UM1016
User manual

Getting started with the STEVAL-ISV002V2, 3000 W photovoltaic converter for grid connected applications

Introduction

This document describes the procedure and steps to follow in order to correctly operate the 3 kW STEVAL-ISV002V2 photovoltaic converter. This system consists of an isolated DC-DC converter and a full bridge inverter used to deliver sinusoidal current at 50 Hz to the grid. The system operates with input voltages in the range of 200 V to 400 V and is tied to the grid at 230 Vrms, 50 Hz, through an LCL filter. The demonstration board is provided with a fully digital control algorithm, including power management for grid-connected operation and MPPT (maximum power point tracking) algorithm. This has been implemented on a dedicated control board, equipped with the latest generation 32 bit STM32F103ZE microcontroller.

Figure 1. 3 kW PV system image

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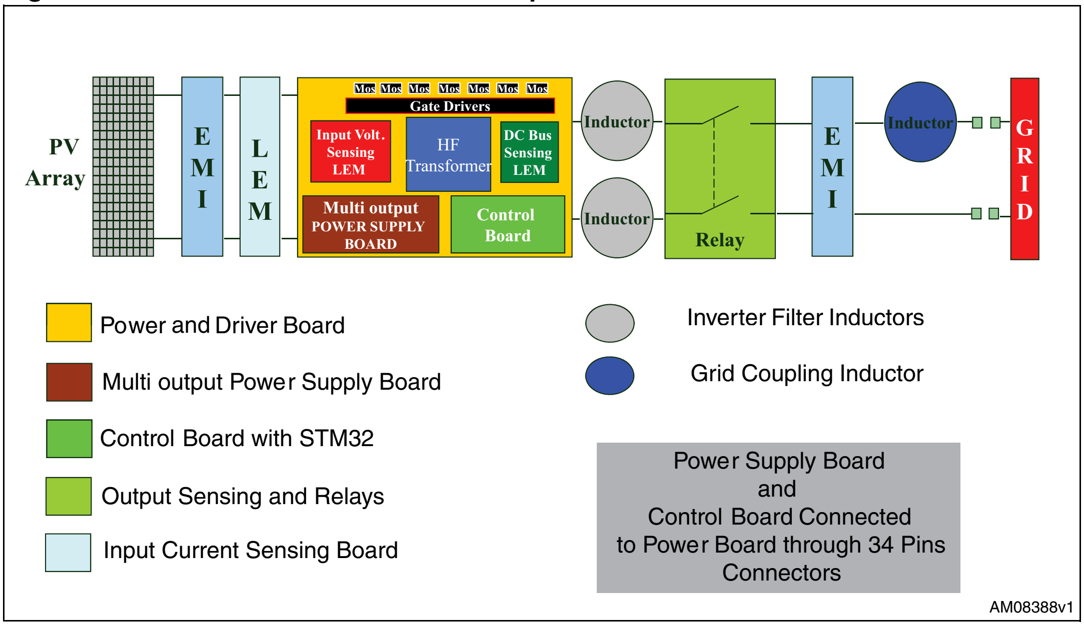
1 System description

Figure 2 is a block scheme representing the hardware implementation adopted for the STEVAL-ISV002V2 demonstration board.

Figure 2. Block scheme of hardware implementation



It consists of 5 PCBs electrically connected by means of suitable connectors. The 5 PCBs are listed below and are hereafter referred to with the following nomenclature:

- Main power board
- Multi-output power supply board
- Control and signal conditioning board
- Output sensing and relay board
- Input current sensing board

The system can be completed by adding two additional boards with input and output EMI filters which, at the moment, are not included in the final prototype, even though they are shown in the block scheme of *Figure 2*.

The main power board consists of the DC-DC converter, supplied by the PV array, and a sinusoidal PWM full bridge inverter realizing grid connection at 230 Vrms and 50 Hz. Gate driving circuitry, input and output voltage sensors of the DC-DC converter and the high frequency (HF) transformer are also placed on the main power board. The multi-output power supply board and the control board are connected to the main power board by means of 34-pin connectors. The connection/disconnection of these PCBs is very easy. This type of connection was chosen to allow separate debug and characterization of each board, independently from the others.

The output sensing and relays board realizes the interface between the power system and the grid. This task is accomplished with the implementation of a proper control algorithm which requires both grid current and grid voltage sensing. For this reason, the system is equipped with current and voltage Hall effect sensors. Two relays, controlled by an I/O of the

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microcontroller, are also placed on the same PCB to interrupt/connect phase and neutral of the system to phase and neutral of the grid. Moreover, this board is provided with 2-way connectors for electrical wiring of the LCL filter to the main power board.

The multi-output power supply board implements two independent offline flyback converters, with a wide input voltage range, based on VIPer™ technology, to generate the following output voltages:

- +5 V to supply DC-DC converter gate drivers
- +5 V to supply DC-AC converter gate drivers
- +5 V to supply the microcontroller
- +/-15 V for LEM sensor supply
- 24 V for relay supply

Figure 3. Description of the STEVAL-ISV002V2 main parts

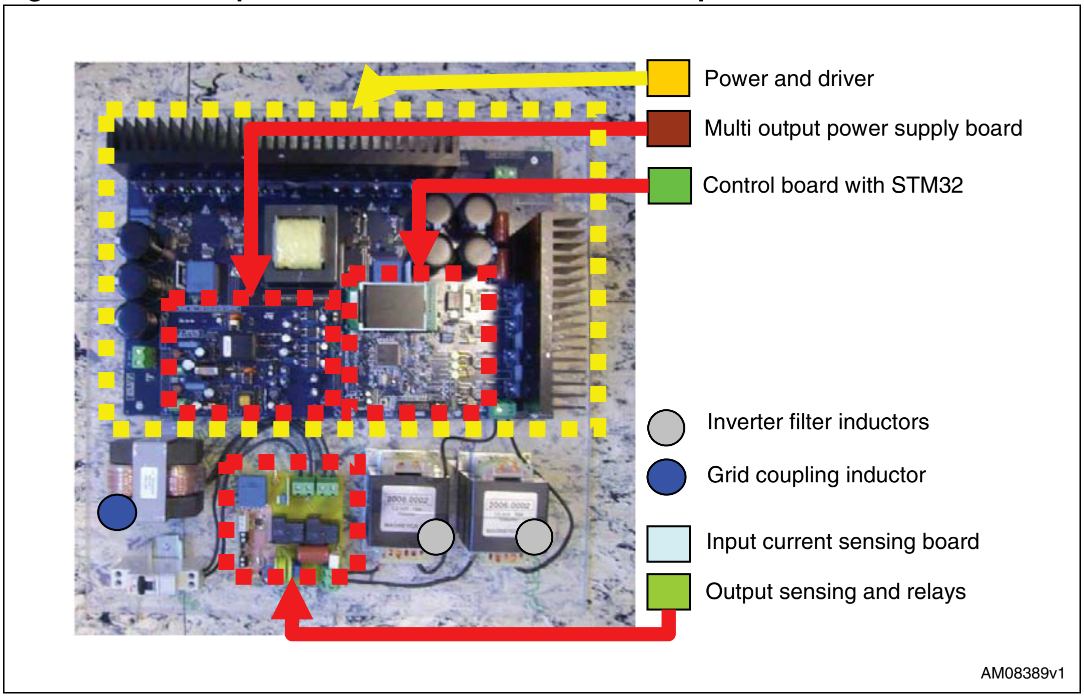

Figure 3 shows a more detailed description of the hardware implementation according to the nomenclature used above.

The main power board is highlighted in yellow and clearly shows the way it hosts two ancillary boards: the multi-output power supply board and the control board with STM32F103ZE. They are both highlighted in red in *Figure 3*. Also the output sensing and relay board is highlighted in red and placed near the two filter inductors highlighted with a grey circle and the coupling inductor highlighted by a blue circle. The coupling inductor is also connected in series with a circuit breaker providing fault protection.

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Figure 4. Coupling inductors wiring

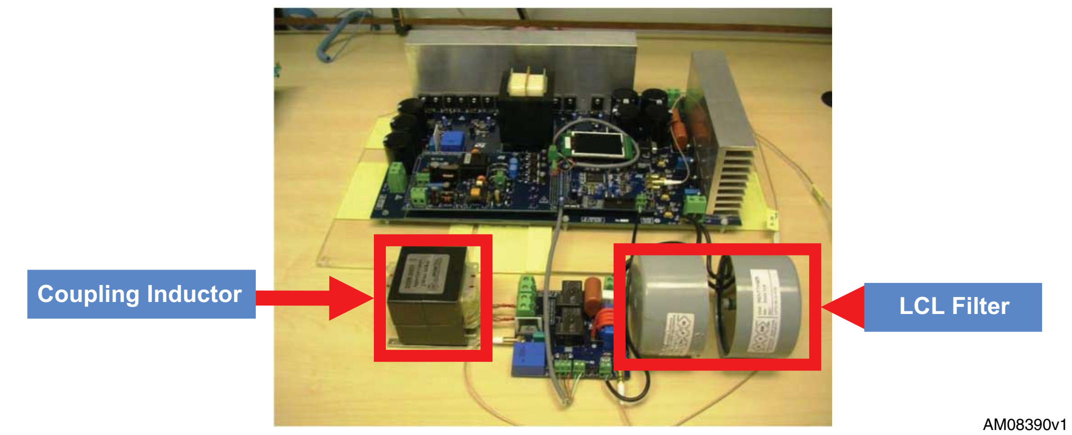
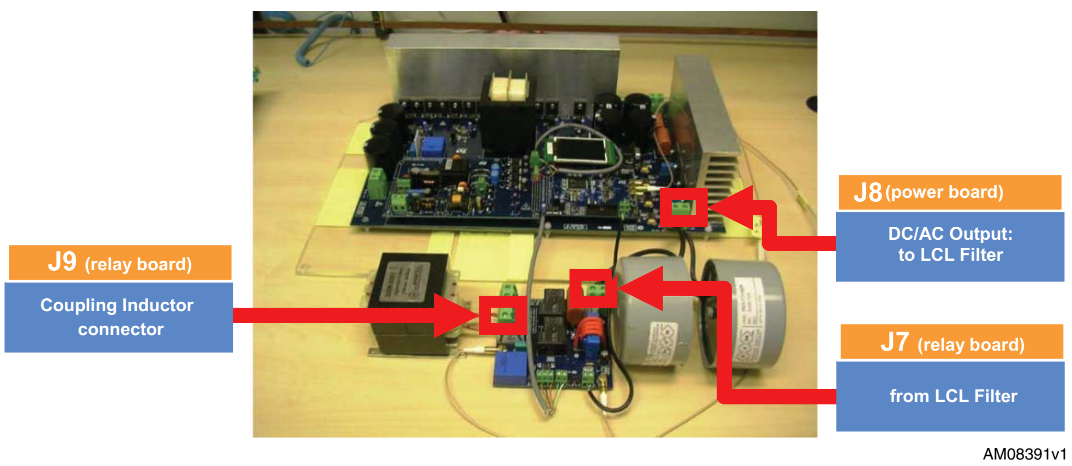


Figure 4 shows how the filter and coupling inductors are actually wired, between the middle point of each leg of the full bridge inverter and the output relay and sensing board.

Figure 5. Connectors used to wire the filter inductors and coupling reactor



In *Figure 5* the three 2-way screw terminal connectors are highlighted. The filter inductors are connected to J8, placed on the main power board and to J7 which is placed in the output sensing and relay board. The coupling reactor is also connected to the output sensing and relays board through J9. It is important to underline that while the filter inductors have the two wires connected between J7 and J8, both the wires of the coupling inductor are connected to J9.

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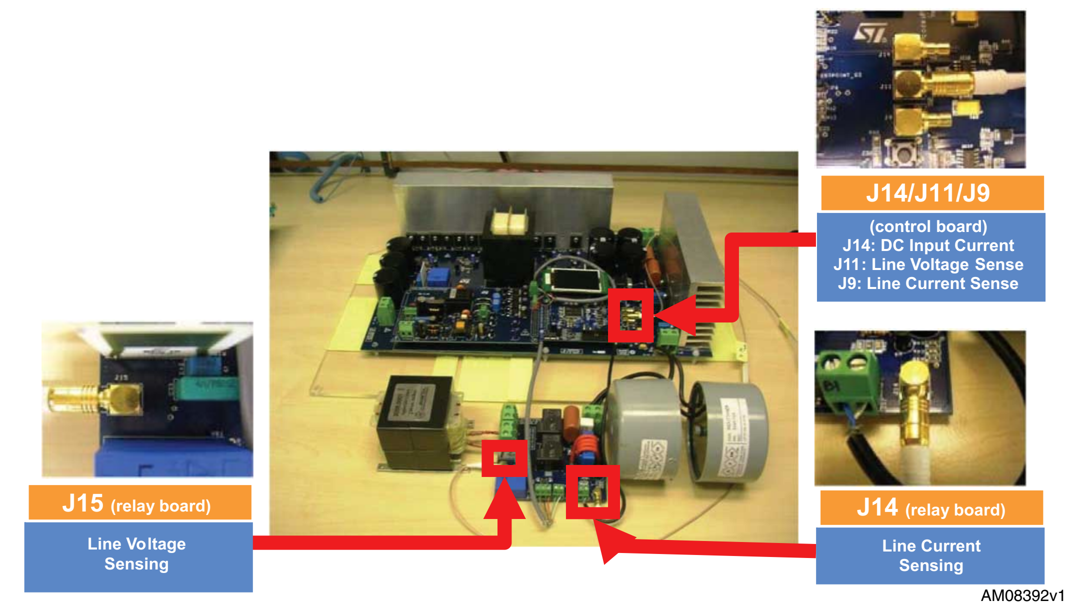
Figure 6. Connectors used for the sensing signals



- Connect J15 (relay board) with J11 (control board)
- Connect J14 (relay board) with J9 (control board)
- Connect J14 (relay board) with DC input current sensor

The microcontroller board and the output sensing and relay board are also equipped with mini BNC connectors. These connectors are used to carry the current and voltage measuring signals by means of shielded wires, running from the sensing device to the microcontroller board, where they are then conditioned and properly filtered to be acquired through the ADCs. In particular, on the microcontroller board, J14 is used to connect the wire carrying the signal proportional to the input DC current. The second terminal of this wire is connected on the input current sensing board. The wire carrying the signal proportional to the line voltage is connected to J11 at one end, on the microcontroller board and, on the other end, to J15 which is placed on the output sensing and relay board. The wire carrying the signal proportional to the grid injected current is connected to J9, placed on the microcontroller board, and to J14 which is soldered on the sensing and relay board.

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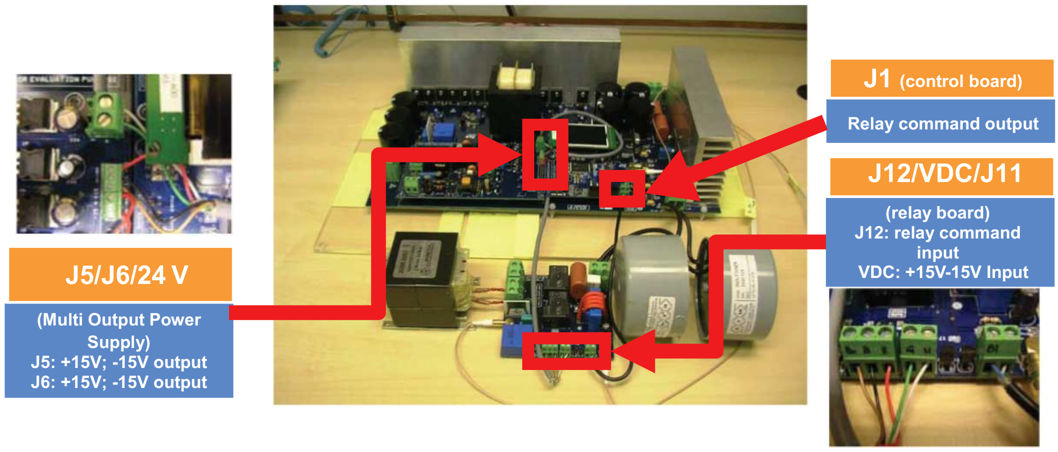
Figure 7. Connectors used for power supply and relay command



- Connect J6 (multi-output power supply board) to VDC (relay board)
- Connect 24 V (multi-output power supply board) to J11 (relay board)
- Connect J1 (control board) to J12 (relay board)

The output sensing and relay board is also equipped with additional screw connectors used for the power supply cables and also the signal provided by the microcontroller to command the operation of the relay. The voltage sensor needs a +/-15 V supply voltage which is provided by means of a multi-wire cable running from J5 on the power supply board to the 3-way screw terminal connector, called VDC, on the output sensing board. The +15 V is also used to obtain the +5 V supplying the Hall effect current sensor.

The relay coil is supplied with 24 V provided by the multi-output flyback of the power supply board and running on a multi-core shielded wire connected between the 24 V connector of the power supply board and J11 on the output sensing board. The relay command cable is connected between J1 and J12, placed on the microcontroller board and output sensing board respectively.

Figure 8 shows a close-up of the output sensing board and provides clear instructions on how to correctly carry out the wiring of this part of the system.

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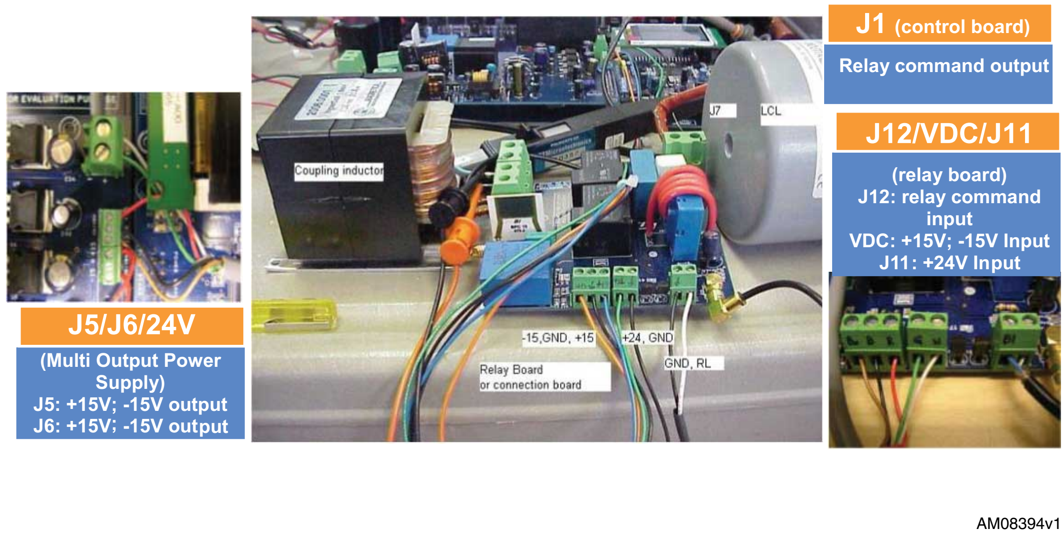
Figure 8. Wiring setup of the output sensing and relay board

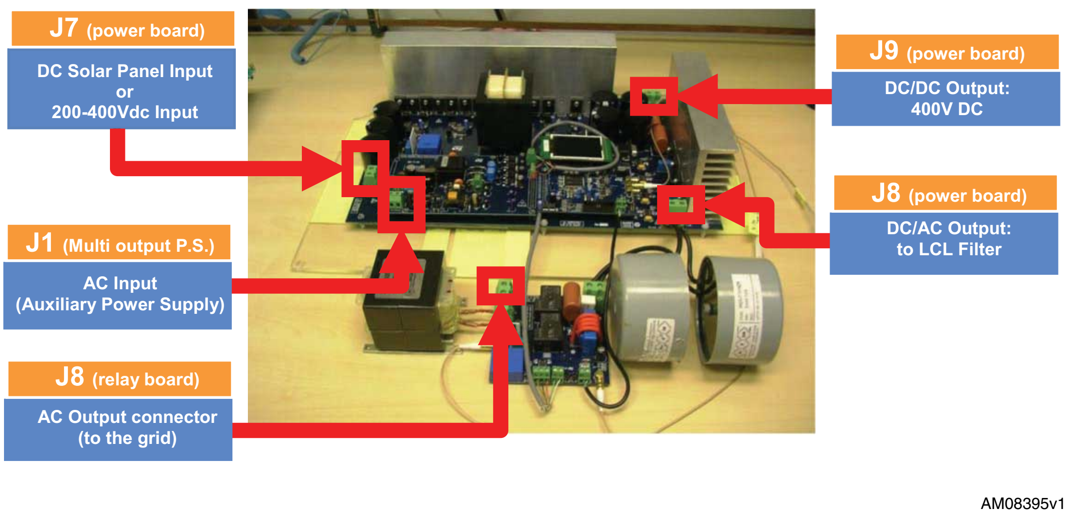


- Connect J6 (multi-output power supply board) to VDC (relay board)
- Connect 24 V (multi-output power supply board) to J11 (relay board)
- Connect J1 (control board) to J12 (relay board)

Open loop operation

The control firmware can operate either in open loop or closed loop mode. The open loop mode of operation has been included to allow debugging and component evaluation when the system is not connected to the grid and therefore delivering power to a suitable external load. The open loop function and hardware configuration allows also to independently test both the DC-DC converter and the DC-AC converter. In this case, connector J9 shown in *Figure 9*, can be used to either connect an electrical load when testing the DC-DC converter or to connect a DC power supply when testing the DC-AC inverter.

Figure 9. Input and output power connectors



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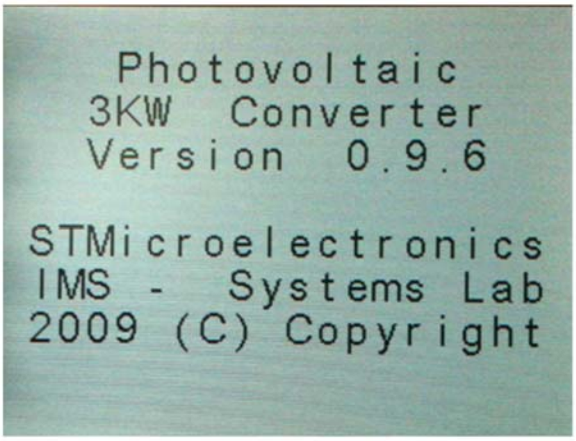
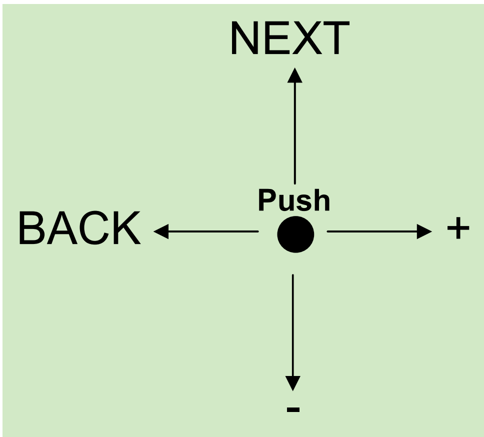
After having connected the AC voltage to connector J1, the LCD display on the control board lights up and shows the screen shot in *Figure 10*, indicating the firmware version:

Figure 10. First screen shot shown on the LCD display at startup



The control board is equipped with a miniature joystick that can be used to scroll the menu for functions included in the firmware. The joystick has five commands as detailed in *Figure 11*:

Figure 11. Description of the joystick commands



The test procedure detailed below can be followed in order to test the system with the open loop control firmware:

1. Connect a suitable electrical load to connector J7. Keep the filter inductors wire connected on J7 as well.
2. Move the joystick up to select the next window on the LCD display. The screen shot of *Figure 12* appears.

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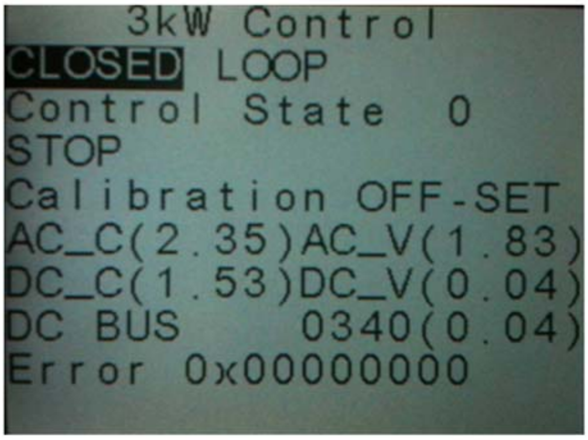
Figure 12. Closed loop/open loop selection window



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The closed loop operation is highlighted in the second string of characters. To switch to open loop operation mode, move the joystick right and the display shows the screen shot of *Figure 13*, with the open loop selection option highlighted and control state in stop.

Figure 13. Open loop screen shot with control state in Off

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3. Connect a DC power supply and set the input voltage. The input voltage value in open loop operation can be set arbitrarily, making sure not to exceed the allowed maximum input voltage. Please note that no protections are enabled and no regulation of input or output voltages and currents is active.
4. Push the joystick to enable the control loop modulation. The display shows the screen shot in *Figure 14*, indicating that the control loop state is in start.

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Figure 14. **Screen shot with control loop state in start**

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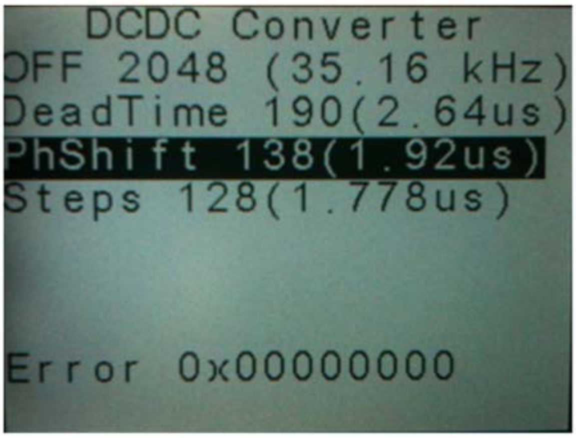
5. Increase the phase shift control value by moving the joystick up until the string window DC-DC converter appears on the LCD display. Continue moving the joystick up until the string "PhShift" is highlighted. The screen shot in *Figure 15* appears.

Figure 15. **DC-DC converter control window**



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6. Move the joystick right to increase the phase shift. The incremental step is highlighted in the last string of characters (1.778 us in *Figure 5*) and can be modified. The power output increases proportionally to the phase shift.
7. The amount of power delivered to the electrical load depends also on the value of the inverter modulation index. The default value is very low and is shown in *Figure 16*.

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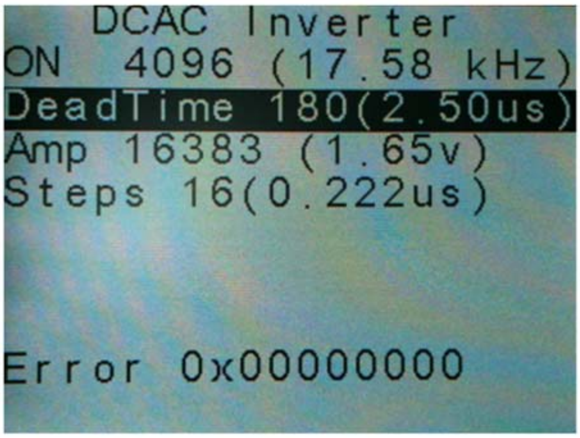
Figure 16. DC-AC converter control window



The modulation index can be modified by selecting the string “Amp” and moving the joystick right until the “Amp” parameter is modified to the desired value.

For open loop operation it is suggested to set an “Amp” value equal to 2.5 V and vary the output power by acting only on the DC-DC converter phase shift parameter.

8. To stop delivering power to the electrical load during open loop operation it is convenient to turn off the DC supply and leave the modulation enabled in order to ensure that all the power capacitors are discharged on the electrical load.

Closed loop operation

The closed loop operation allows to connect the system to the grid and to start current injection at 230 V and 50 Hz.

Before realizing the first grid connection it is advised to follow the procedure below. This procedure allows to check, in a safe way, for any potential problems that might affect the demonstration board, without the risk of seriously damaging it. The procedure may be summarized as follows:

- Disconnect the coupling inductor at J9 on the relay board
- Do not connect the DC input to J7 on the power board
- Connect J1 on the power supply board to 230 V AC and power the system up
- Reset the microcontroller firmware and make sure the screen shot shown on the display is the one in *Figure 17*: Closed Loop - Control State 0-stop.

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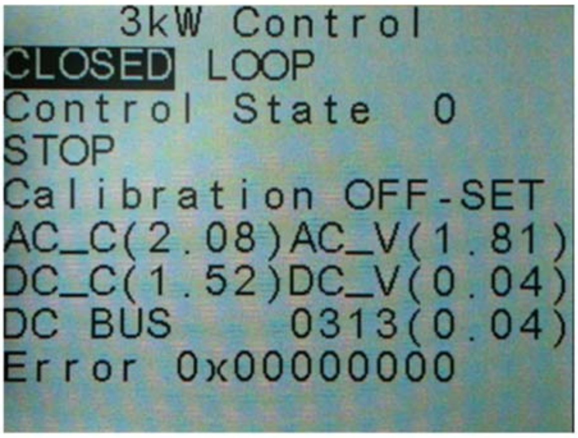
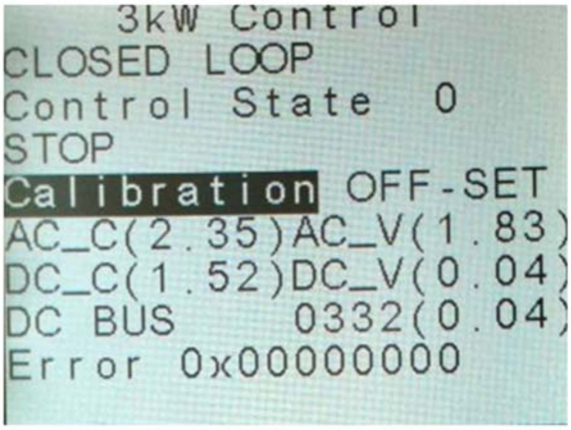
Figure 17. LCD display screen shot after microcontroller reset



- Connect J8 (relay board) to the grid and switch the grid breaker on
- Run the calibration function, navigating the display (*Figure 18*) and pushing the joystick button

Figure 18. Calibration function



- Verify that the AC current (AC_C) offset value is between 2.3 and 2.5 V and the AC voltage offset value (AC_V) is between 1.8 V and 1.9 V
- Navigate the display to again enter the closed loop string
- Set the DC input voltage to 170 V (with the output disabled) and connect it to J7 on the power board. Do not enable the DC source while setting the voltage value
- Enable the DC source
- Push the joystick button
- The LCD display shows that the firmware is now in start mode, as shown in *Figure 19*

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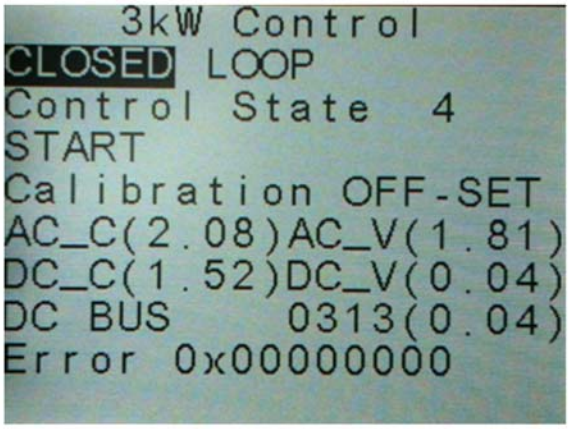
Figure 19. LCD display showing the closed loop control is in start mode



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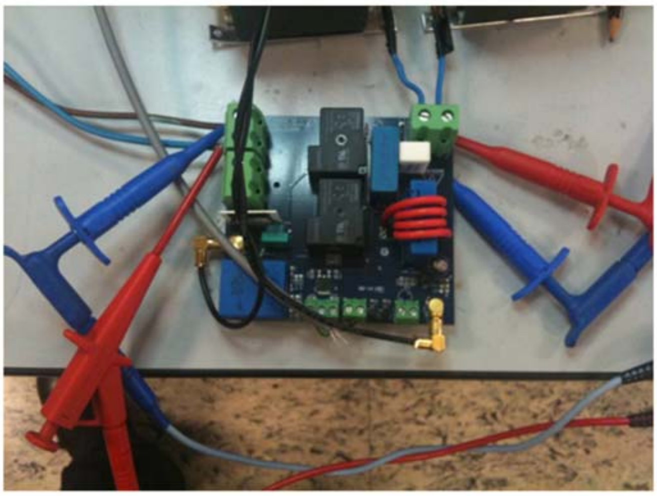
- The DC-DC section starts switching by entering the burst mode of operation to charge the DC intermediate bus up to 380-420 V (hysteresis band). It is suggested to monitor the DC bus voltage with a multimeter.
- Once the DC bus voltage is within the correct hysteresis band, the inverter modulation is enabled and the inverter sinusoidal output voltage is generated
- If two voltage probes are placed on the inverter output (*Figure 20*), across the capacitor of the LCL filter and on the grid connector, it is possible to see, on the scope, a sinusoidal voltage slightly lagging the grid voltage and having a higher peak value

Figure 20. Voltage probe placement to compare inverter generated voltage and gird voltage



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- If the grid voltage is in the proper range (190-265 Vac) then the connection relay is closed automatically. At this point the systems would be grid connected if the coupling inductor was not disconnected.
- The LCD display shows the screen shot in *Figure 21*, with the control state update from start to grid insertion

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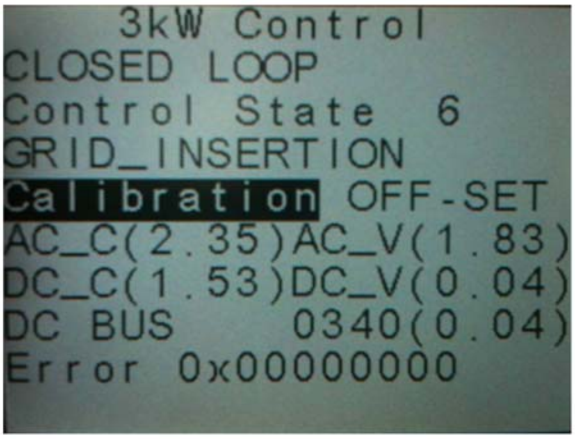
Figure 21. Control state “Grid Insertion”



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- After a few seconds the bus undervoltage protection triggers and the relay switches again to disconnect the system from the grid.

If the steps in this procedure are correctly performed, with the inverter generating a clean sinusoidal voltage waveform, the system is ready to be actually connected to the grid and current injected at 230 V and 50 Hz.

Current injection can be started by following the procedure below:

Closed loop with coupling inductor

- Disconnect all the cables previously connected to the grid
- Connect the coupling inductor to J9 on the relay board
- Connect the power supply board to the grid
- Reset the microcontroller
- Connect the power cable to the grid and switch on the circuit breaker
- Run the calibration function, navigating the display. When the calibration function is executed the display shows a grid current offset of about 2.5 V and a grid voltage offset of about 1.8 V. Do not start the closed loop operation if the offset values are not close to the values specified above.
- Navigate the display to the closed loop string
- Set the DC input voltage to 170 V (disabled) and connect it to J7 (power board)
- Enable the DC source
- Press start
- The DC-DC section starts switching, slowly charging (burst mode) the DC intermediate bus up to 380-420 V (it is suggested to monitor the DC bus voltage with a multimeter)
- Then the inverter section starts switching
- If the grid voltage is in the proper range (190-265 Vac) then the grid relay is closed automatically. At this point the system is grid connected.
- The system injects a few tens of Watts into the grid
- To increase the current injected into the grid you can either:
  – Increase the DC source voltage
  – Increase the phase shift value on the DC-DC converter control menu.

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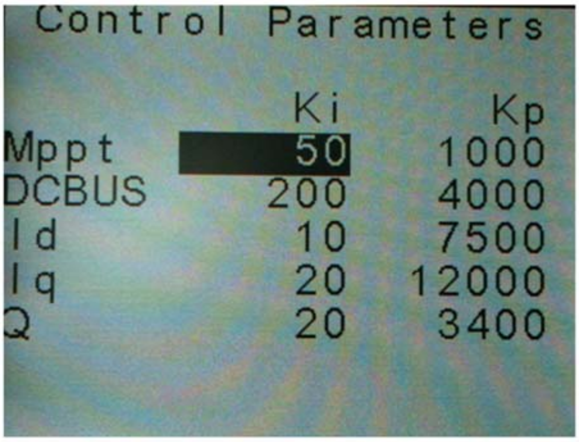
As the system has always been tested in a laboratory using a DC power source, the MPPT function is disabled in the 0.9.6 firmware version. The MPPT function is actually implemented, but it hasn't been tested on a solar array. This means that a PI fine tuning is required in order to allow the MPPT function to correctly operate.

Fine tune the current injected into the grid

The current THD and power factor strictly depend on the values of PI regulator parameters (Ki and Kp) and on the PI regulator parameters of the PLL.

- In order to improve the quality of the output current it is possible to fine tune all the control loop PI regulators by navigating the display menu (*Figure 21*). The PLL PI parameters can be modified only by acting on the firmware.

Figure 22. Control parameters tuning



- Always monitor the grid current waveform, THD, and power factor when attempting to modify any of these parameters
- Note that modifying any of these parameters can make the control loop unstable. If this happens the system might be damaged.
- It is strongly recommended to proceed with particular care

Shut down

- For system shutdown, lower the phase shift and DC input voltage to the startup values
- Verify that the injected power is a few tens of Watts
- Disconnect the grid and disable the DC input source
- Do not press reset as long as any voltage (except auxiliary voltages) on the power board is present.

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2 Revision history

Table 1. Document revision history

Date	Revision	Changes
09-Feb-2011	1	Initial release.

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