Power electronic bundle - quick start guide

PN171 | Posted on November 29, 2021 | Updated on August 8, 2025

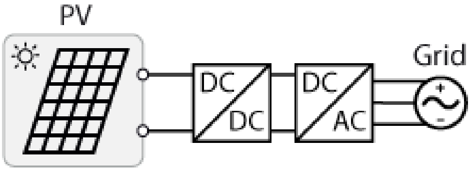
Jonathan ORSINGER
Project & Development Engineer
imperix • in

Table of Contents

Thanks to its flexibility, the **power electronic bundle** allows for the implementation of numerous power converter topologies. As an example, this page explains how to get it configured as a 3-phase solar inverter, which is the default configuration of the bundle.

The page focuses on the basic commissioning and provides a comprehensive overview of the hardware configuration and step-by-step instructions. For a more theoretical approach to this application, please refer to the note AN006.

The considered topology, as shown below, is based on a DC/DC boost connected to a 3-phase inverter.



3-phase solar inverter block diagram

Setting up the power electronic bundle

The content of the power electronic bundle, listed below, includes all the components needed for the implementation of the solar inverter.

- Programmable controller (B-Box RCP)
- ACG SDK toolbox for automated generation of the controller code from Simulink or PLECS
- 6x phase-leg modules (PEB8038, PEB8024 or PEB4050)
- Passives filter box
- Grid connection panel with switchgear and precharge circuit
- 6x voltage sensors
- 4x current sensors
- All necessary RJ45 and fiber optic cables
- 4mm Safety laboratory cables (banana cables)

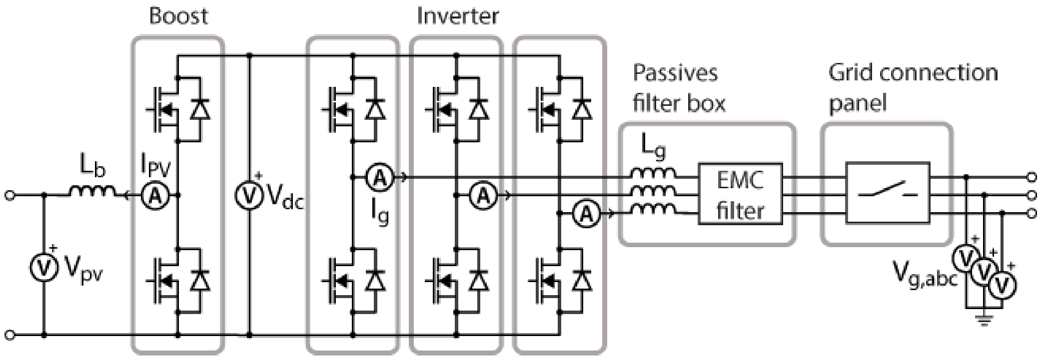
On top of that, some additional material, listed below, is required to test the system before operating the full converter.

- Laboratory DC power supply (rated for at least 100V, 5A)
- 3x power resistors (5-100Ω) to emulate a load at the grid terminal

Before commissioning the bundle with the present quick start guide and the proposed code example, the wiring of the power and control stages as well as the front panel configuration of the B-Box RCP must correspond to the default configuration presented hereafter.

Wiring of the power stage

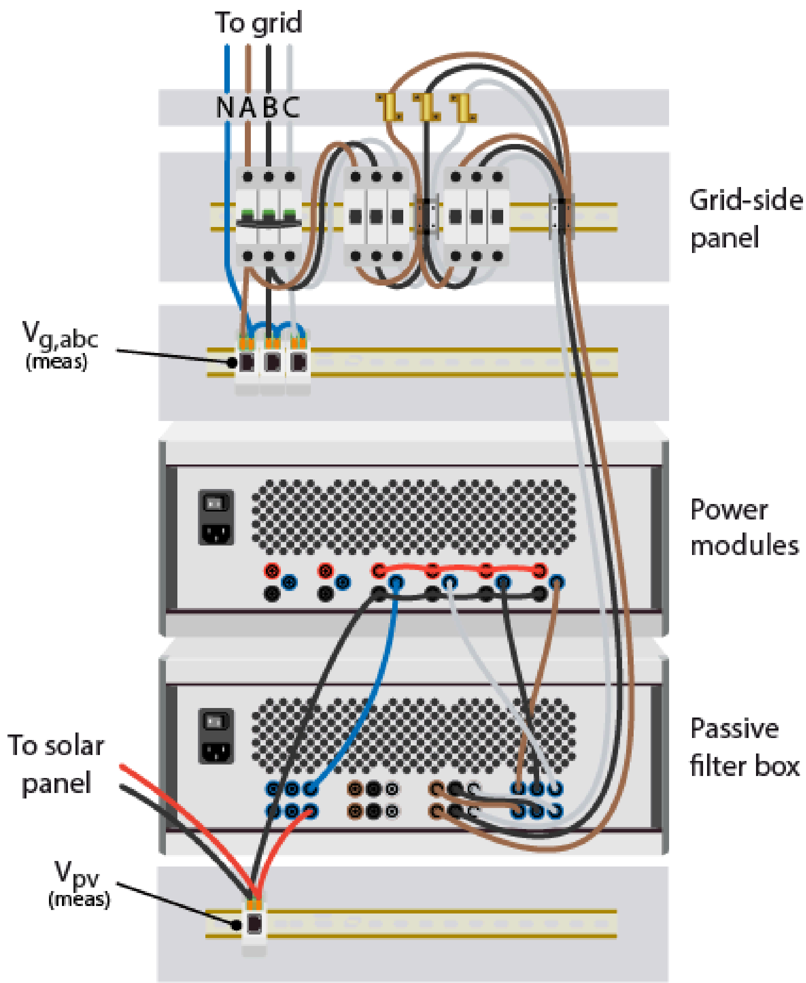
Per default, the power stage is wired as a grid-tied solar inverter as presented in the image below. The photovoltaic panel is connected to a boost stage that charges the DC link of the power modules. Connected to this DC link is a 3-phase inverter tied to the grid.



3-phase solar inverter schematic

For the basic commissioning presented in this quick start guide, the photovoltaic panel and the associated relay will be emulated by a DC power supply and the grid will be replaced by a resistive load (3 power resistors).

The illustration below details the wiring corresponding to the schematic above. The solar panel (i.e. the DC power supply) is connected to the first power module through an inductor from the passive filter box. The DC links of the modules are connected together. The middle points of the three other modules are connected through 3 inductors and the EMC filter to the grid-side panel.

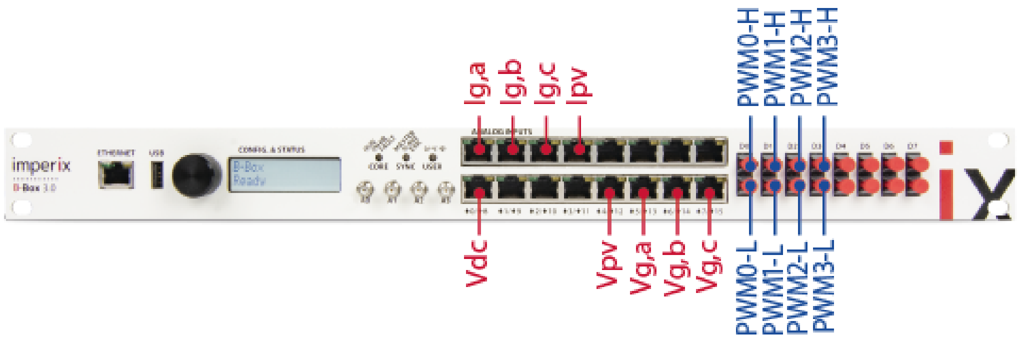


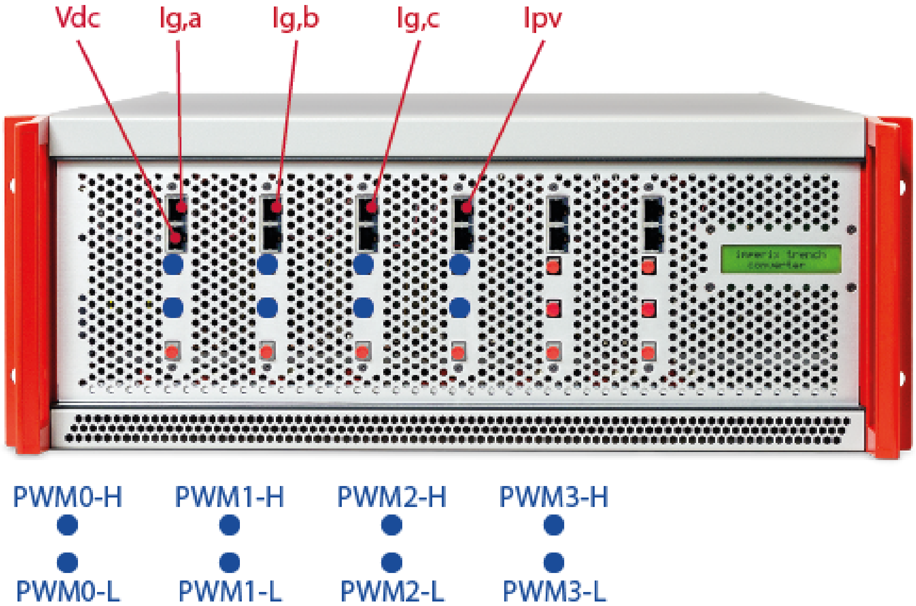
3-phase solar inverter wiring

Wiring of the control stage

Considering the measurements, the three grid voltages and the solar panel voltage are measured with external sensors mounted at the back of the converter. All currents and the DC link voltage are measured using the modules' internal sensors.

The two following schematics illustrate the connections for the measurements (in red) and for the PWM signals (in blue). The measurement channels for `Vpv` and the grid voltages `Vg,a`, `Vg,b` and `Vg,c` must be wired to the external voltage sensors at the back (see "meas" in the wiring above).





Front panel configuration of the B-Box RCP

To ensure that the ratings of the power converter are never exceeded, the hardware protection limits of the B-Box RCP must be configured properly. A detailed explanation of how to compute these limits is given in PN105. Here the limit for the solar panel current and voltage are set to 30A and 600V respectively. These limits correspond to analog signals of 6V and 5.9V. The DC link voltage is limited to 800V. The grid voltage and current are limited to 370V and 25A, respectively. The table below gives the complete configuration of the analog front-end of the B-Box according to the aforementioned limits.

Measured signal	**Sensor type**	**Input channel number**	**Low impedance**	**Gain**	**Filter**	**Limit high [V]**	**Limit low [V]**	**Disable safety**
$I_{g,a,b,c}$	PEB8038 Current	0,1,2	no	x4	no	5	-5	no
I_{pv}	PEB8038 Current	3	no	x4	no	0.5	-6	no
V_{dc}	PEB8038 Voltage	8	no	x2	no	7.9	-0.5	no

Measured signal	Sensor type	Input channel number	Low impedance	Gain	Filter	Limit high [V]	Limit low [V]	Disable safety
V_{pv}	DIN800V	12	no	x4	no	5.9	-0.5	no
$V_{g,a,b,c}$	DIN800V	13,14,15	no	x4	no	3.7	-3.7	no

Analog input configuration

Note that due to the topology of the converter, the sensor for the PV output current I_{pv} will measure negative currents. Therefore, for the PV output current measurement, the limit high is set to 0.5V and the limit low to -6V. The limits -0.5V for V_{dc} and V_{pv} (respectively 0.5V for I_{pv}) are chosen slightly negative (resp. positive) to prevent measurement noise around 0 from tripping the limit.

Commissioning the 3-phase solar inverter

Before operating the system, it is always a good idea to test that everything is properly wired and configured. With the help of the Simulink (or PLECS) model below, the following test procedure can be used to check the behavior of the power electronic bundle wired as a 3-phase solar inverter. The test will be performed in two steps: first by checking the correct operation of the inverter stage, and second by including the operation of the boost stage.

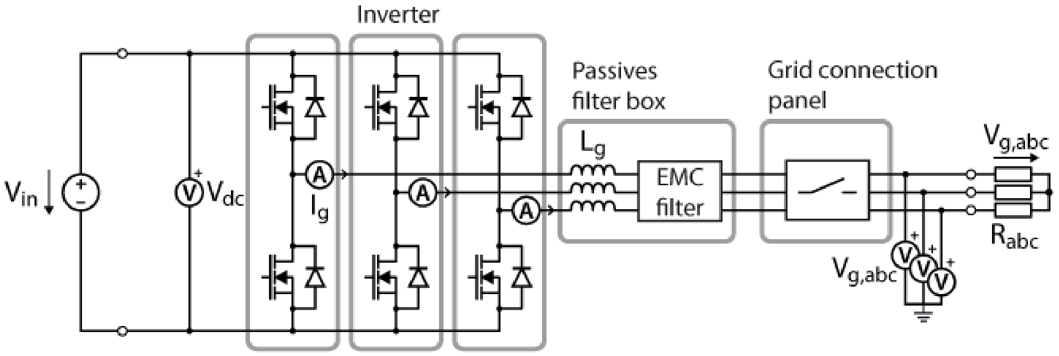
The B-Box controller can be programmed using Automated Code Generation (ACG) tools from Simulink and PLECS or directly in C++. In this section, the code examples are implemented with Simulink and PLECS. If needed, further information on the automated generation of code using Simulink or PLECS is given in Getting started with ACG SDK on Simulink or Getting started with ACG SDK on PLECS. In any case, the user should make sure to install the latest version of ACG SDK beforehand, available for download at imperix.com/downloads/.
PV_Inverter_Open_Loop_v1.slxDownload the test model (Simulink)
PV_Inverter_Open_Loop_v1.plecsDownload the test model (PLECS)
The code example in Simulink uses Simscape Electrical to model the converter. Matlab R2016a (or later) is required to run the model in simulation mode.

These basic models are designed to operate the boost converter and 3-phase inverter individually and in an open-loop configuration. Hence, ADC blocks retrieve the analog measurements for monitoring purposes only. On the other side, PWM blocks, along with the tunable parameters, send PWM signals with the desired duty cycle to the power converter. The relays of the grid connection panel are operated directly with tunable parameters.

The code examples above require that the grid is emulated by a passive load. In order to connect the 3-phase inverter to the grid, a pre-charge of the DC link capacitors is required, which is out of the scope of this quick start guide. For further details on the grid connection and the pre-charge, please refer to Three-phase PV inverter for grid-tied applications and TN131.

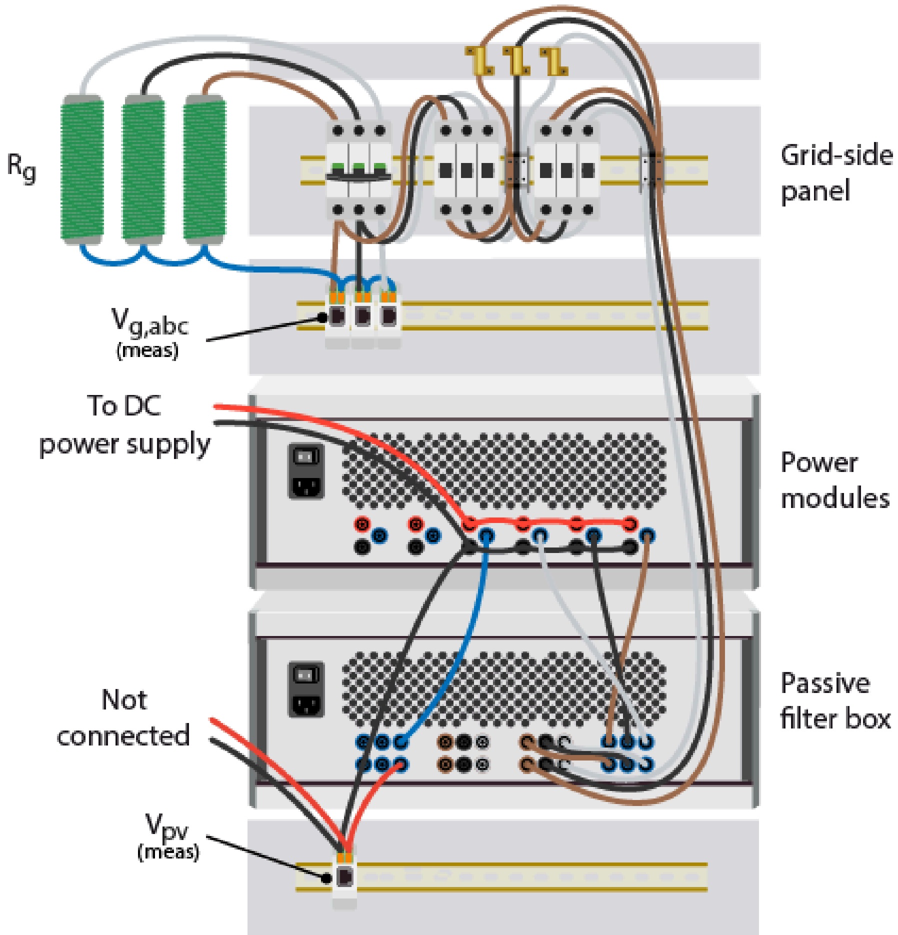
Test 1: 3-phase inverter stage

An easy way to test the inverter stage is to operate it in an open-loop fashion on a passive load. The 3-phase inverter is wired according to the following schematic. For more information on 3-phase inverters, please refer to the note on the Voltage Source Inverter (VSI).



3-phase inverter schematic

A DC power supply should be connected to the DC link of the power modules. Furthermore, three resistors should be set in a star configuration on the AC side of the converter, as shown in the diagram below.



Converter wiring for test 1: A DC power supply is connected to the DC link and a resistive load is connected in star at the grid terminal

Dimensioning of the load resistors

The resistors must be properly dimensioned to prevent them from overheating. To do so, the expected RMS current through a resistor must not exceed its maximum rated current. The details of the computations are given hereafter.

The theoretical RMS current can be computed as

$$I_{g,rms} = \frac{\sqrt{2} \cdot V_{dc} \cdot M_{inv}}{4 \cdot \sqrt{R_g^2 + (2\pi f L)^2}}$$

where V_{dc} is the DC link voltage, M_{inv} the modulation index of the inverter (tunable parameter `M_inv`), R_g the resistance of the load, $f = 50\,\mathrm{Hz}$ the AC frequency (hard-coded in the Simulink model) and $L = 2.2\,\mathrm{mH}$ is the equivalent inductance of the passive filter box.
In this guide, R_g is chosen as $8.5\,\Omega$, $M_{inv} = 0.5$ and $V_{dc} = V_{in} = 200\,\mathrm{V}$. This results in an RMS current of $4\,\mathrm{A}$ through the resistors, which is within the rated current of the selected resistors $(13.5\,\mathrm{A})$.
If the rating of the resistor is exceeded, the DC supply voltage and/or the modulation index of the inverter can be reduced accordingly.

Loading the code and setting up the workspace in Cockpit

- In Simulink:
    1. Open the Simulink model and set the mode to *Automated Code Generation* in the *CONFIG* block.
    2. Build the model (Ctrl + B). It will automatically launch Cockpit.
- Or in PLECS:
    1. Open the PLECS model.
    2. Open the coder options (Ctrl + Alt + B) and click *Build* in the bottom right. It will automatically launch Cockpit.
- In Cockpit:
    1. Set the target IP in Cockpit and click on *Create* to generate a new project.
    2. Add a new **rolling plot** module and drag and drop the `Vdc` variable to monitor the DC link voltage.
    3. Add a new **scope** module. Click on the "+" icon on the bottom right of the scope to add a second plot to the scope. Drag-&-drop the grid currents `Ig_a`, `Ig_b` and `Ig_c` to the upper plot and the grid voltages `Vg_a`, `Vg_b` and `Vg_c` to the lower plot.

Step-by-step test procedure

1. Manually close the circuit breaker on the grid connection panel.
2. To let power flow, close the relays of the grid connection panel by setting the variables `precharge_relay` and `bypass_relay` to 1 in Cockpit.
3. Make sure that `activate_inverter` and `activate_boost` are 0 so that the converter is not active.
4. Set the inverter modulation index `M_inv` to the value selected for the dimensioning of the load resistors (e.g. leave as 0.5 in the case of the present example).
5. Gradually increase the DC supply voltage to $200\,\mathrm{V}$ (or to the value chosen in the dimensioning of the resistors) and check in Cockpit that `Vdc` matches the voltage of the source.
6. Enable the PWM pulses in the inverter stage by setting `activate_inverter` to 1 and by toggling the PWM switch in the upper left corner in Cockpit.
7. Verify that the AC voltages `Vg_a`, `Vg_b` and `Vg_c` are sinusoidal voltages with fundamental amplitude

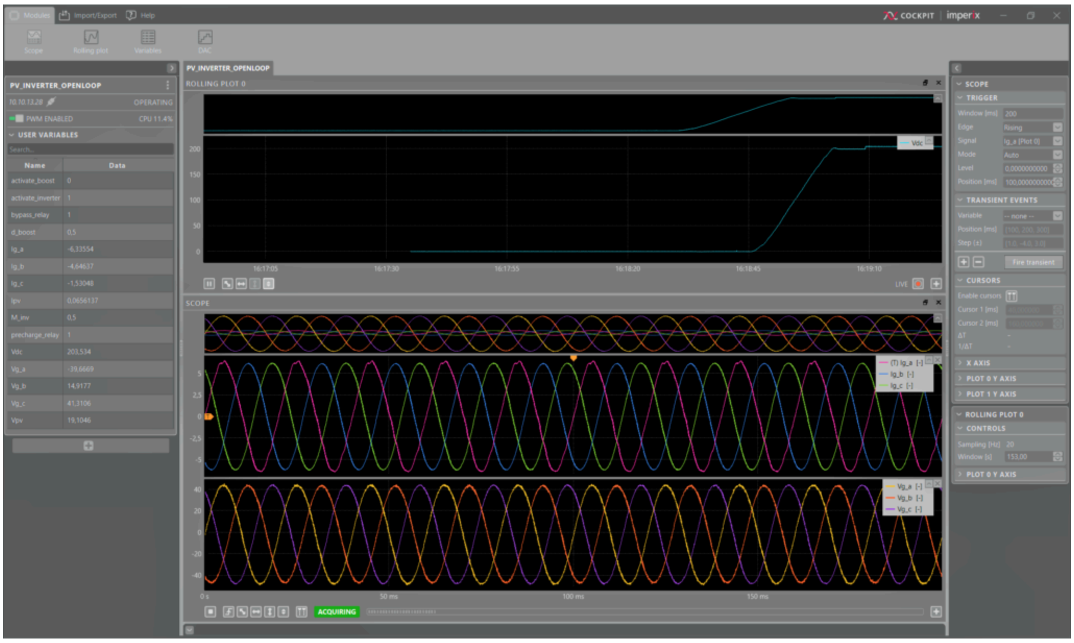
$$\langle \hat{V}_g \rangle = \frac{V_{dc}}{2} \cdot M_{inv} \ \ (\approx 50\,\mathrm{V}).$$

8. Verify that the AC currents `Ig_a`, `Ig_b` and `Ig_c` are sinusoidal currents with fundamental amplitude

$$\langle \hat{I}_g \rangle = \frac{V_{dc}}{2} \cdot \frac{M_{inv}}{\sqrt{R_g^2 + (2\pi f L)^2}} \ \ (\approx 5.8\,\mathrm{A}).$$

9. Decrease the DC supply voltage to $0\,\mathrm{V}$ and observe that the DC-link gets discharged (voltage `Vdc` should decrease to 0).
10. Deactivate the inverter by setting `activate_inverter` to 0 and by disabling the PWM pulses with the switch in Cockpit.

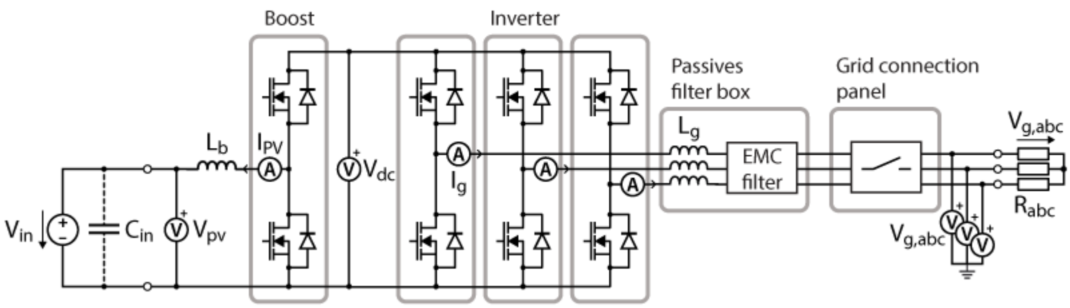
The screenshot below shows how the workspace could look in the end, while running the test procedure.



Running the test 1 using Cockpit

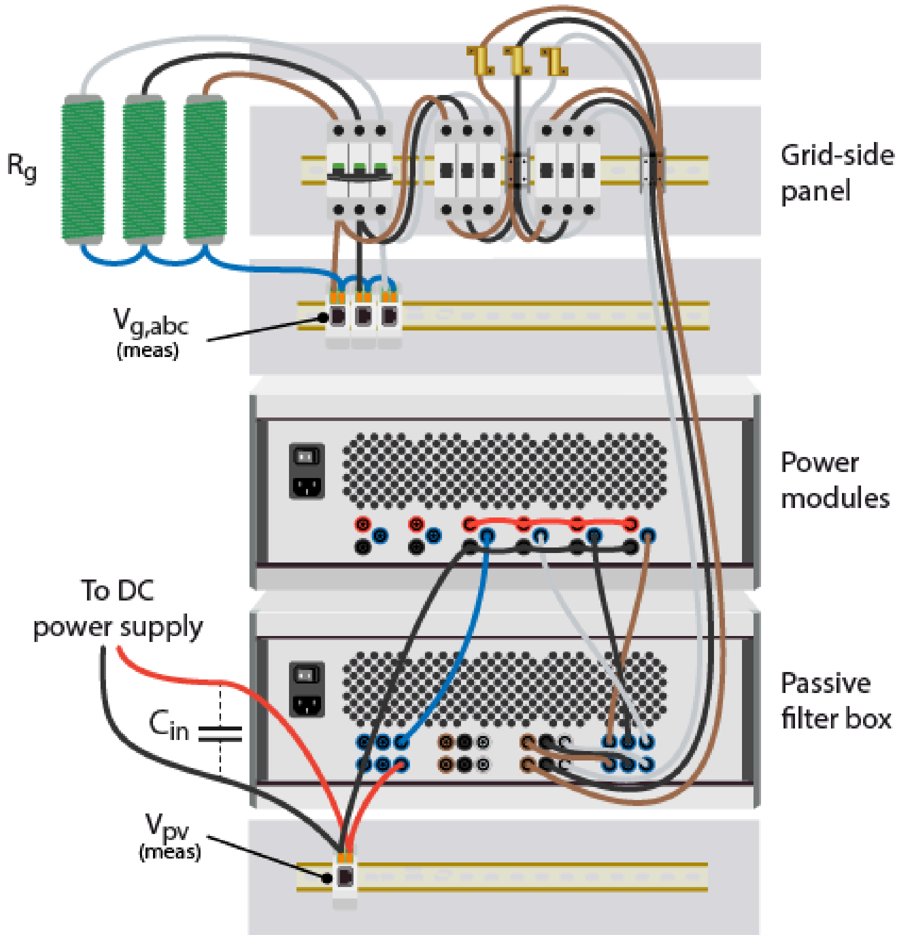
Test 2: Include the boost stage

In order to test the whole 3-phase solar inverter, the boost stage must be operated as well. To do so, the DC power supply should be connected to the PV terminals, as in the figure below. At the grid side, the three resistors must be kept in star connection.



Schematic of the setup for test 2: A DC power supply is connected to the PV terminal and a resistive load is connected in star at the grid terminal.

If a DC power supply with low output capacitance is used, it might be unable to regulate its output voltage to the desired value. To avoid this issue, an additional capacitor of some 100µF can be connected in parallel (see C_{in} in the figures below). Make sure the input voltage does not exceed the ratings of the capacitor and observe the polarity if the capacitor is polarized (positive and negative terminals).



Converter wiring for test 2: A DC power supply is connected to the PV terminal and a resistive load is connected in star at the grid terminal

Dimensioning of the load resistors

The resistors must be properly dimensioned to prevent them from overheating. To do so, the expected RMS current through a resistor must not exceed its maximum rated current. The details on the computations are given hereafter. Note that the dimensioning is identical to test 1, provided the DC supply voltage is chosen twice as low (100V) and the duty-cycle of the boost stage is chosen as 0.5.

The theoretical RMS current can be computed as

$$I_{g,rms} = \frac{\sqrt{2} \cdot V_{in} \cdot M_{inv}}{4 \cdot (1 - d_{boost}) \cdot \sqrt{R_g^2 + (2\pi f L)^2}}$$

where V_{in} is the DC supply voltage, M_{inv} the modulation index of the inverter (tunable parameter `M_inv`), d_{boost} the duty-cycle of the boost stage (tunable parameter `d_boost`), R_g the resistance of the load, $f = 50\,\mathrm{Hz}$ the AC frequency (hard-coded in the Simulink model) and $L = 2.2\,\mathrm{mH}$ is the equivalent inductance of the passive filter box.
In this guide, R_g is chosen as $8.5\,\Omega$, $M_{inv} = 0.5$, $d_{boost} = 0.5$ and $V_{in} = 100\,\mathrm{V}$. This results, as in test 1, in an RMS current of $4\,\mathrm{A}$ through the resistors, which is within the rated current of the selected resistors ($13.5\,\mathrm{A}$).

If the rating of the resistor is exceeded, the DC supply voltage, the duty-cycle of the boost stage and/or the modulation index of the inverter can be reduced accordingly.

Loading the code and setting up the workspace in Cockpit

- In Simulink:
    1. Open the Simulink model and set the mode to *Automated Code Generation* in the *CONFIG* block.
    2. Build the model (Ctrl + B). It will automatically launch Cockpit.
- Or in PLECS:
    1. Open the PLECS model.
    2. Open the coder options (Ctrl + Alt + B) and click *Build* in the bottom right. It will automatically launch Cockpit.
- In Cockpit:
    1. Set the target IP in Cockpit and click on *Create* to generate a new project.
    2. Add a new **rolling plot** module and drag-&-drop the variable `Vdc` and `Vpv` to monitor the DC voltages.
    3. Add a second **rolling plot** module and drag-&-drop the input current `Ipv`.
    4. Add a new **scope** module. Click on the "+" icon on the bottom right of the scope to add a second plot to the scope. Drag-&-drop the grid currents `Ig_a`, `Ig_b` and `Ig_c` to the upper plot and the grid voltages `Vg_a`, `Vg_b` and `Vg_c` to the lower plot.

Step-by-step test procedure

Since the boost converter will be operated in open-loop, no active control of the DC link voltage `Vdc` and the input current `Ipv` is implemented. Therefore, carefully follow the instructions below to prevent uncontrolled transients from triggering an over-current fault.

1. Manually close the circuit breaker on the grid connection panel.
2. To let power flow, close the relays of the grid connection panel by setting the variables `precharge_relay` and `bypass_relay` to 1 in Cockpit.
3. Set the inverter modulation index `M_inv` to the value selected for the dimensioning of the load resistors (e.g. leave as 0.5 in the case of the present example).
4. Set the boost duty-cycle `d_boost` to the value selected for the dimensioning of the load resistors (e.g. leave as 0.5 in the case of the present example).
5. Make sure that the DC link voltage V_{dc} is **very close to** $0\,\mathrm{V}$.
6. The PWM pulses must be enabled in the inverter stage and in the boost stage. To do so, set the variables `activate_inverter` and `activate_boost` to 1 and toggle the PWM switch in the upper left corner in Cockpit.
7. **Slowly** increase the DC supply voltage to $200\,\mathrm{V}$ (or to the value chosen in the dimensioning of the resistors) and check in Cockpit that V_{PV} matches the voltage of the source.
8. Verify that the DC-link voltage V_{dc} has the expected value

$$V_{dc} = \frac{V_{in}}{1 - d_{boost}} \quad (\approx 200\,\mathrm{V}).$$

9. Verify that the AC phase-to-neutral voltages `Vg_a`, `Vg_b` and `Vg_c` are sinusoidal voltages with fundamental amplitude

$$\langle \hat{V}_g \rangle = \frac{V_{dc}}{2} \cdot M_{inv} \;\; (\approx 50\,\mathrm{V}).$$

10. Verify that the AC currents `Ig_a`, `Ig_b` and `Ig_c` are sinusoidal currents with fundamental amplitude

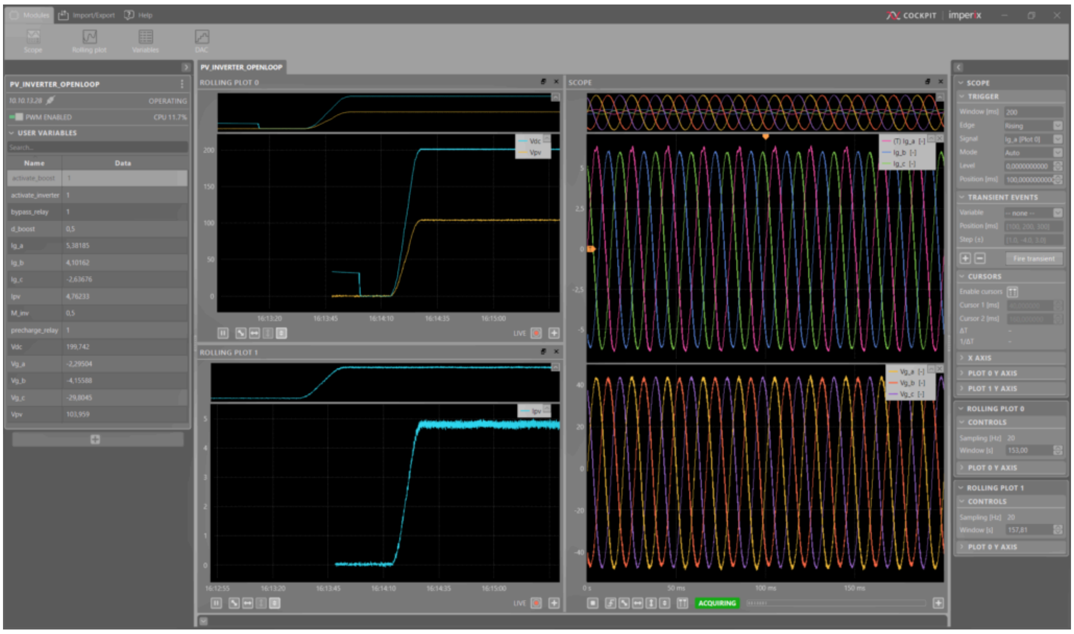
$$\langle \hat{I}_g \rangle = \frac{V_{dc}}{2} \cdot \frac{M_{inv}}{\sqrt{R_g^2 + (2\pi f L)^2}} \;\; (\approx 5.8\,\mathrm{A}).$$

11. Verify that the averaged measured input current `Ipv` corresponds to the expected value

$$\overline{I_{pv}} = \frac{3 \cdot R_g \cdot \langle \hat{I}_g \rangle^2}{2 \cdot V_{in}} \;\; (\approx 4.4\,\mathrm{A}).$$

   Note that the measured value might be slightly higher than the theoretical value, due to the simplifications made in the computation (higher harmonics and losses disregarded).
12. Deactivate the boost stage by setting `activate_boost` to 0 and observe that `Vdc` decreases until reaching the voltage of the DC supply.
13. Decrease the DC supply voltage to $0\,\mathrm{V}$ and observe that the DC-link gets discharged (voltage `Vdc` should decrease to 0).
14. Deactivate the inverter by setting `activate_inverter` to 0.

The screenshot below shows how the workspace could look in the end, while running the test procedure.



Running the test 2 using Cockpit

Testing of the other power modules

In case it is desired to test all power modules (i.e. not only the first four ones), the above-presented tests should be repeated by shifting the inverter and boost phases (e.g. inverter phases in bays 2-4 and boost in bay 5). In this case, the wiring of the control stage (front of the cabinet) and the power stage (back of the cabinet) must be modified accordingly. Additionally, the channel mapping of the ADC inputs and PWM outputs in Simulink or PLECS must be adapted.

To go further…

With the basic functionality of the equipment tested, one could dive deeper into the control strategy for the 3-phase solar inverter, including its connection to the grid: Three-phase PV inverter for grid-tied applications.