smart ctrl

control design for power electronics

Resonant Converter Control Loop Design

Tutorial –December 2018-

How to Contact:

info@powersmartcontrol.com

www.powersmartcontrol.com

Notice

Power Smart Control tutorials or other design advice, services or information, including, but not limited to, reference designs, are intended to assist designers who are developing applications that use SmartCtrl; by downloading, accessing or using any particular Power Smart Control resource in any way, you (individually or, if you are acting on behalf of a company, your company) agree to use it solely for this purpose and subject to the terms of this notice.

Power Smart Control reserves the right to make corrections, enhancements, improvements and other changes to its resources.

You understand and agree that you remain responsible for using your independent analysis, evaluation and judgment in designing your applications and that you have full and exclusive responsibility to assure the safety of your applications and compliance of your applications with all applicable regulations, laws and other applicable requirements.

Disclaimer

Power Smart Control S.L. (PSC) makes no representation or warranty with respect to the adequacy or accuracy of this documentation or the software which it describes. In no event will PSC or its direct or indirect suppliers be liable for any damages whatsoever including, but not limited to, direct, indirect, incidental, or consequential damages of any character including, without limitation, loss of business profits, data, business information, or any and all other commercial damages or losses, or for any damages in excess of the list price for the licence to the software and documentation.

The software SmartCtrl© used in this tutorial is furnished under a license agreement. The software may be used only under the terms of the license agreement.

Power Smart Control SL

General index

1. Introduction 3
2. AC Sweep Analysis 3
3. Control design in SmartCtrl 5
4. Validation 9

Figure index

Figure 1: AC analysis configuration 3
Figure 2: Circuit schematic including the AC sweep 4
Figure 3: Frequency response of the resonant converter...............................4
Figure 4: SmartCtrl shortcut access...5
Figure 5: Exportation to SmartCtrl options window 5
Figure 6: Transfer function imported 5
Figure 7: Plant transfer function fully imported 6
Figure 8: Sensor definition 6
Figure 9: compensator definition 7
Figure 10: Solution map view 7
Figure 11: SmartCtrl loop with all the elements fully defined.........................8
Figure 12: SmartCtrl loop solution 8
Figure 13: Kp and Ti values extracted from SmartCtrl 9
Figure 14: Psim schematic including a input voltage step.............................. 10
Figure 15: Output voltage... 10

1. Introduction

SmartCtr is a general-purpose software specifically designed for power electronics application. This tutorial is intended to guide you, step by step, to design the control loop of a resonant converter.

Since the transfer function of a resonant converter is difficult to derive, one of the main purposes of this example is to illustrate that the resonant converter can be represented by the imported ac sweep results from PSIM, and the control loop of the resonant converter can be designed using SmartCtrl.

This example demonstrates the power and flexibility of using SmartCtrl in combination with PSIM to design the control loop of any power converters.

The first step is to obtain the resonant converter frequency response by means of the PSIM ac analysis.

2. AC Sweep Analysis

1. Perform ac analysis in PSIM

The frequency response of the plant is obtained directly from the circuit of the resonant converter using PSIM's ac analysis, there is no need to generate an averaged model. The converter circuit is shown in Figure 2.

To perform the ac analysis, the ac sweep block, the ac source for signal injection and the AC probe are needed.

To configure the AC seep, use the parameters of Figure 1.

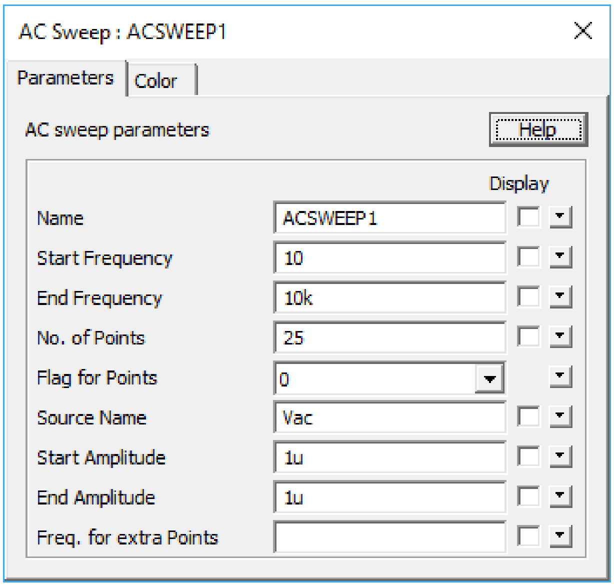

Figure 1: AC analysis configuration

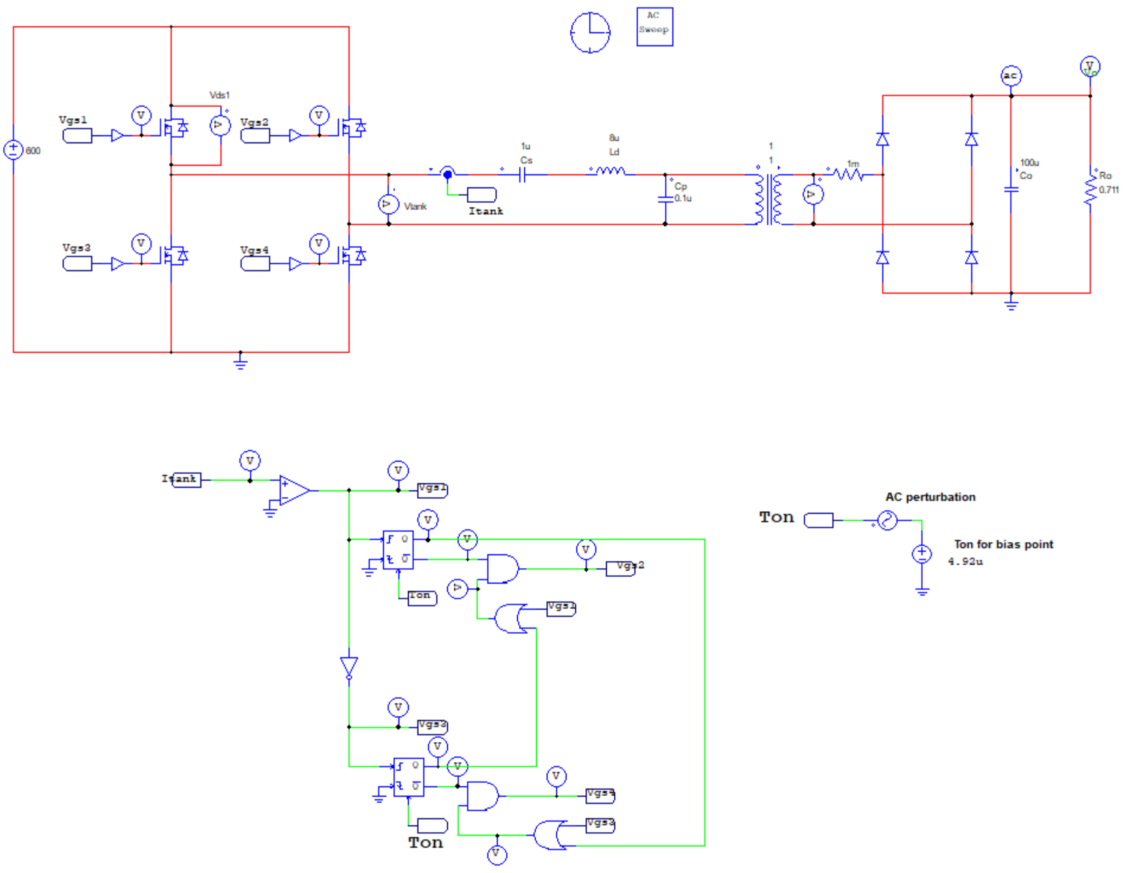

Figure 2: Circuit schematic including the AC sweep

After the simulation, the frequency response of the output voltage versus the control variable Ton is obtained, as shown in Figure 3. Once the frequency response is obtained, it can be imported into SmartCtrl.

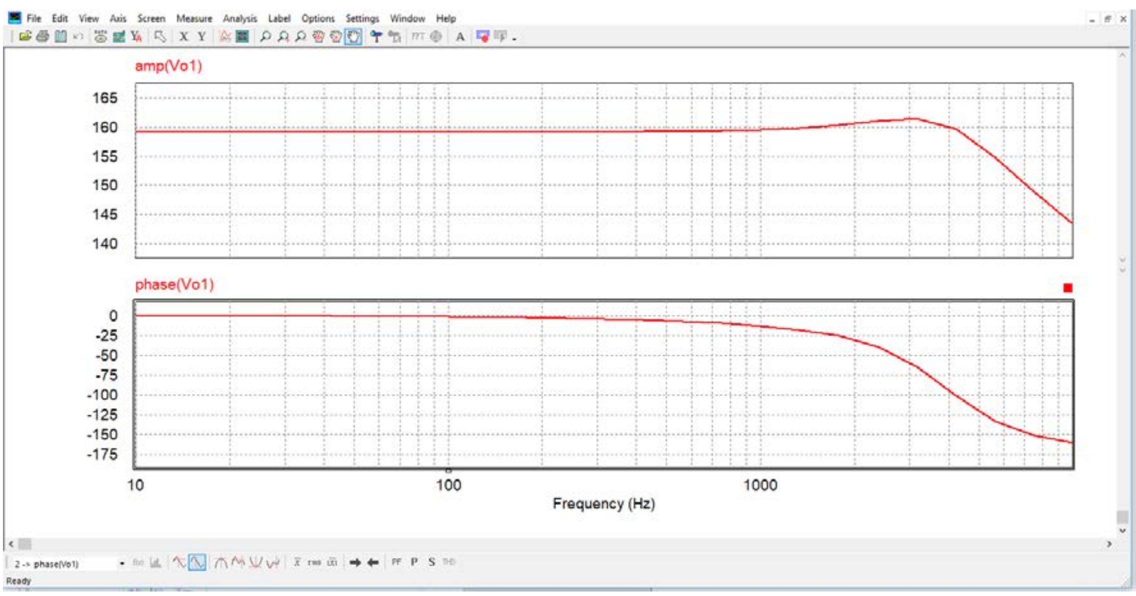

Figure 3: Frequency response of the resonant converter

3. Control design in SmartCtrl

1. Import the frequency response data into SmartCtrl

Click the SmartCtrl button shown in Figure 4 to open SmartCtrl. This action sends the frequency response data from the PSIM ac analysis to SmartCtrl. Enter the output voltage and the switching frequency and click OK to continue. See Figure 5.

Figure 4: SmartCtrl shortcut access

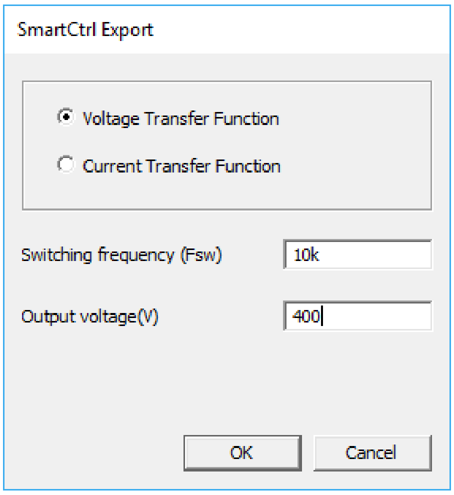

Figure 5: Exportation to SmartCtrl options window

The loaded transfer function is automatically plotted as shown in Figure 6.

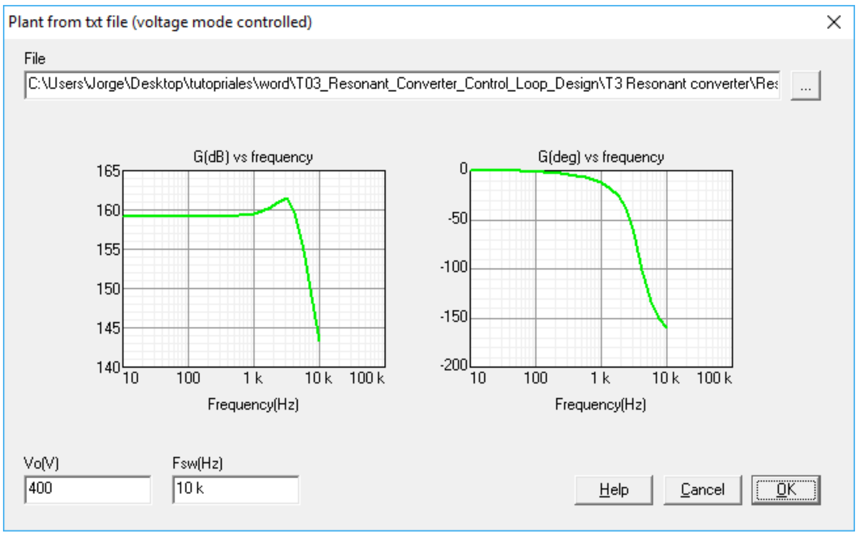

Figure 6: Transfer function imported

At this point, the plant is fully defined by the AC sweep import from Psim. The next step is to define the sensor and the regulator. See Figure 7.

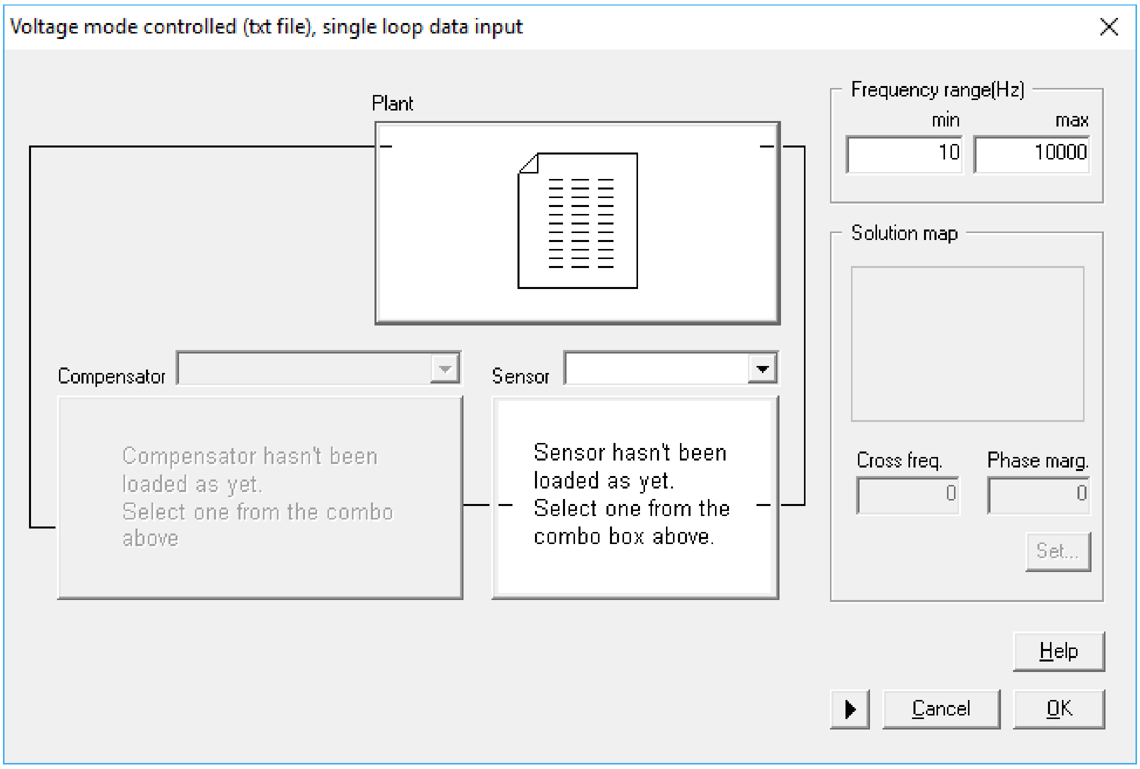

Figure 7: Plant transfer function fully imported

Click in the sensor tab and select a “voltage divider” sensor topology. Type a reference voltage of 4.89uV and click in “calculate gain” button. See Figure 8.

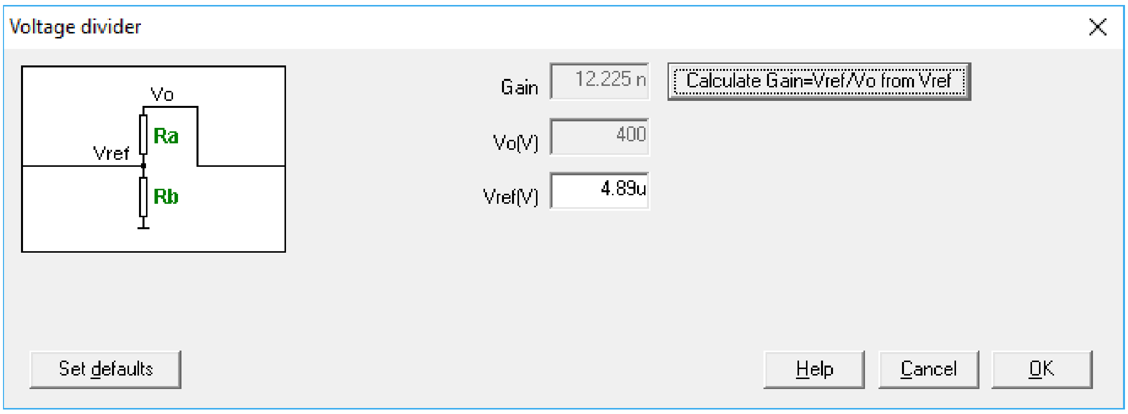

Figure 8: Sensor definition

To configure the compensator click in “compensator tab”, select a PI compensator and parametrize it as shown in Figure 9.

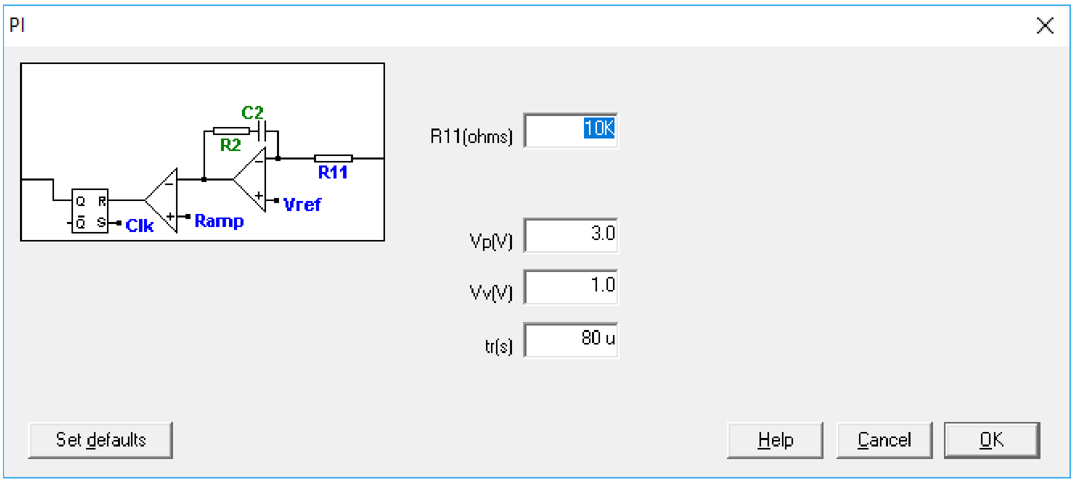

Figure 9: compensator definition

Once all the loop transfer elements are defined, the crossover frequency and the phase margin can be selected. SmartCtrl provides a guideline and an easy way of selecting the crossover frequency and the phase margin through the ***Solution Map***.

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, click on the **Set** button and SmartCtrl will display the solutions map. Then left click a point within the white area, and click OK to continue. For this tutorial a cross freq of 4.235kHz and a phase margin of 72.6degrees have been chosen.

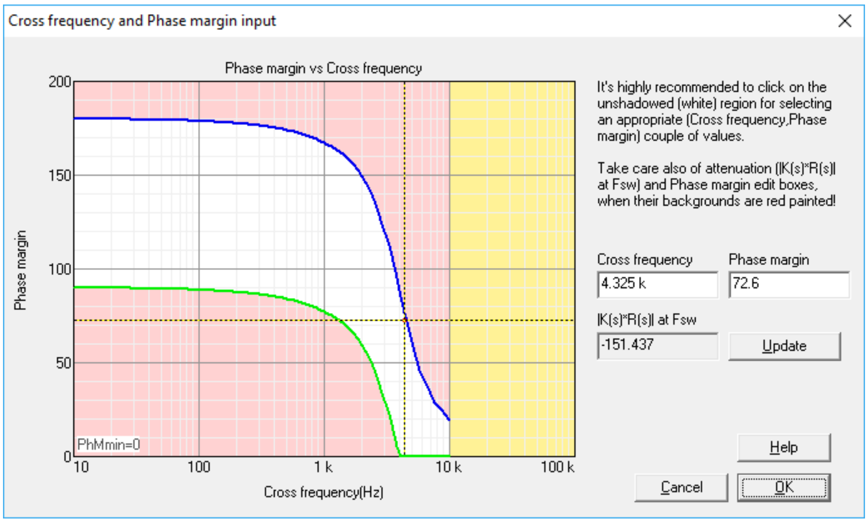

Figure 10: Solution map view

Once the crossover frequency and the phase margin are selected, the solution map will be shown on the right side of the input data window. If, at any time, these two parameters need to be changed, just click on the shown solution map.

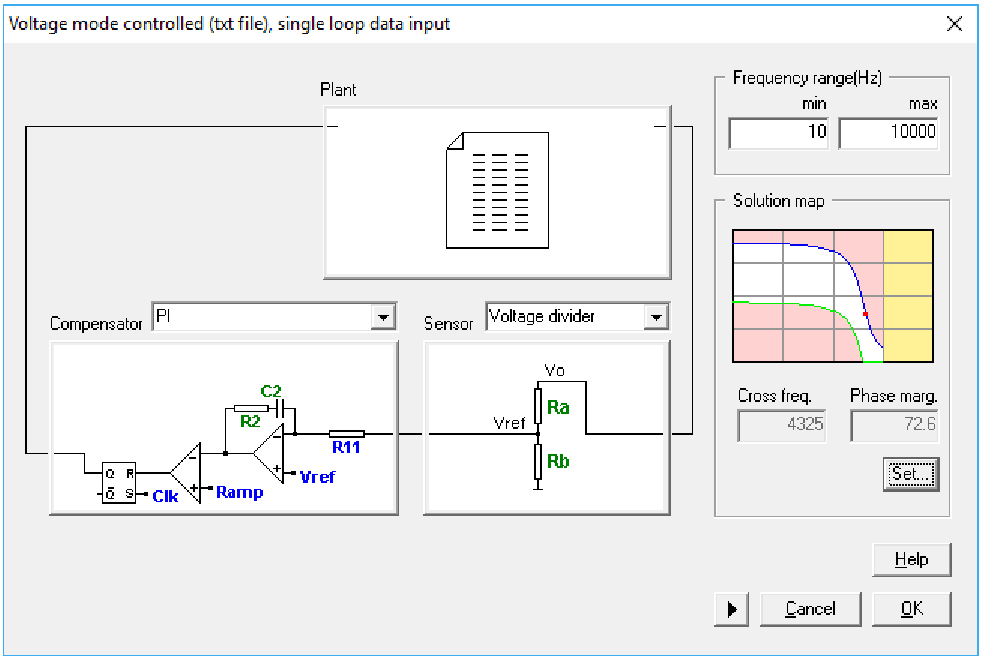

Figure 11: SmartCtrl loop with all the elements fully defined

Now accept the selected configuration and confirm the design, the program will automatically show the system performance in terms of the frequency response and transient response. Please, note that the solution map window is always present.

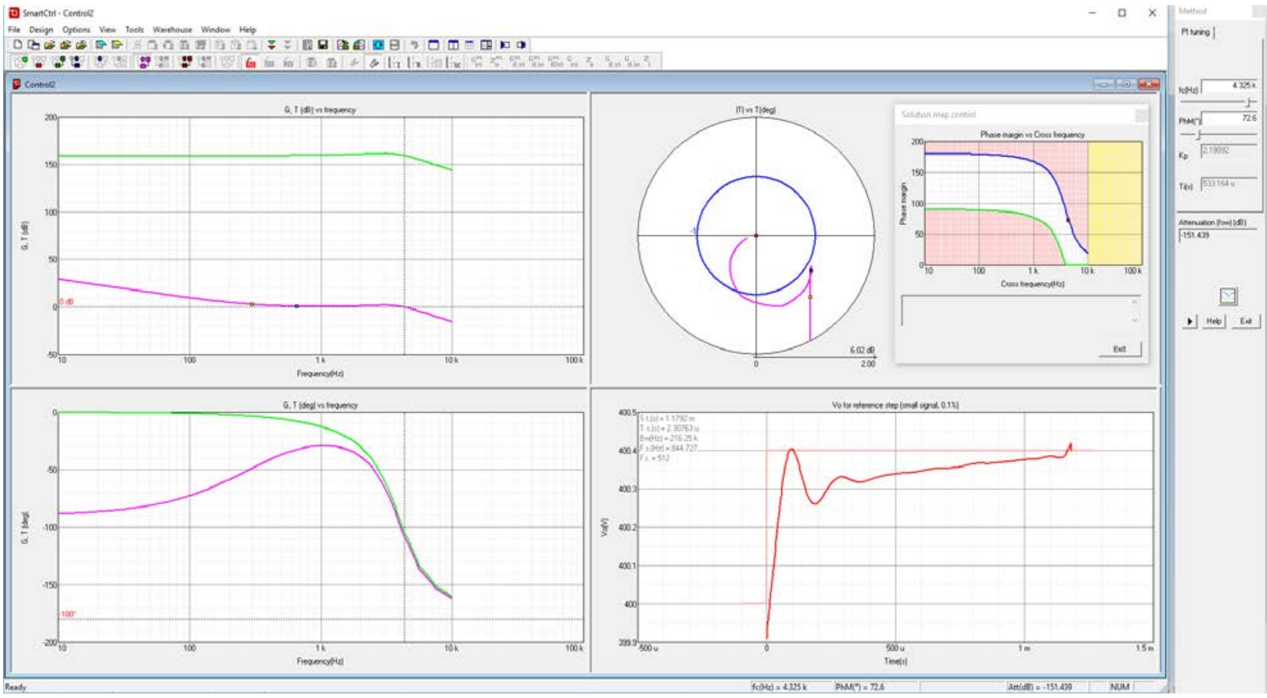

Figure 12: SmartCtrl loop solution

4. Validation

1. Validate the control loop design

In order to check the closed loop performance of the regulator designed by SmartCtrl, a closed loop time-domain simulation is carried out in PSIM.

Two different designs are obtained from SmartCtrl. The following table shows the control loop bandwidth (BW) and the phase margin (PM) of these two designs, as well as the regulator parameters.

Design #1	**Design #2**
Bandwidth = 3.5kHz Phase Margin = 55º	Bandwidth = 1kHz Phase Margin = 90º
Kp = 1.198 Kint = 38.92u	Kp = 471m Kint = 35.56u

Those values can be obtained from SmartCtrl as shown in Figure 13.

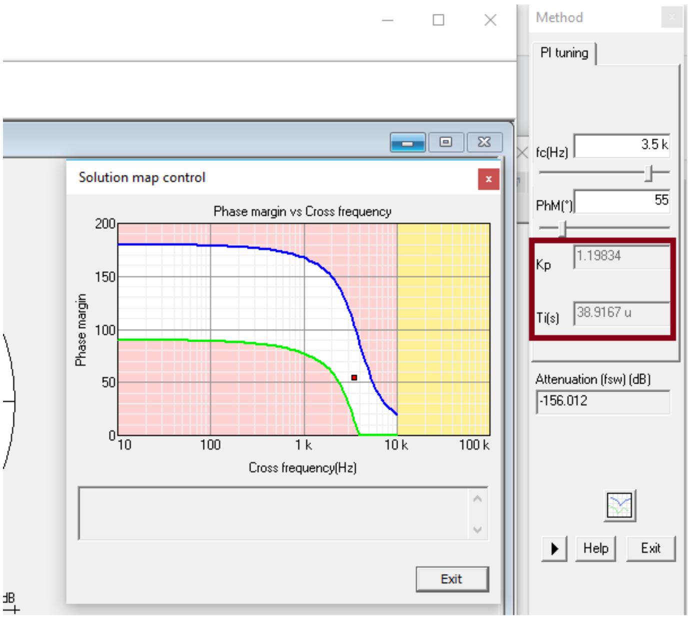

Figure 13: Kp and Ti values extracted from SmartCtrl

Using the two regulators from the table above, the corresponding closed loop responses are simulated in PSIM. PSIM schematic can be found in Figure 14. In this schematic, an input voltage step at 5ms has been added to test the dynamical response of the calculated compensator.

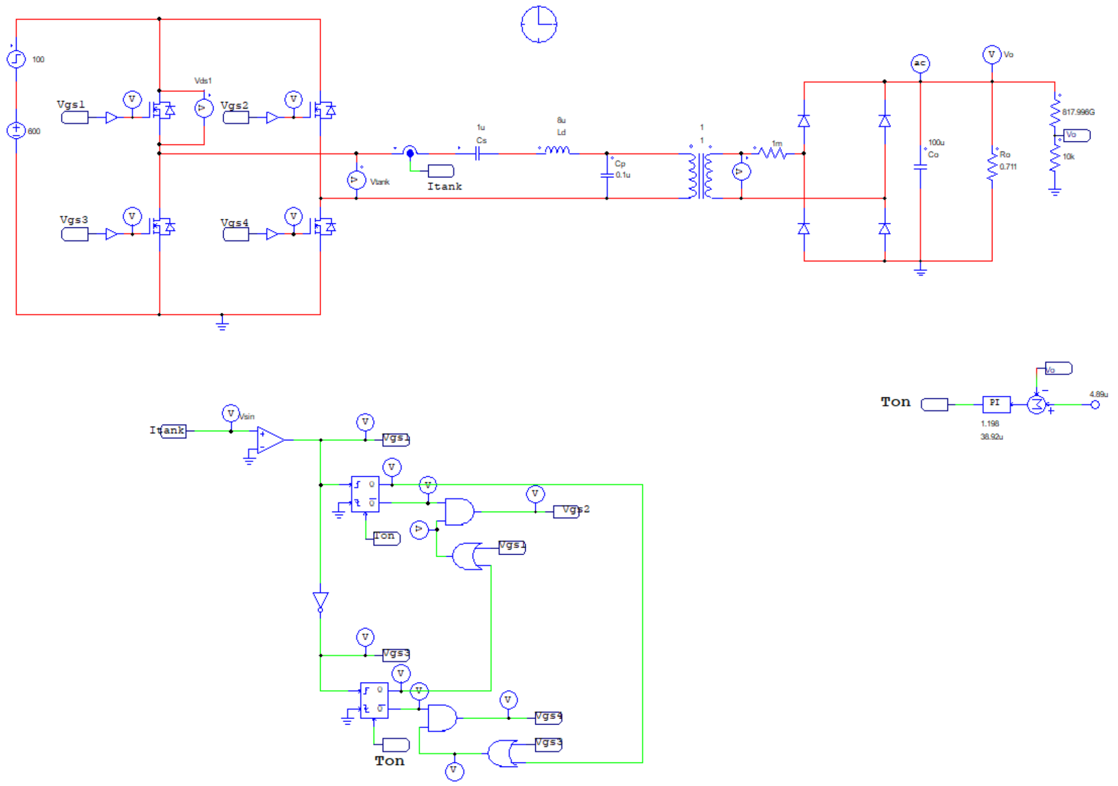

Figure 14: Psim schematic including a input voltage step

It can be seen in Figure 15 the result of the simulation. The steady state output voltage is 400V, as it was specified and it can be seen how it is maintained even with an input step of 100V.

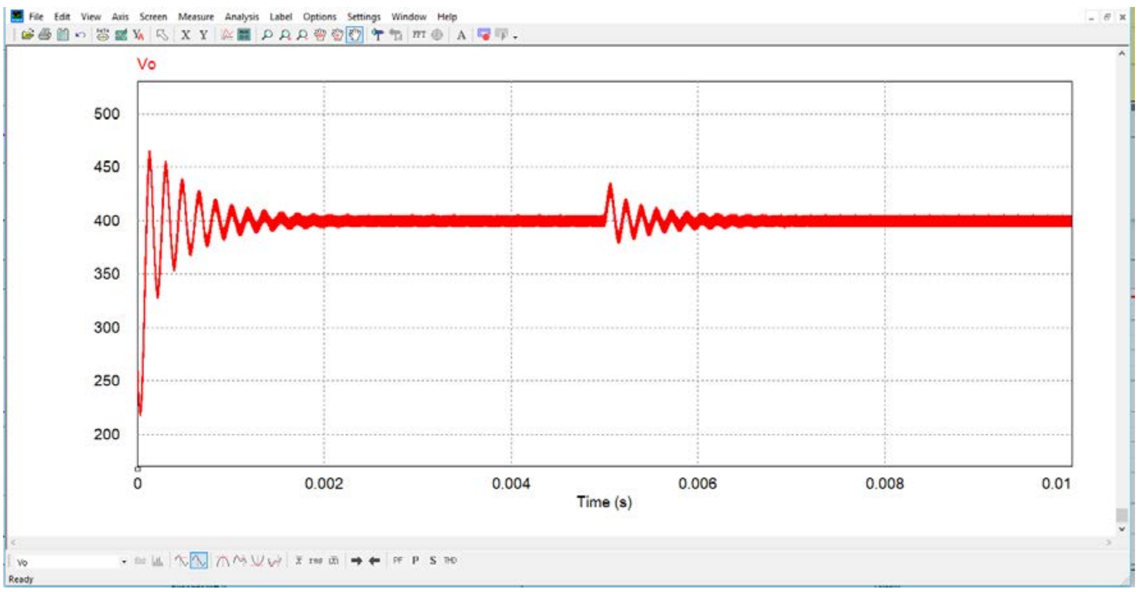

Figure 15: Output voltage

If this simulation is repeated but with the other values of the PI compensator (Kp = 471m / Kint = 35.56u) it can be observed from the waveforms that the first design

(Design #1) tracks the reference signal more accurately than the second design (Design #2). Although Design #1 has a lower phase margin with under-damped oscillations, its higher bandwidth and higher low-frequency gain leads to a faster response.

This example shows that, ***SmartCtrl in combination with PSIM,*** with the capability to import frequency response results from PSIM, provide a fast and powerful platform for control loop design and optimization of any power converters.