means of the solution map. See Figure 9.

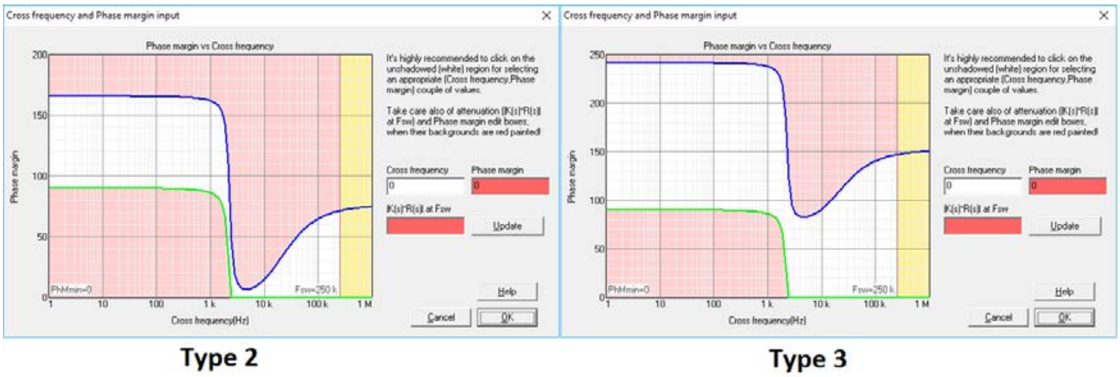


Figure 9: Solution map quick comparison between type 2 and 3 controllers

Due to the fact that the plant is a second order one, the best choice in order to obtain a proper phase margin and enough bandwidth is to use a Type 3 regulator as it provides the wider white area.

A remark should be done: the solution map window shows all the pairs *Phase Margin – cross Over Frequency*. All the ones contained in the white area will generate a perfectly stable controller. On the contrary, if chosen in the red area the controller will almost for sure be unstable.

In this tutorial, a Type 3 compensator has been chosen. So select the compensator type from the corresponding drop-down menu and parametrize it as done in Figure 10 and Figure 11.

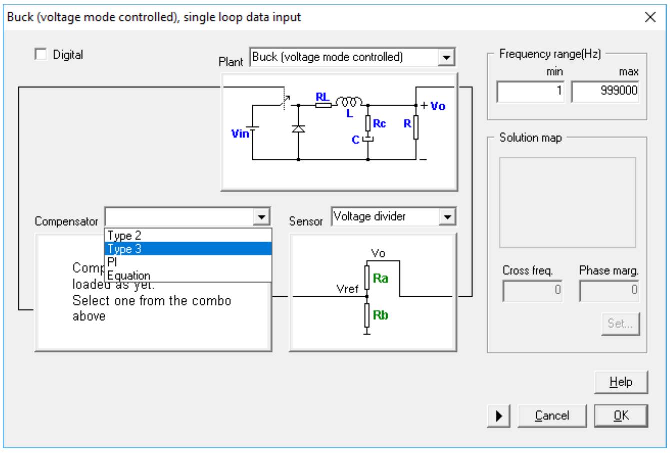


Figure 10: Choosing Type 3 compensator

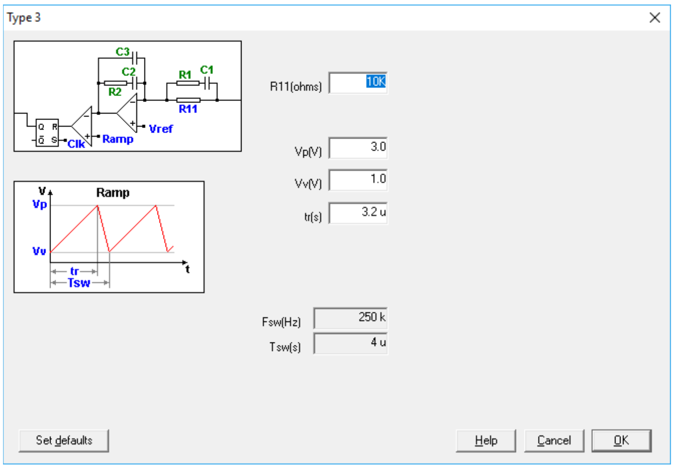


Figure 11: configuring Type 3 compensator

The fields Vp, Vv and tr are referred to the modulator and all of them defined the gain of the modulator.

5. Once the system has been defined, the crossover frequency and the phase margin of the open loop must be selected.

SmartCtrl provides a fast shortcut to select the crossover frequency and the phase margin called solutions map. This window has been partially introduced in the previous point.

Each point within the white area corresponds to a combination of cross freq. and phase margin that lead to a stable solution. In addition, when a point is selected, the attenuation given by the sensor and the regulator at the switching frequency is provided. Note that not enough attenuation at the switching frequency could provoke high frequency oscillations.

To carry out the selection just click on the "Set" button and SmartCtrl will display the solutions map. Then select a point within the white zone (left click) and click OK to continue. See Figure 12 and Figure 13.

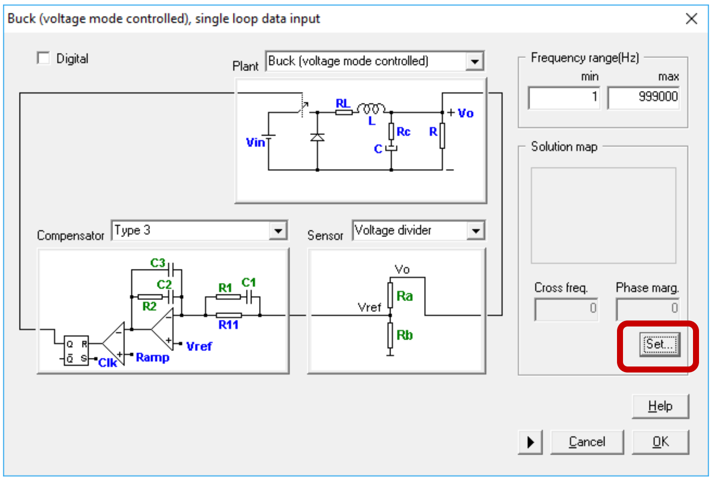


Figure 12: Access to the solution map

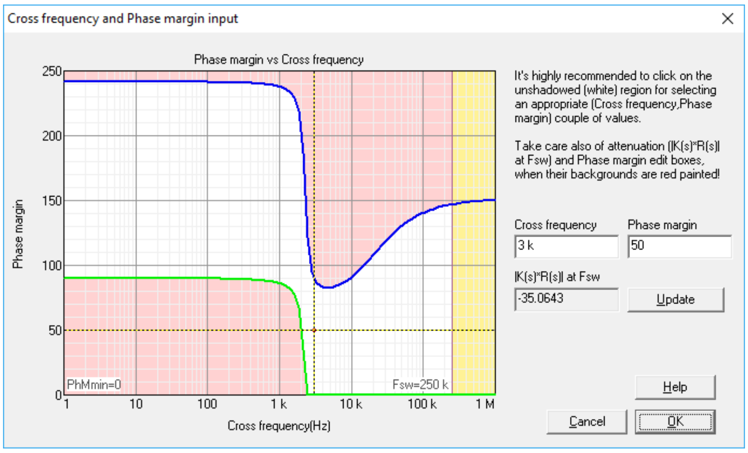


Figure 13: Defining a point in the solution map

All the points in the white area will be stable what will vary will be the dynamic response of the controller. As a rule of thumb, a good point for controlling is about:

a) A phase margin of about 45 to 60 degrees
b) A cross over frequency = Switching frequency/10

Please, notice this rule of thumb is not always achievable, but the nearest point in the white area will be good enough.

The solutions map will be shown on the right side of the input data window. See Figure 14.

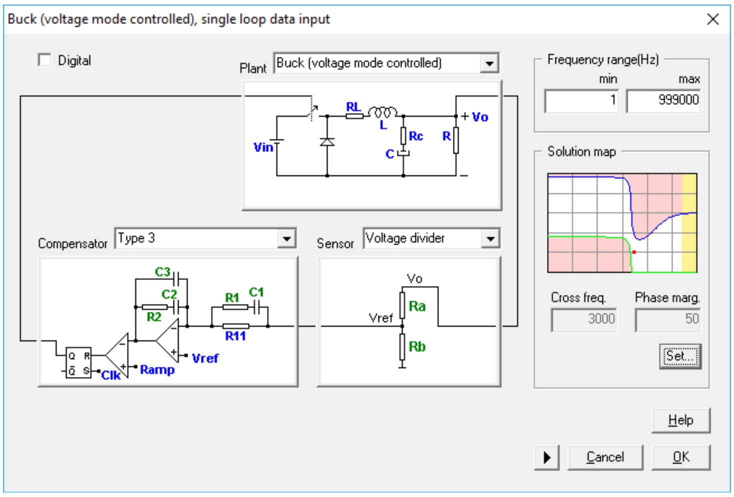


Figure 14: converter definition window

6. Click OK to confirm the design and the program will automatically show the performance of the system in terms of frequency response, Nyquist plot, transient response, etc.
Additionally, optimization tools such as parametric sweep for sensibility analysis and control loop optimization algorithms, are provided. See the Figure 15.

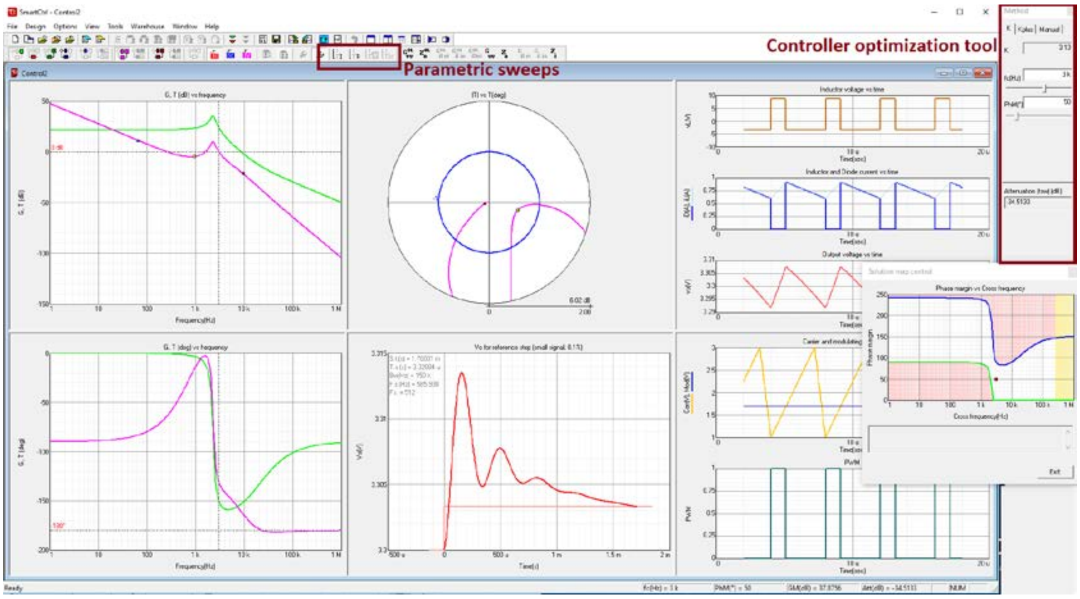


Figure 15: SmartCtrl results window

SmartCtrl also provides the components values needed to implement the compensator, the voltage divider resistors and the input parameters like the topology. To obtain those windows, click on the button of Figure 16 and Figure 17:

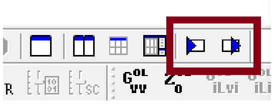
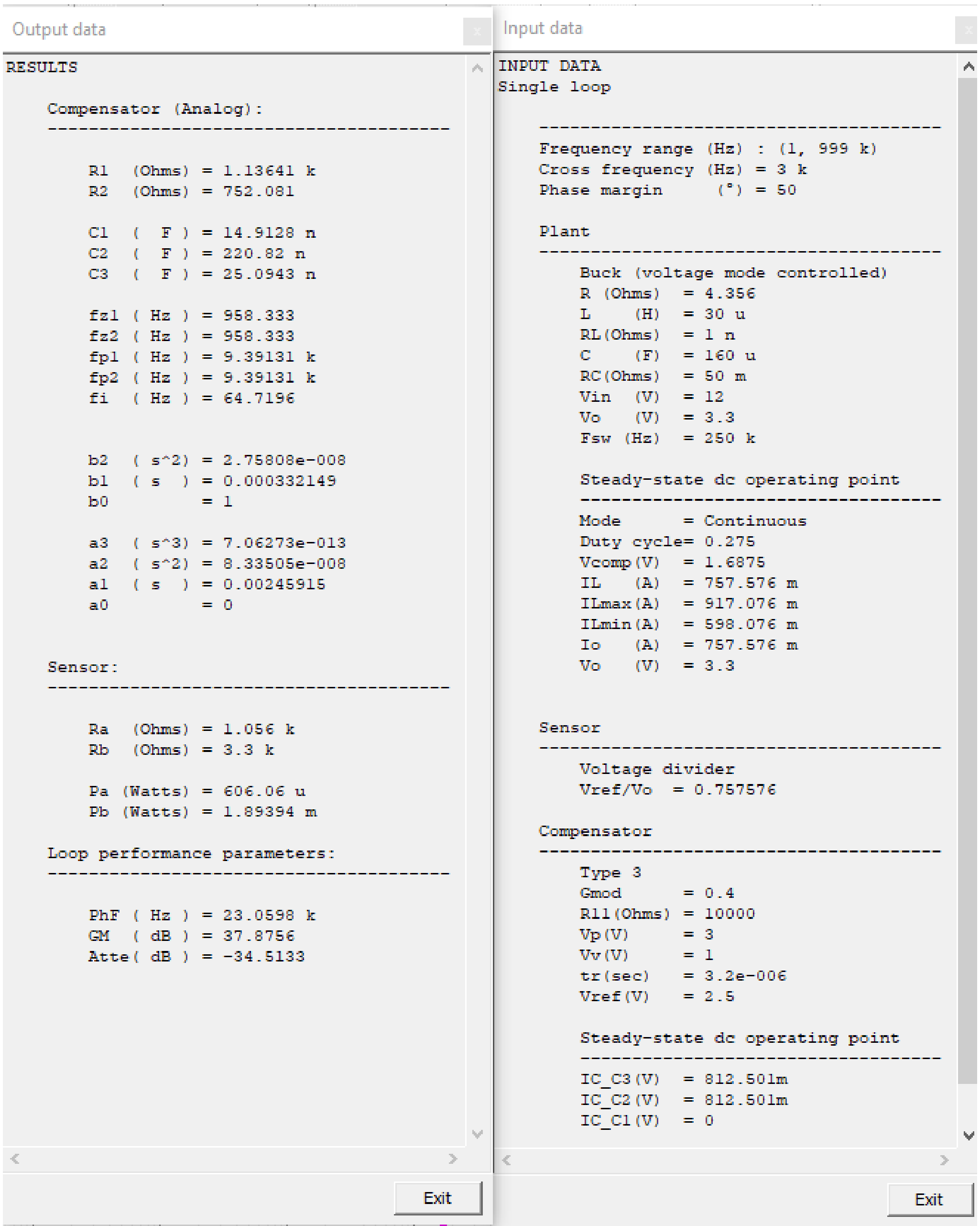


Figure 16: Report buttons



```
Output data

RESULTS

    Compensator (Analog):
    ----------------------------------------

        R1   (Ohms) = 1.13641 k
        R2   (Ohms) = 752.081

        C1   (  F ) = 14.9128 n
        C2   (  F ) = 220.82 n
        C3   (  F ) = 25.0943 n

        fz1  ( Hz ) = 958.333
        fz2  ( Hz ) = 958.333
        fp1  ( Hz ) = 9.39131 k
        fp2  ( Hz ) = 9.39131 k
        fi   ( Hz ) = 64.7196


        b2   ( s^2) = 2.75808e-008
        b1   ( s  ) = 0.000332149
        b0          = 1

        a3   ( s^3) = 7.06273e-013
        a2   ( s^2) = 8.33505e-008
        a1   ( s  ) = 0.00245915
        a0          = 0


    Sensor:
    ----------------------------------------

        Ra   (Ohms) = 1.056 k
        Rb   (Ohms) = 3.3 k

        Pa  (Watts) = 606.06 u
        Pb  (Watts) = 1.89394 m

    Loop performance parameters:
    ----------------------------------------

        PhF  ( Hz ) = 23.0598 k
        GM   ( dB ) = 37.8756
        Atte( dB )  = -34.5133

Exit
```

```
Input data

INPUT DATA
Single loop

    ----------------------------------------
    Frequency range (Hz) : (1, 999 k)
    Cross frequency (Hz) = 3 k
    Phase margin     (°) = 50

    Plant
    ----------------------------------------
        Buck (voltage mode controlled)
        R (Ohms)   = 4.356
        L     (H)  = 30 u
        RL(Ohms)   = 1 n
        C     (F)  = 160 u
        RC(Ohms)   = 50 m
        Vin   (V)  = 12
        Vo    (V)  = 3.3
        Fsw  (Hz)  = 250 k

        Steady-state dc operating point
        --------------------------------

        Mode       = Continuous
        Duty cycle= 0.275
        Vcomp(V)   = 1.6875
        IL    (A)  = 757.576 m
        ILmax(A)   = 917.076 m
        ILmin(A)   = 598.076 m
        Io    (A)  = 757.576 m
        Vo    (V)  = 3.3


    Sensor
    ----------------------------------------
        Voltage divider
        Vref/Vo   = 0.757576

    Compensator
    ----------------------------------------
        Type 3
        Gmod       = 0.4
        R11(Ohms)  = 10000
        Vp(V)      = 3
        Vv(V)      = 1
        tr(sec)    = 3.2e-006
        Vref(V)    = 2.5

        Steady-state dc operating point
        --------------------------------
        IC_C3(V)   = 812.501m
        IC_C2(V)   = 812.501m
        IC_C1(V)   = 0

Exit
```

Figure 17: input and output data reports

3. Design exportation to Psim

To export to Psim click on this button. Figure 18.

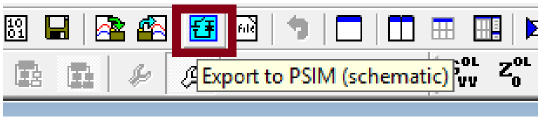


Figure 18: Exportation to Psim button

And configure the exportation. See Figure 19.

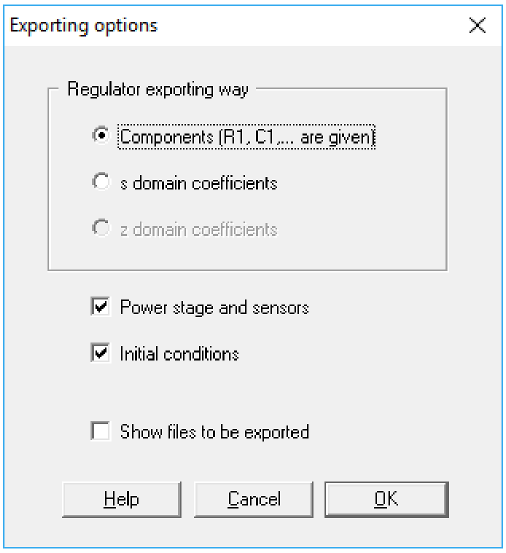


Figure 19: exportation to Psim settings

Click OK and Psim will be automatically opened and the simulation launched.

4. Design validation

In Psim, the following system has been automatically created and configured by SmartCtrl. SeeFigure 20.

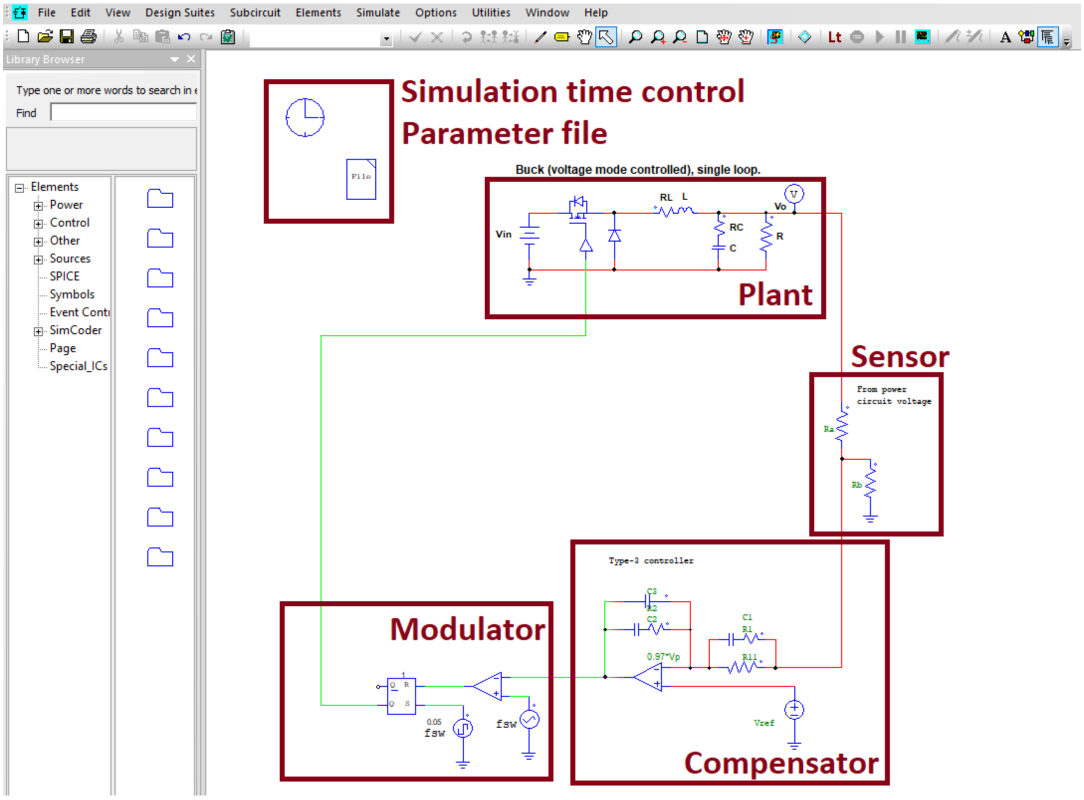


Figure 20: Psim exported system

In this picture, all the different functional blocks have been highlighted. Ensure to configure the simulation time control as follows. Figure 21.

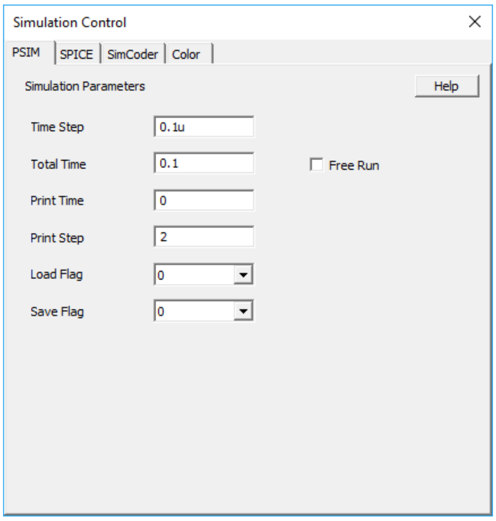


Figure 21: clock configuration in Psim

The result of the simulation is shown in Figure 22:

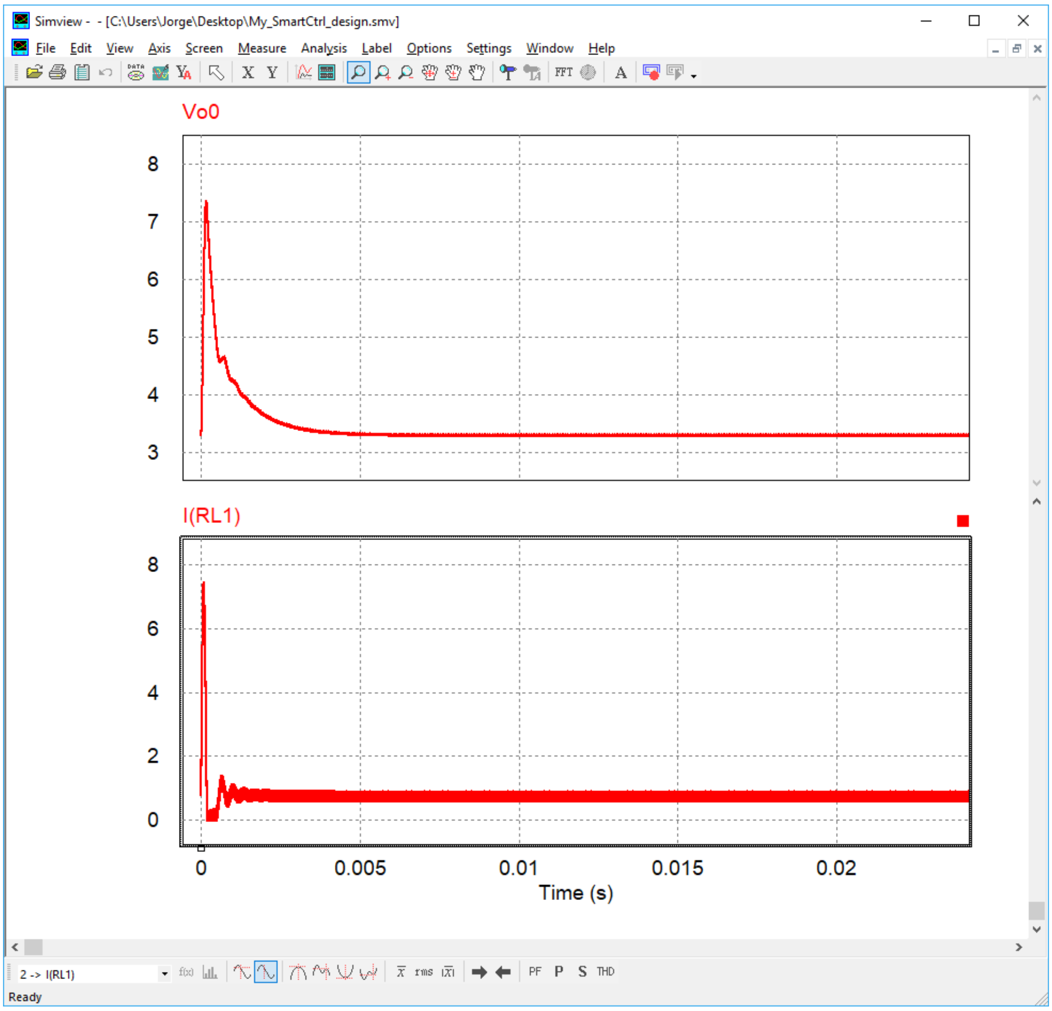


Figure 22: result of Psim simulation

As it can be seen, the output voltage is 3.3V, it is exactly what have been specified in SmartCtrl.

If the dynamic response of the system is to be analyzed, it would be necessary to introduce a step, for example, in the input voltage. See Figure 23.

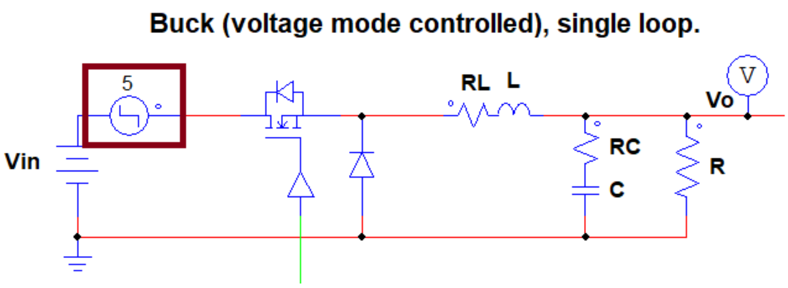


Figure 23: input voltage step in Psim

The result of this new system can be seen in Figure 24.

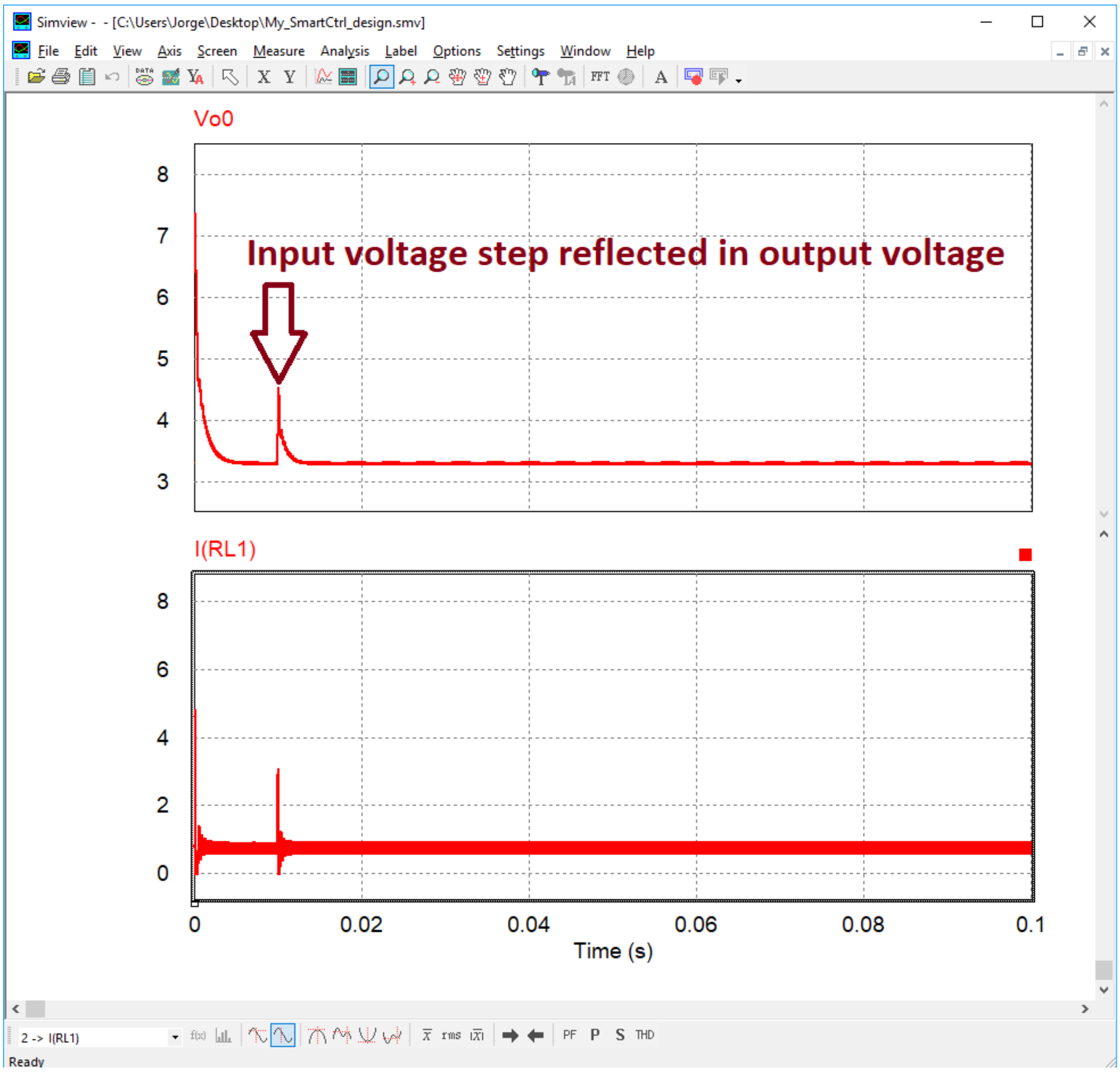


Figure 24: New Psim simulation where dynamic response can be seen