

3 Phase grid connected PV inverter

Tutorial – January 2025 -



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1. Introduction

This tutorial is intended to guide you, step by step, to design the inner control loop in dq axis of a three-phase grid connected PV inverter from its imported frequency response.

In this tutorial have not been included the outer control loop and the MPPT (Maximum Power Point Tracker) algorithm. See Figure 1.

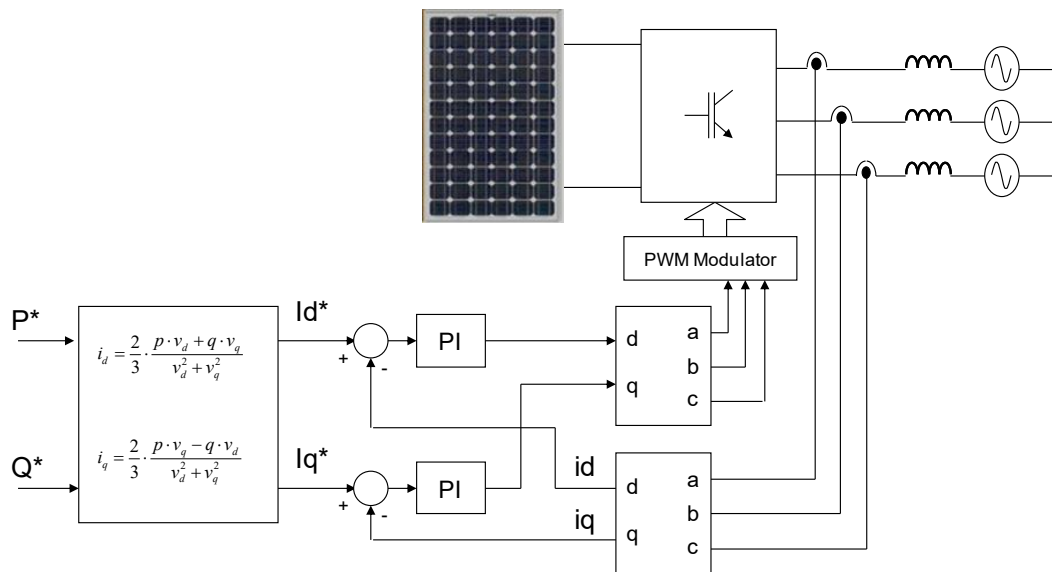


Figure 1: Block scheme of the system

There are a lot of possibilities to design the control loop of the aforementioned system. One of them is the conventional control using axis decoupling by means of feedforward loops as shown in Figure 2.

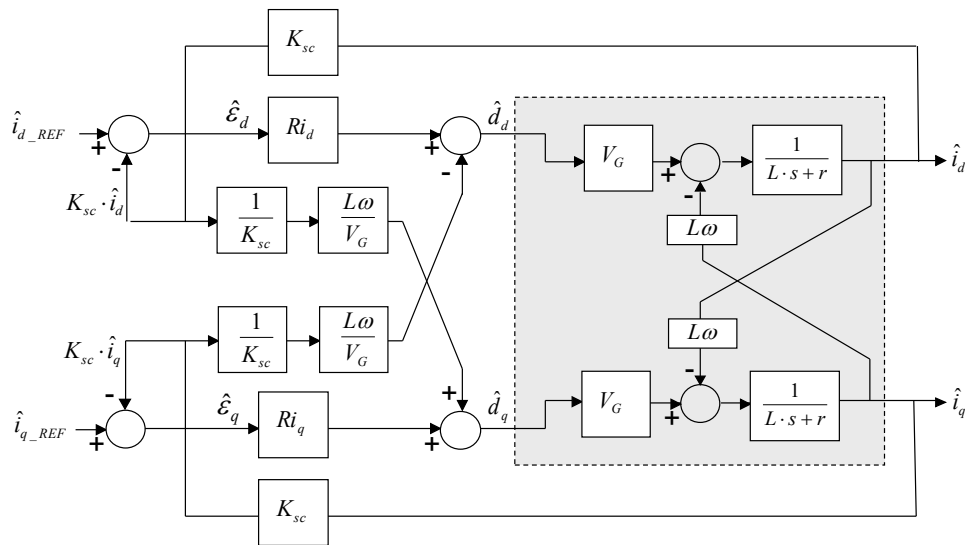


Figure 2: Feed forward axis decoupling

Due to the axis decoupling, the conventional control scheme requires the implementation of algorithms with high computational cost.

For low-cost applications a simplified control strategy is proposed and shown in Figure 3. As it can be seen in Figure 3, a direct PI control (without feedforward loops for axis decoupling) has been proposed. This technique is the one that has been used in this tutorial.

Taking into account the symmetry of the balanced three phase inverter, two identical PI controllers must be tuned. In order to design this PI compensator, two different possibilities can be selected.

- It can be considered the mutual transfer function.
- It can be considered the self-transfer function.

Due to the higher bandwidth and stable (together enough phase margin and stable operation) is preferable to use the self-transfer function.

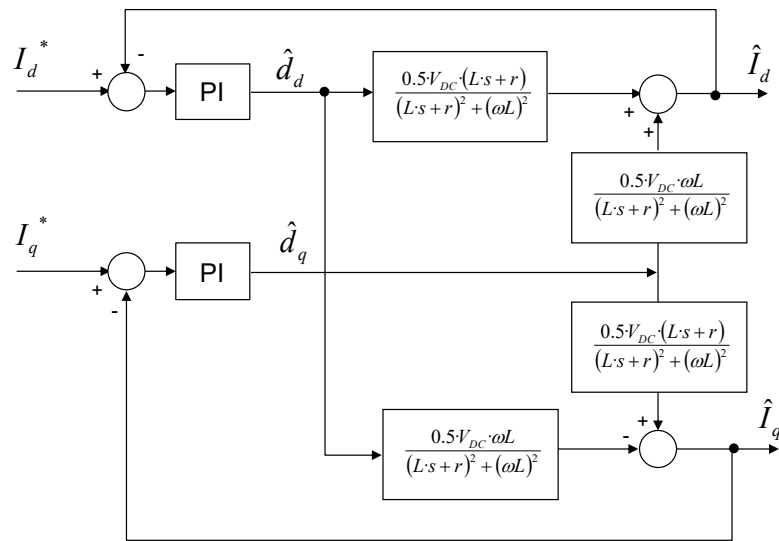


Figure 3: Simplified control strategy for the inverter

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

2. AC Analysis in PSIM

The frequency response of the plant is obtained from the averaged model of the three-phase inverter.

To do so, the PSIM AC analysis tool is used. The schematic necessary to generate this AC seep is shown in Figure 4. Being its result the one shown in Figure 5.

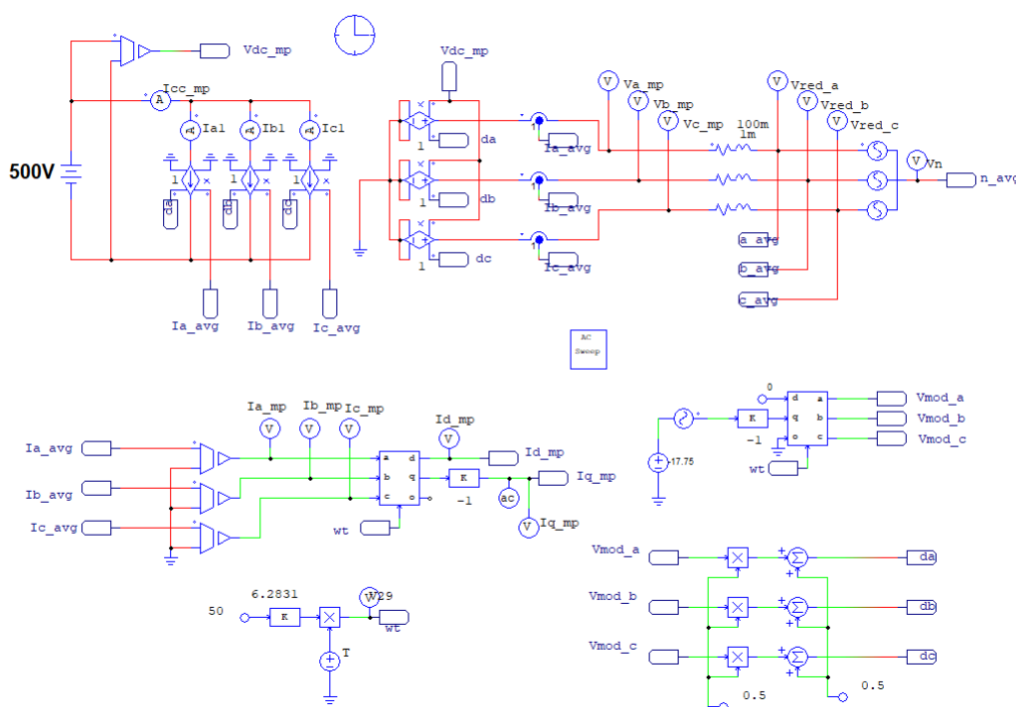


Figure 4: Schematic for AC sweep analysis in PSIM

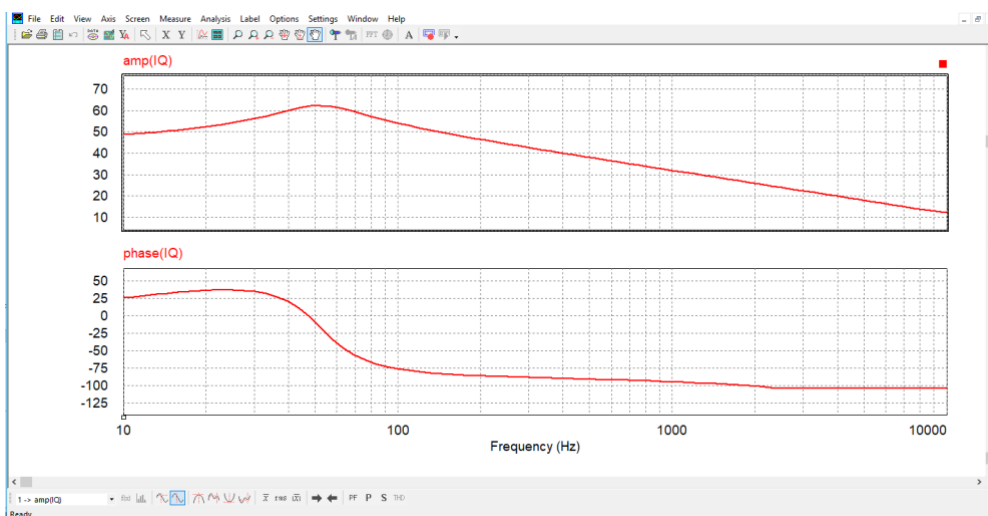


Figure 5: AC sweep response of the system

Save the data with the menu **File** -> **save as** -> AC_Sweep_data_points / .txt excel compatible

3. Import transfer function to SmartCtrl and control loop design

1. Open your SmartCtrl Software and select Import frequency response data from txt file as shown in Figure 6. And select current mode controlled.

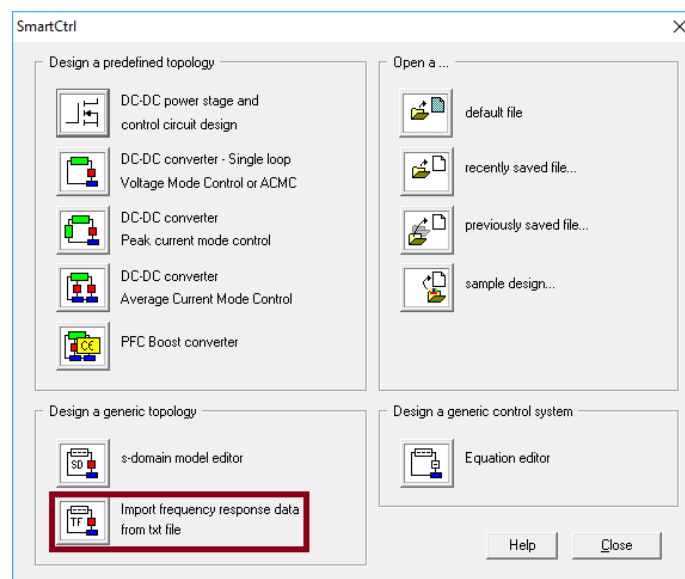


Figure 6: SmartCtrl option to load AC sweep data in txt format

2. Configure the input data and click OK to continue. See Figure 7.

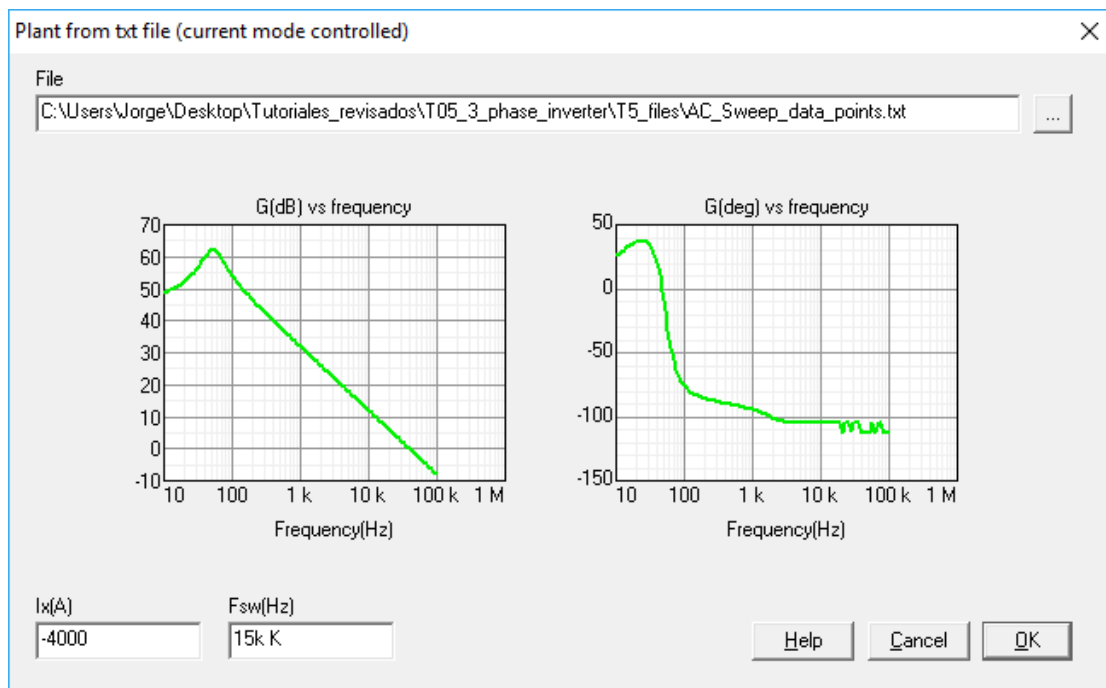


Figure 7: Input data configured in SmartCtrl

3. Specify the current sensor. See Figure 8 and Figure 9.

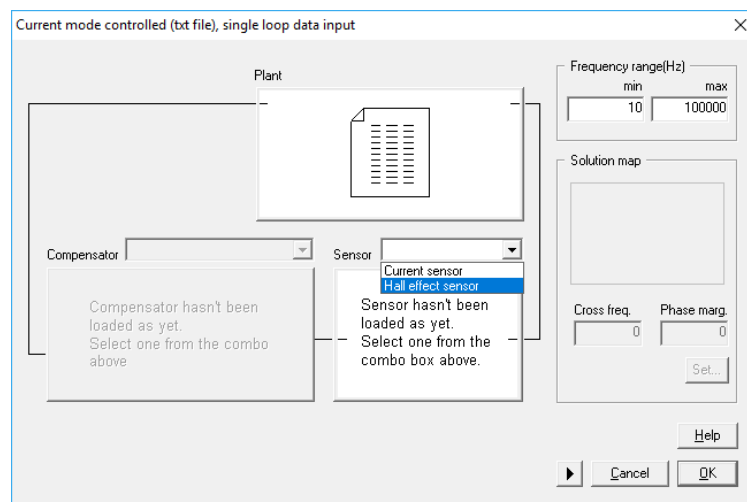


Figure 8: Current sensor choices

The current sensor specification window is automatically shown. It is necessary to set the sensor gain and the bandwidth (pole frequency) of the Hall effect sensor. Then, press OK. Type the values shown in Figure 9

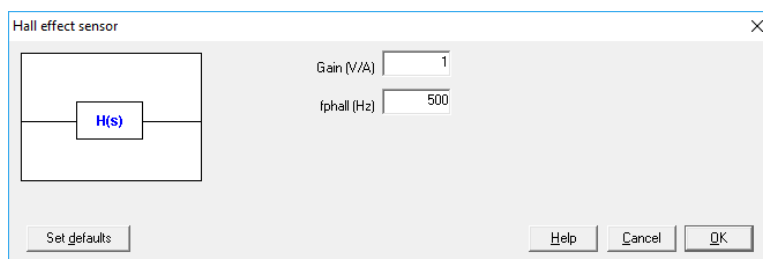


Figure 9: Current sensor parameters

4. Select a PI compensator. See Figure 10 and type the values shown in Figure 11.

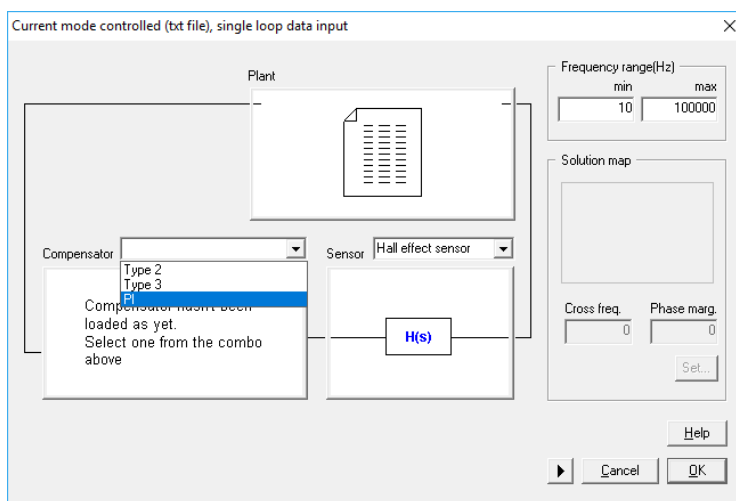


Figure 10: Compensator choice

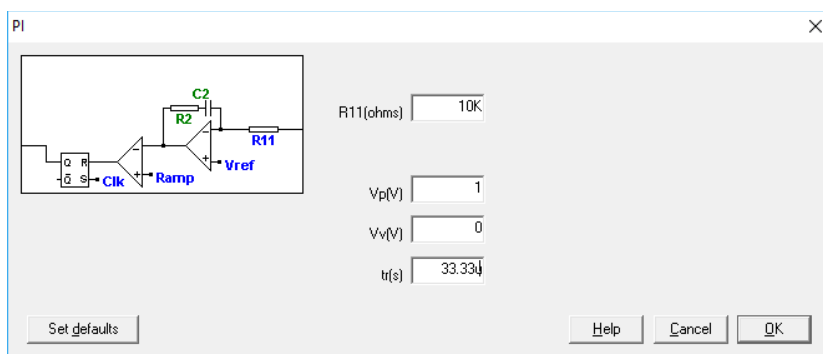


Figure 11: PI compensator parameters

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. Once the values of Figure 11 have been introduced press OK.

- Once all the control elements have been defined, the crossover frequency and the phase margin must be selected. Click on the "Set.." button and the solutions map will be displayed. See Figure 12.

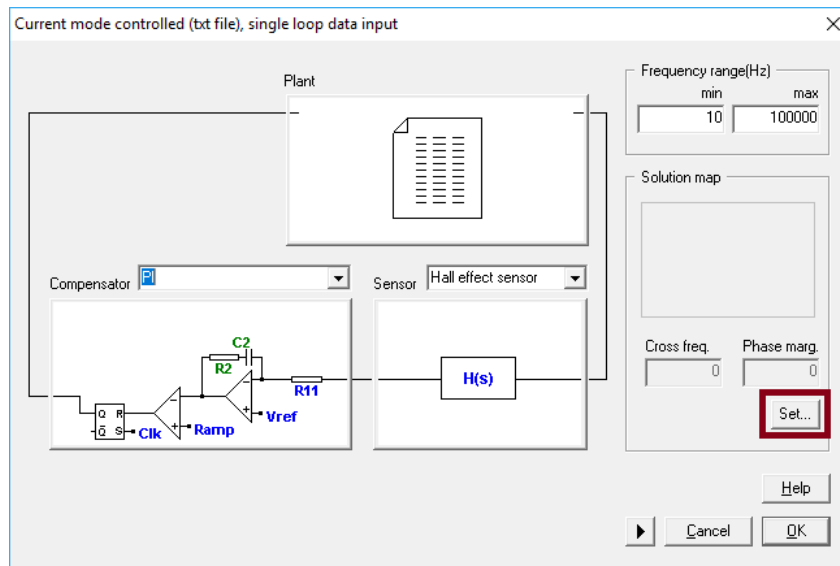


Figure 12: Access to solution map

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 provide stable operation. Optimization process can be carried out in the main SmartCtrl window.

In this tutorial, a f_c of 300Hz and a PM of 45 degrees have been chosen. See Figure 13.

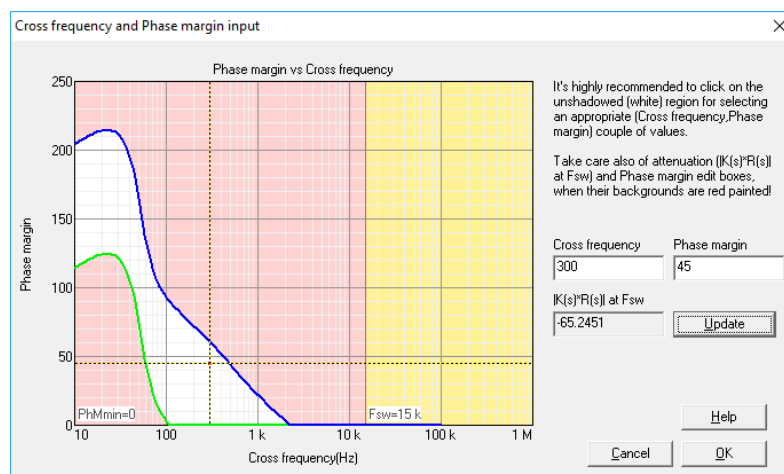


Figure 13: Solution map with the point already defined

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, the two parameters need to be changed, just click on the shown solution map. See Figure 14.

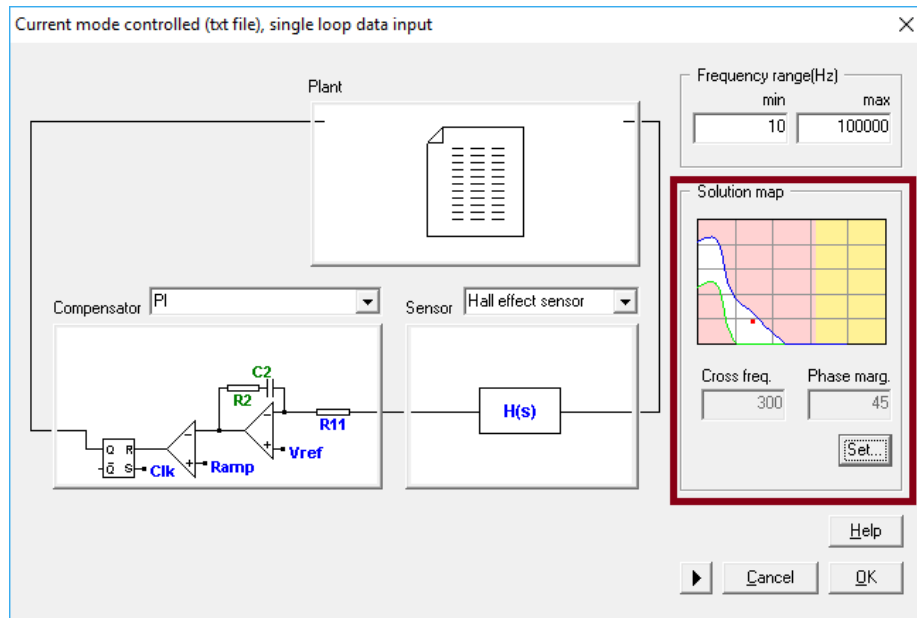


Figure 14: SmartCtrl wizard fully completed

Confirm the design by pressing OK and the program will automatically show the performance of the system in terms of frequency response, etc. The regulator parameters to be introduced into PSIM are K_p and K_{int} . See Figure 15 and Figure 16.

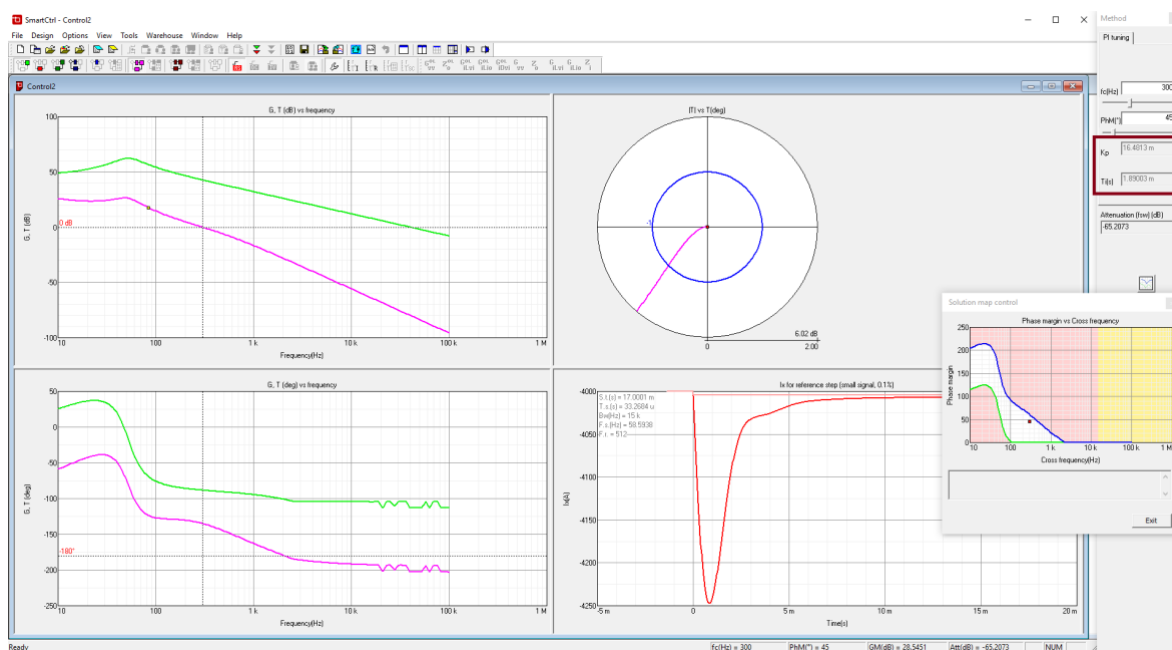


Figure 15: SmartCtrl dynamic response analysis window

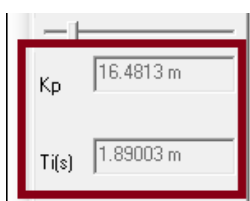


Figure 16: Zoom over SmartCtrl output window

The compensator values calculated with SmartCtrl for the identical PI are:

- $K_p = 16.48e-3$
- $T_i = 1.89e-3$

4. Closed loop performance

In order to check the closed loop performance of the regulator calculated with SmartCtrl, a closed loop simulation with PSIM has been carried out. The simulation schematic circuit can be seen in Figure 17; and, its simulation result, in Figure 18.

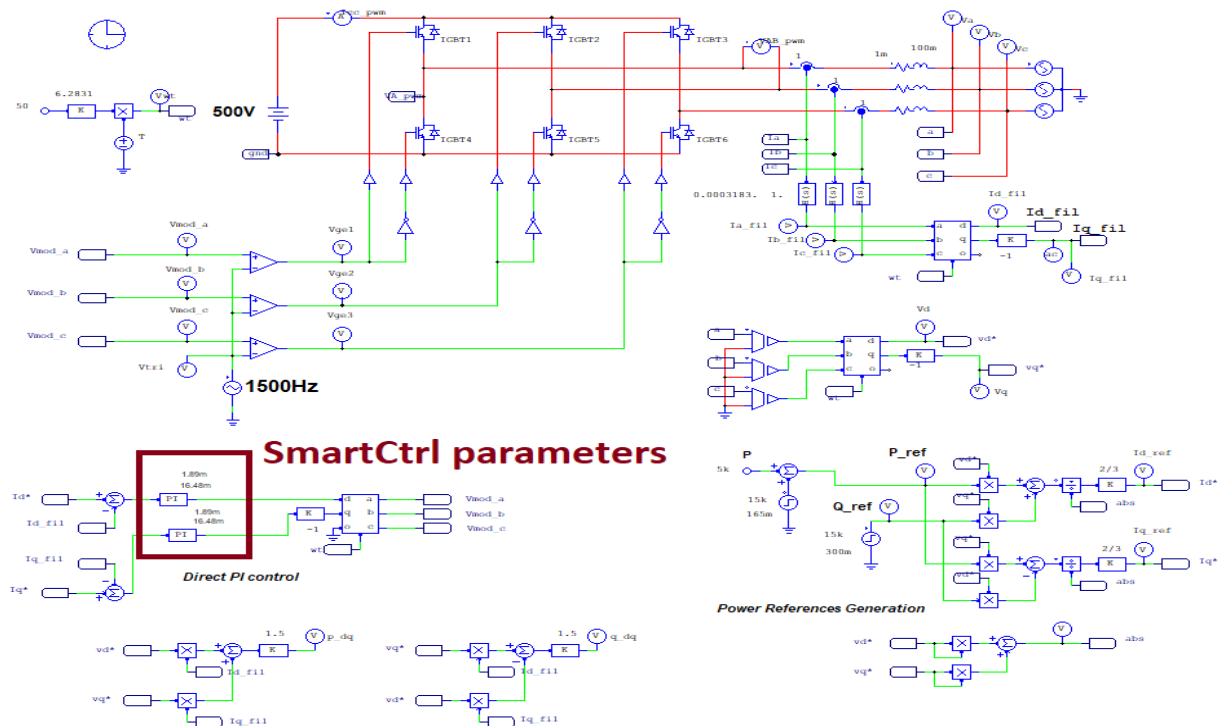


Figure 17: PSIM schematic with SmartCtrl parameters

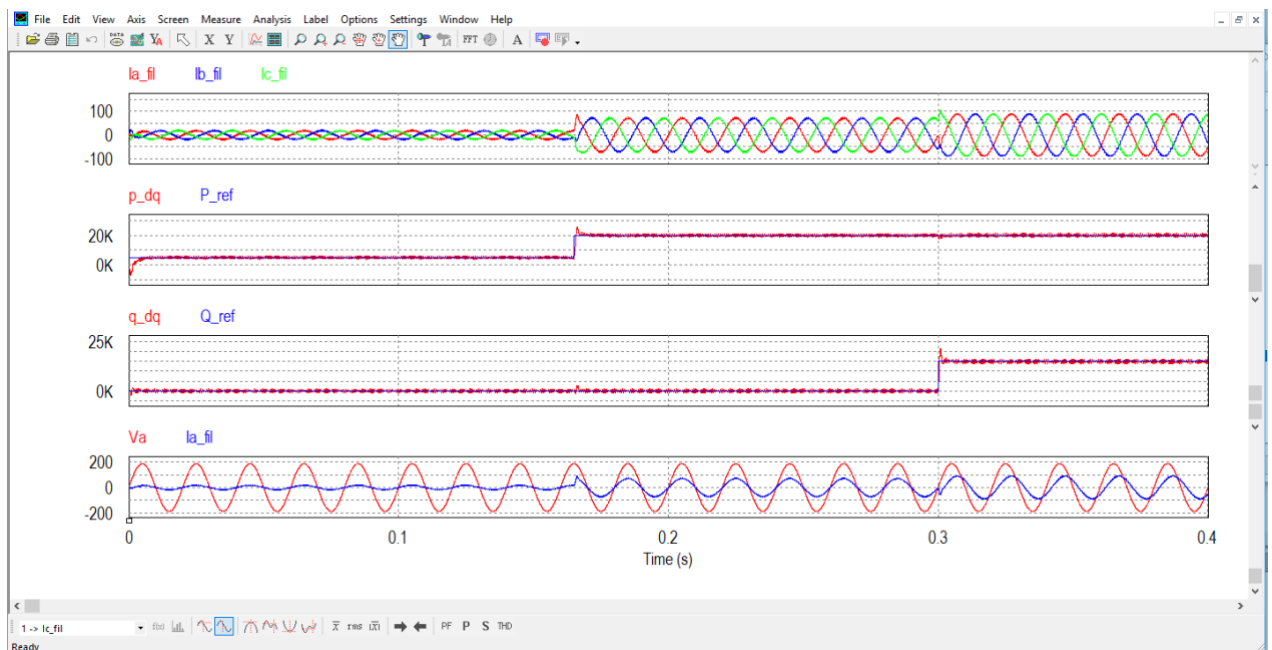


Figure 18: Results of the PSIM simulation

As it can be seen in Figure 18, the system has a good performance (without the use of feedforward decoupling loops). Therefore, the control loop designed with the proposed method by means PSIM and SmartCtrl is valid to connect a three phase PV inverter to the grid.

Note that more detailed power stages can also be controlled by means this strategy (PSIM with SmartCtrl).

LCL filters, digital implementation with delay effects and every other parasitic effect can be included in PSIM before the AC analysis to obtain a plant transfer function as realistic as it will be required.