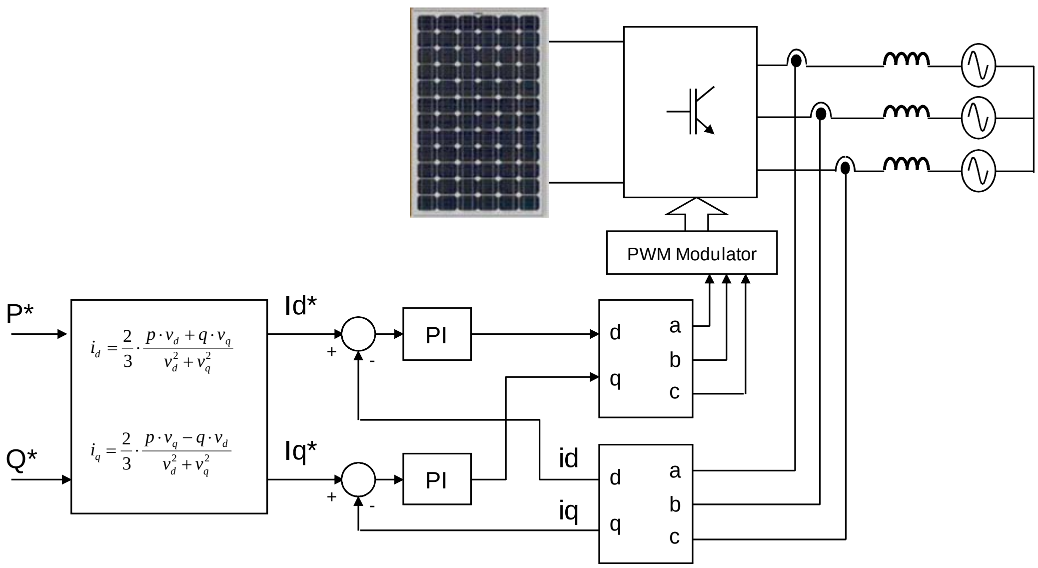
SmartCtrl Tutorial

3-Phase Grid-Connected PV Inverter

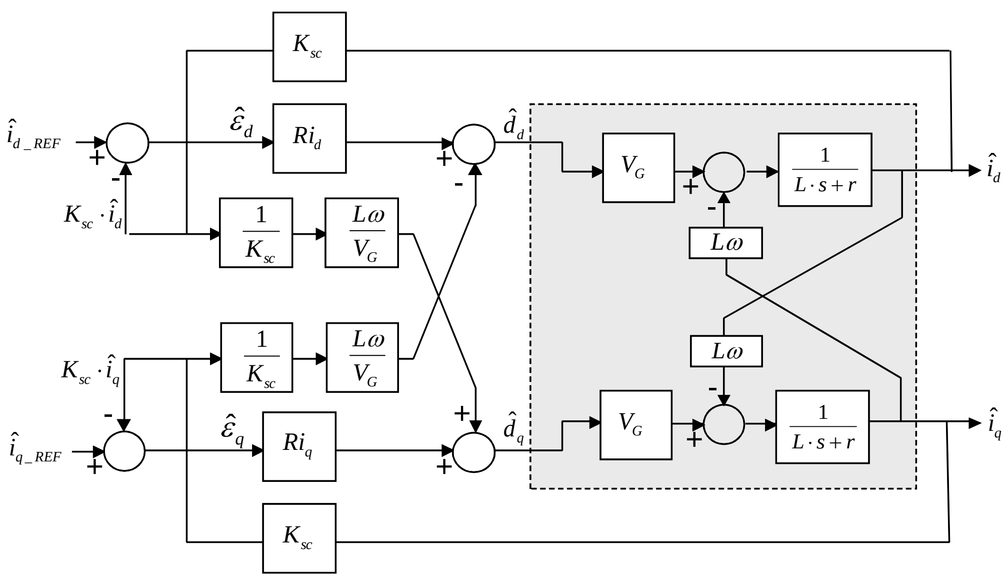
Control Loop Design

SmartCtrl[1] is a general-purpose controller design software specifically for power electronics applications. This tutorial is intended to guide you, step by step, to design the inner control loop in dq axis of a 3-phase grid connected PV inverter from its imported frequency response. The outer control loop design and the maximum power point tracking (MPPT) are not included in this tutorial.

The figure below shows the PV inverter system with the current feedback.

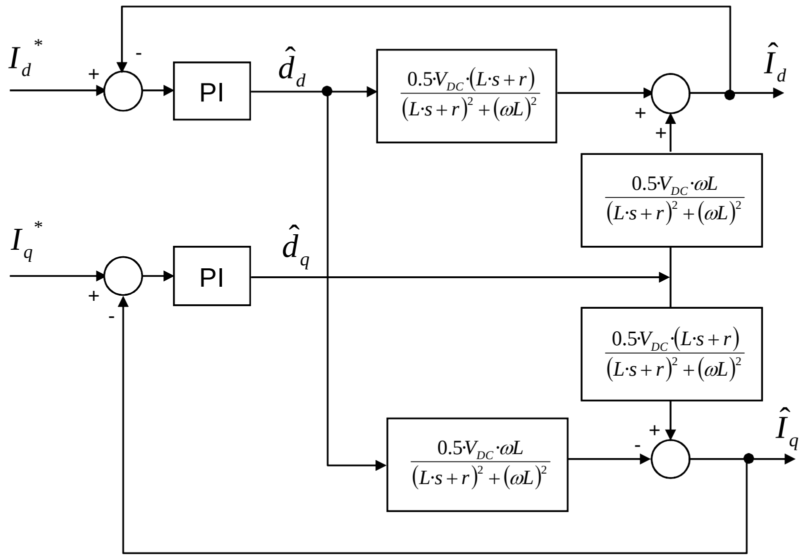


There are different ways to control such a system. One approach is to use the axis decoupling by means of feedforward control as shown in the figure below.



Due to the axis decoupling, this approach requires large amount of computations. For low cost applications (low cost µP, PIC, DSP or small FPGA), a simplified control strategy is needed, as shown in the next figure. In the simplified approach, direct PI control (without feedforward paths for axis decoupling) is used.

[1] SmartCtrl is copyright in 2010 by Carlos III University of Madrid, GSEP Power Electronics Systems Group, Spain



The plant (grey colored area) can be rewritten as it is shown in the figure. The obtained transfer functions can be classified as follows:

- Mutual transfer functions:

$$\left(\frac{\hat{I}_d}{\hat{d}_q} \text{ and } \frac{\hat{I}_q}{\hat{d}_d}\right)$$

- Self transfer functions:

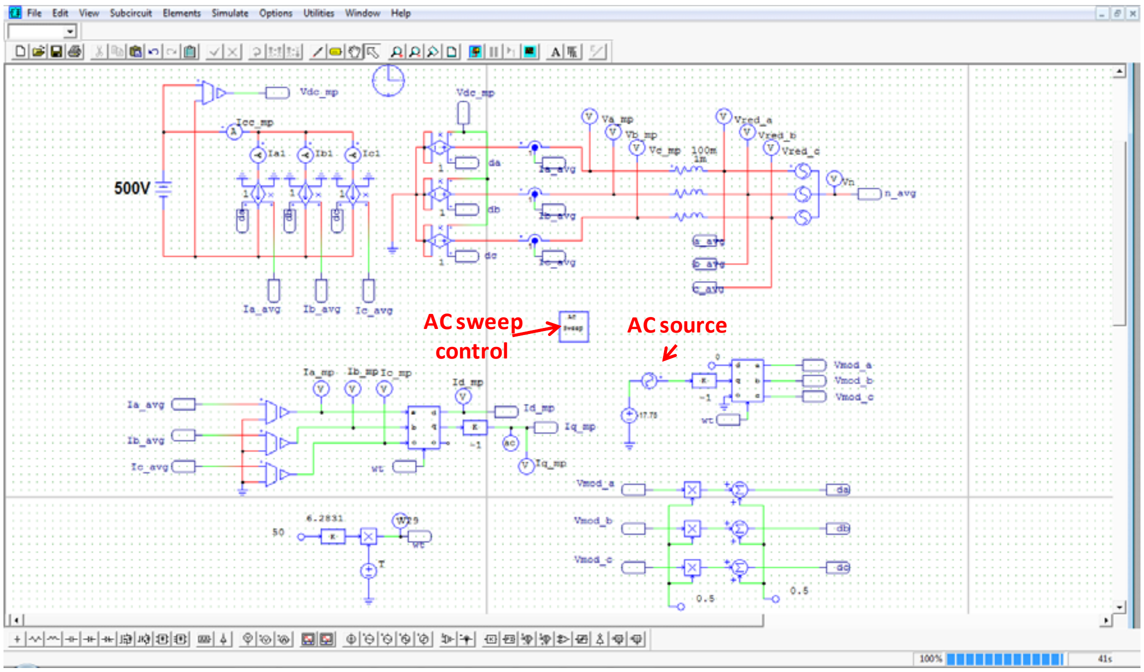
$$\left(\frac{\hat{I}_q}{\hat{d}_q}, \text{ and } \frac{\hat{I}_d}{\hat{d}_d}\right)$$

Taking into account the symmetry of the balanced 3-phase inverter system, two identical PI controllers can be tuned. In order to design this PI compensator, there are two possibilities: the converter plant can be either the mutual transfer function or the self transfer function. Due to the higher bandwidth and better stability, it is preferable to use the self transfer function.

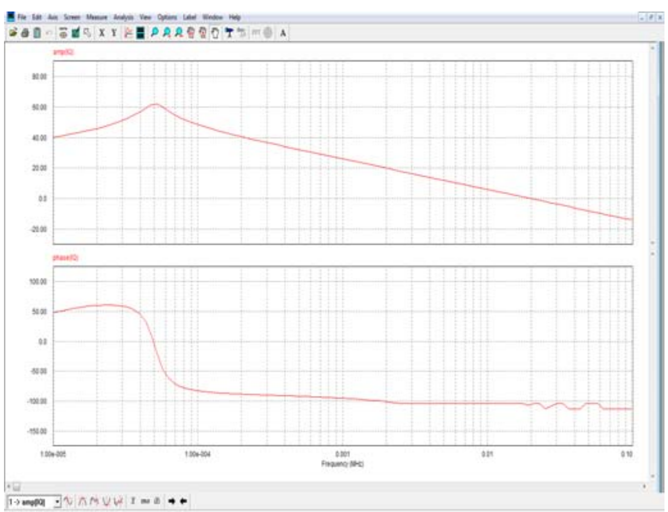
The first step will be to validate the theoretical self and mutual transfer functions by means of a PSIM AC analysis of the 3-phase grid connected inverter.

1. AC Analysis in PSIM

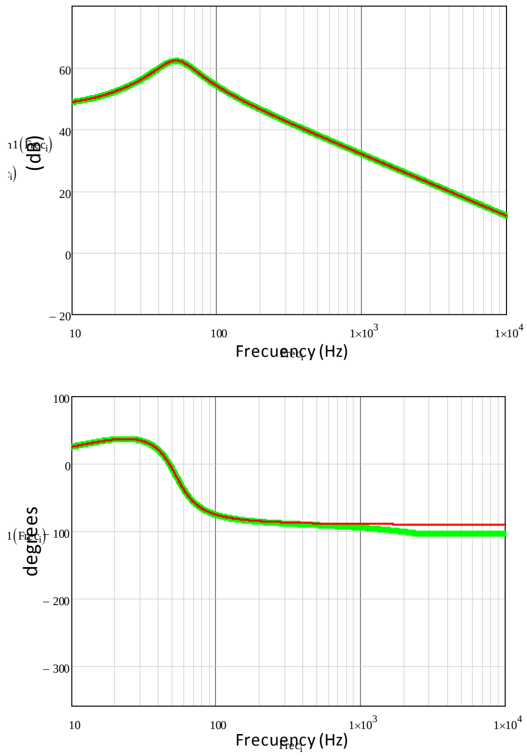
The frequency response of the plant is obtained from the average model of the 3-phase inverter in dq axis by means of the PSIM AC analysis, as shown below.



The frequency response from the ac analysis is shown below:

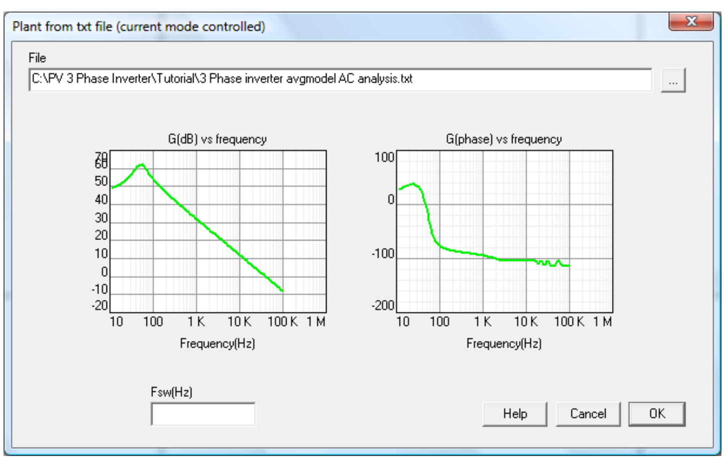


Before proceeding with the control loop design, we would validate the ac sweep results. The figure below shows the frequency response obtained with PSIM (green trace) and from theoretical analysis (red trace). The comparison shows that the simulation result matches very well with the theoretical result.



Once the frequency response is obtained, in PSIM, go to **Utilities** -> **Launch/Export to SmartCtrl** (or click on the icon **Run and Export to SmartCtrl**) to export the ac sweep result to SmartCtrl.

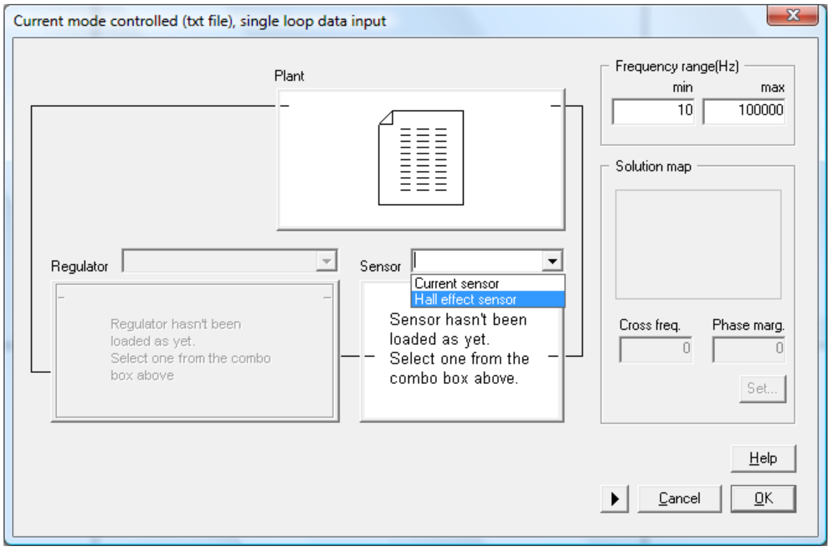
The loaded transfer function in SmartCtrl is shown below.



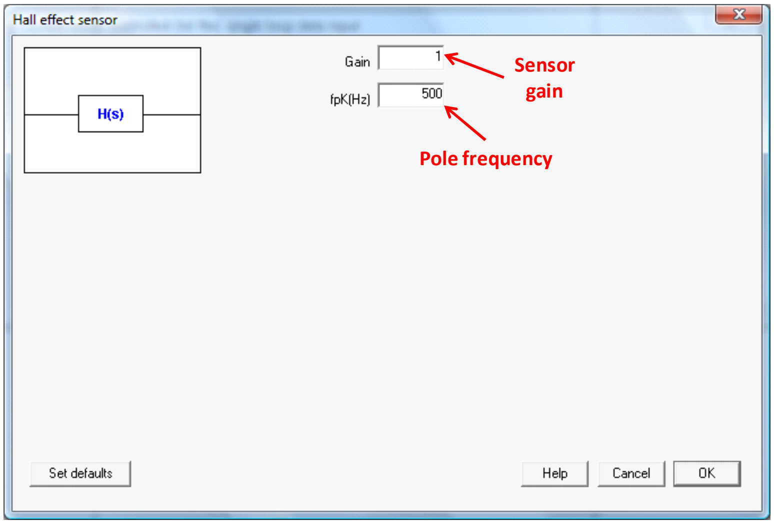
2. Control loop design with SmartCtrl

2.1 Select the sensor type:

The feedback current sensor type is selected from a pull-down listbox as shown below.

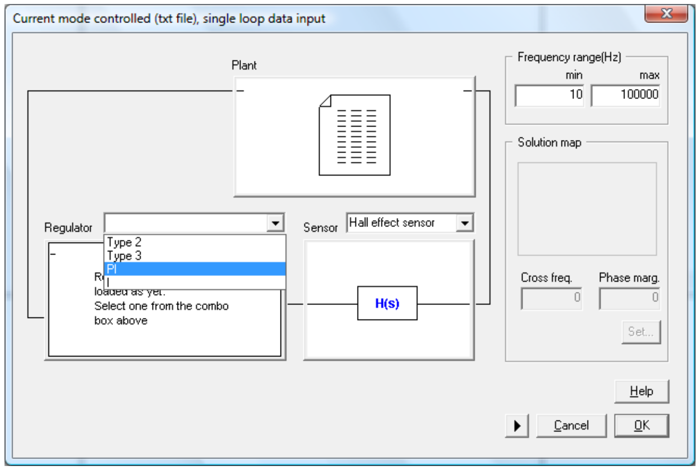


In this case, the hall effect sensor is selected. Then define the sensor gain and the bandwidth (pole frequency) of the Hall effect sensor.

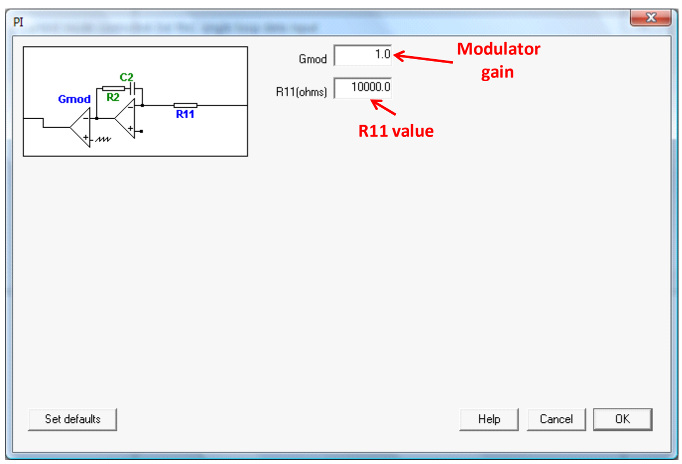


2.2 Select the regulator type

Select the regulator type of the regulator pull-down listbox.



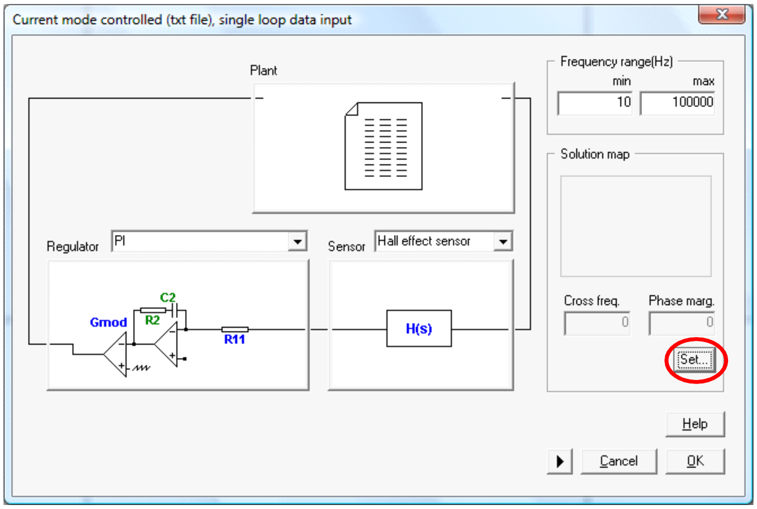
The PI regulator is selected in this case. The PI regulator specification window is shown below.



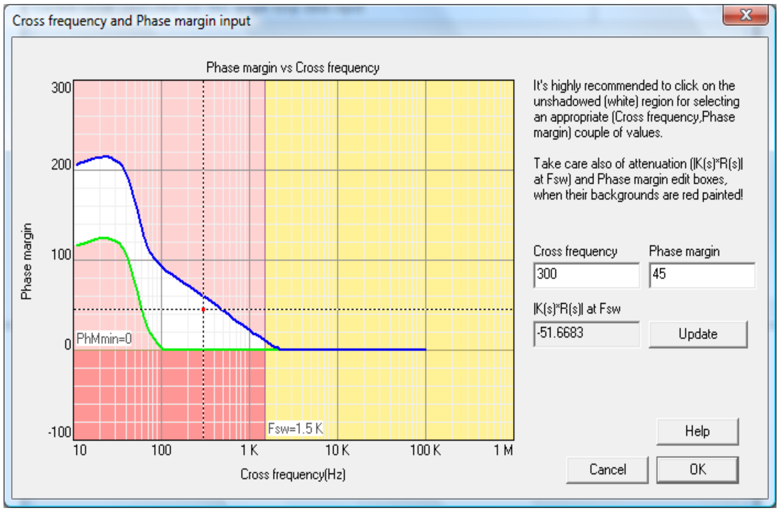
For an equivalent analog implementation of the compensator, it is necessary to set the modulator gain and the value of the resistance “R11”. In this case the resistance value is not important because the PI regulator to be implemented in PSIM is given by the values of the proportional gain and the time constant in s-domain transfer function block diagram.

2.3 Select the crossover frequency and the phase margin

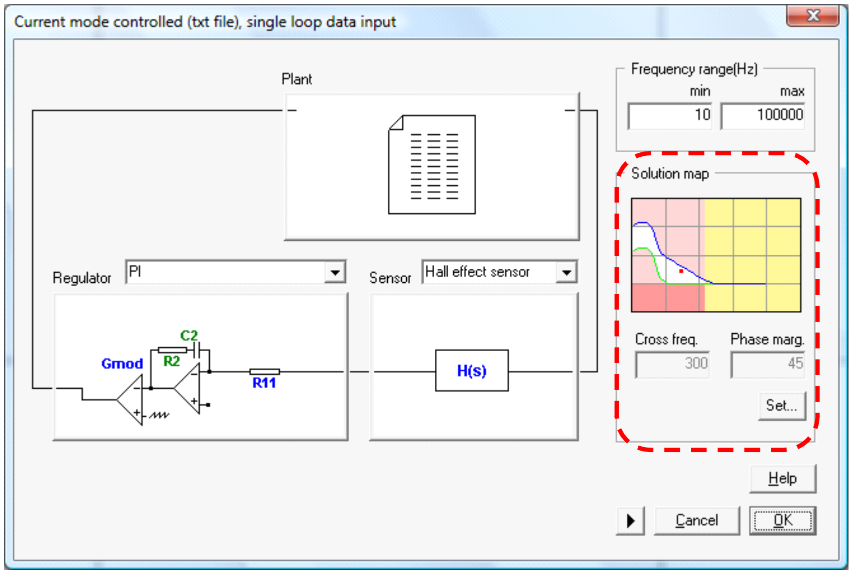
Once all the control loop transfer functions are defined, the crossover frequency and the phase margin must be selected. Click on the "Set.." button and the solutions map will be displayed.



Now, select the crossover frequency and the phase margin of the loop just by clicking within the white zone and click OK to continue. The selected pair (PM and f_{cross}) will provided stable operation. Optimization process could be carried out in the main SmartCtrl window.

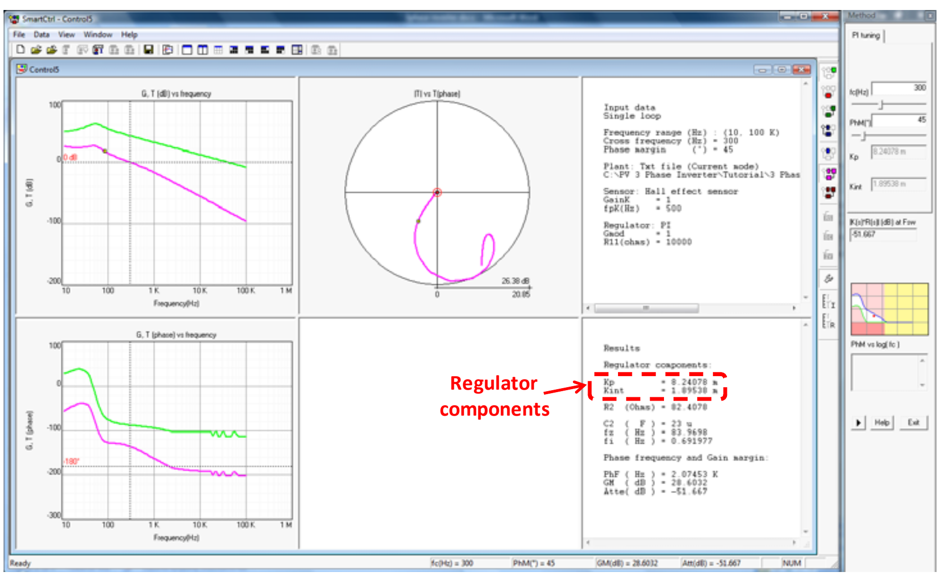


Once the crossover frequency and the phase margin have been selected, the solution map will be shown on the right side of the input data window. If, at any time, these two design parameters need to be changed, just click on the shown solution map (See next figure).



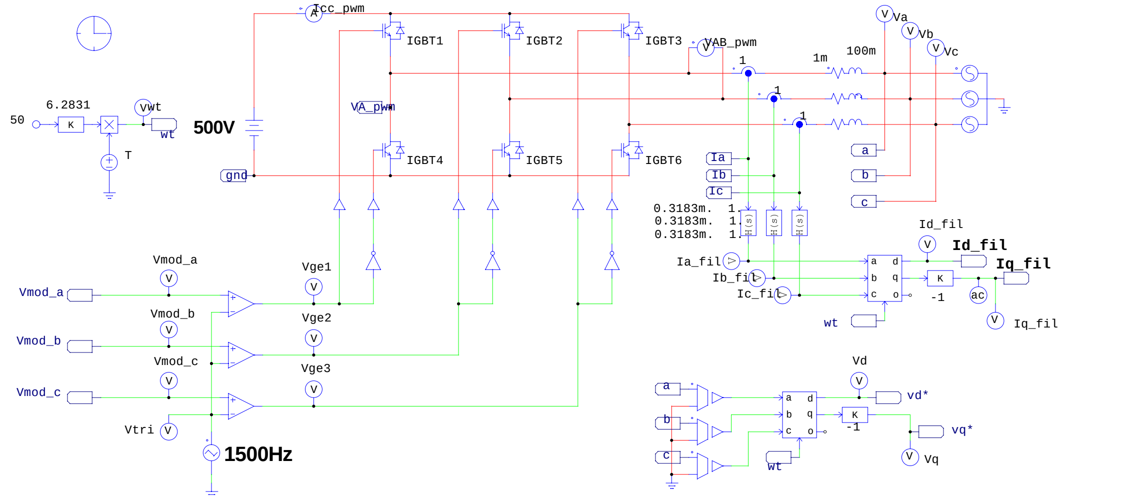
Now accept the selected configuration and confirm the design, the program will automatically show the performance of the system in terms of frequency response, etc.

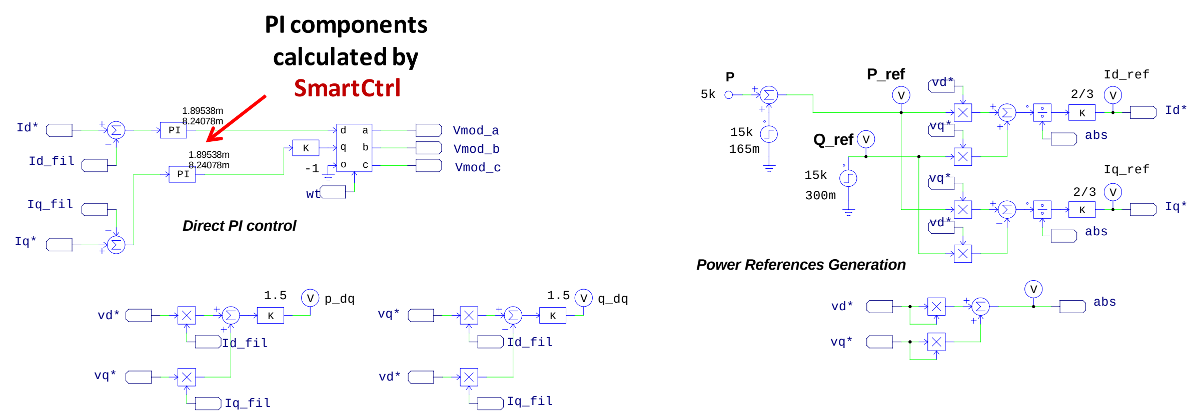
The regulator components to be used in PSIM are the Kp and Kint values.

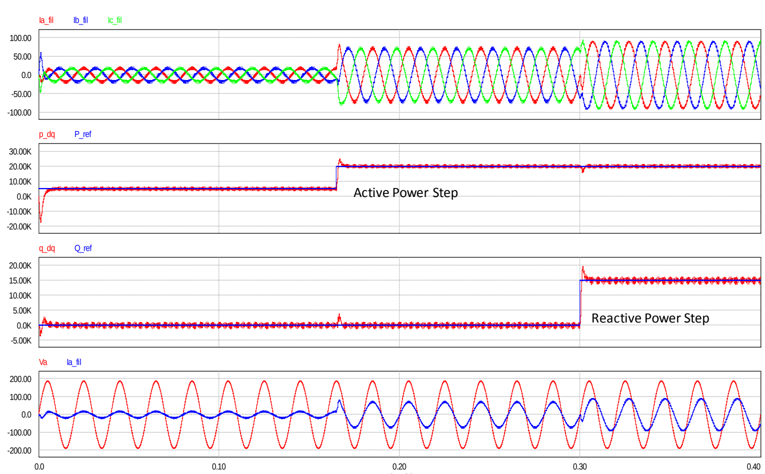


3. Closed loop performance

In order to check the closed loop performance of the regulator designed in SmartCtrl, a closed loop simulation with PSIM will be carried out. Both the simulation schematic circuit and the simulation results are shown below.







As it can be seen from the simulation results, the control loop, designed in SmartCtrl and validated in PSIM, provides a good performance to the 3-phase PV inverter system without the use of feedforward decoupling loops.

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 converter systems.