How to use the STDES-PFCBIDIR reference design

Introduction

The STDES-PFCBIDIR reference design represents a complete solution for high-power, three-phase active front end (AFE) rectifier applications based on the three-level T-Type topology.

This reference design topology is mostly used for DC fast charging applications related to industrial and electric vehicles.

It features full-digital control. The embedded STM32G474RET3 mixed-signal high-performance microcontroller provides the full control of the power factor (PF), the DC voltage, and the auxiliary task to manage the grid connection and the soft startup procedure.

The high-bandwidth continuous conduction mode (CCM) current regulation allows the maximum power quality in terms of total harmonic distortion (THD) and power factor (PF).

Figure 1. DC charging station

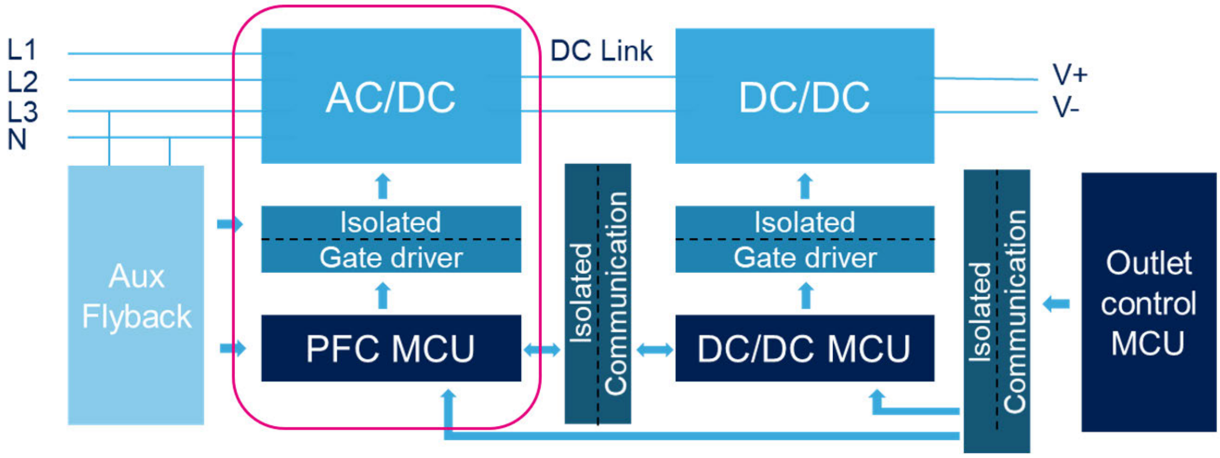
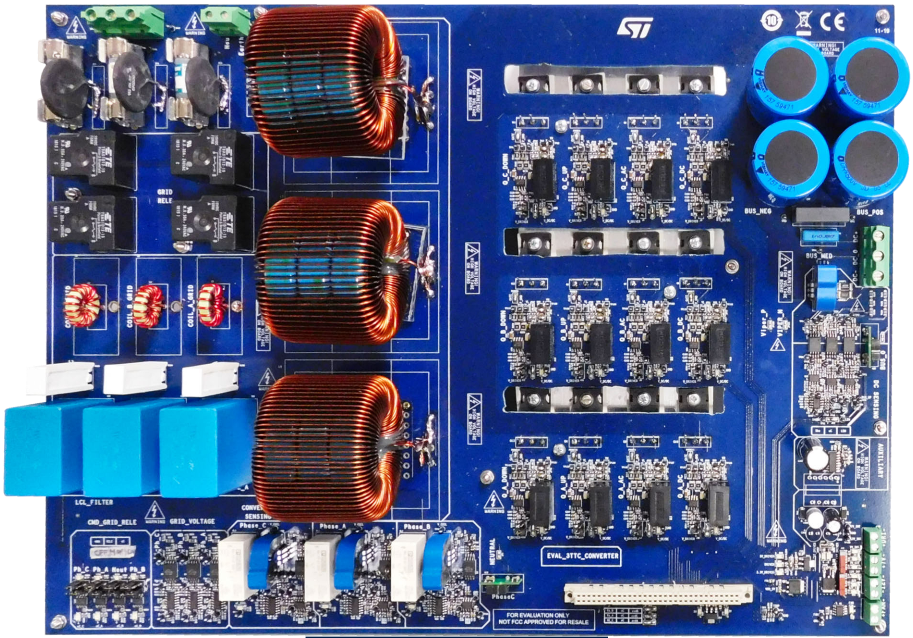
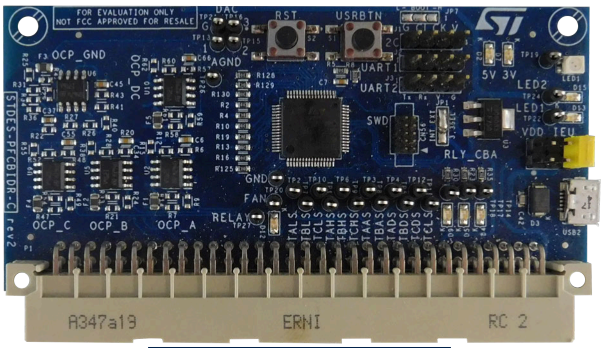


Figure 2. STDES-PFCBIDIR reference design - power board



Fully assembled board developed for performance evaluation only, not available for sale

Figure 3. STDES-PFCBIDIR reference design - control board



Fully assembled board developed for performance evaluation only, not available for sale

The high switching frequency of the SiC MOSFETs (70 kHz) and the multilevel structure allow an efficiency of almost 99% as well as the optimization of passive power components in terms of size and cost.

The high efficiency bidirectional rectifier is designed for several end applications such as electric vehicle (EV), industrial battery chargers, and industrial equipment, which requires a very high PF and low THD.

The STDES-PFCBIDIR is a fully assembled kit developed for performance evaluation only, not available for sale.

1 Getting started

1.1 Safety information

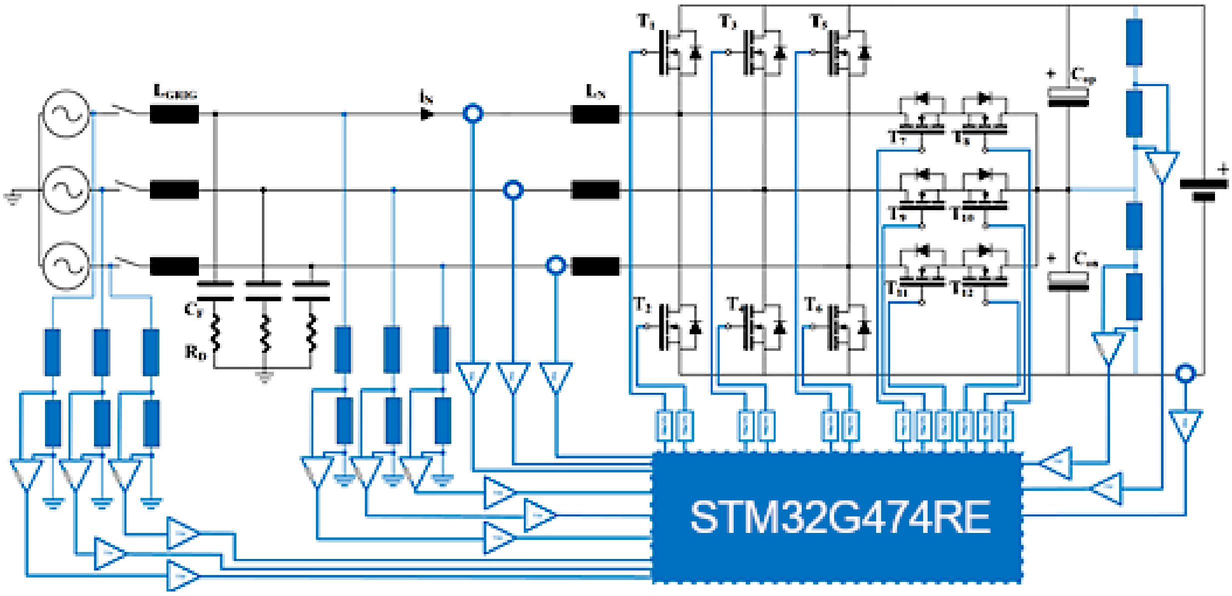
Caution: This reference design is intended for demonstration purposes only and is not for domestic or industrial installations.

Danger: *The high-voltage levels used to operate the reference design can cause serious injury, electrical shock, and even death.*

This reference design is intended for use by experienced power electronics professionals who understand the necessary precautions against potential dangers and risks while operating this board, even when it is not powered. The qualified personnel must be familiar with the installation, use, and maintenance of power electrical systems. During operation, do not touch the board as some of its components could reach a very high temperature.

1.2 Block diagram

Figure 4. **STDES-PFCBIDIR block diagram**



1.3 Features

- 3-phase, 3-level bidirectional AC-DC power converter:
  - Rated nominal DC voltage: 800 V_{DC}
  - Rated nominal AC voltage: 400 V_{AC} at 50 Hz
  - Nominal power: 15 kW
- AC to DC rectifier mode:
  - Power factor: PF >0.99
  - Inrush current control and soft startup
- DC to AC inverter mode:
  - Active and reactive power control
  - Integrated grid connection solution

- Power section based on SiC MOSFETs:
  - High frequency operation (100 kHz)
  - High efficiency: >98%
  - Passive element weight and size reduction
- Control section based on STM32G474RET3 microcontroller:
  - P2P compatible with other STDES 3-phase power converters
  - Four integrated high-performance op-amps
  - Control and monitoring interfaces: SWD, UART, I²C, DACs
  - 64-pin digital power connector
  - Overcurrent and overvoltage protection

1.4 Main characteristics

Table 1. Main characteristics

Description	Symbol	Min.	Typ.	Max.	Unit	Comments
Three-phase input voltage	V_{AC}	208		400	V_{ACLL}	
AC line frequency	Hz	47		63	Hz	
Maximum output power	P_{OUTmax}		15 7		kW	V_{AC} = 230 V_{RMS} I_{AC} = 21 V_{RMS} V_{AC} = 110 V_{RMS} I_{AC} = 21 V_{RMS}
Output voltage	V_{DC}		800		V	
Power factor	PF		>0.99		-	From 20% of load
Total harmonic distortion	THDi		<5		%	From 20% of load
Switching frequency	f_{sw}		70		kHz	

Table 2. Protection characteristics

Description	Symbol	Min.	Typ.	Max.	Unit
HVDC overvoltage protection	V_{DCovp}			900	V
HVCAP overvoltage protection	V_{CAPovp}			500	V
AC overcurrent protection	I_{ACovp}			30	A

1.5 Reference design description

1.5.1 Power board

The figure below shows the power board of the STDES-PFCBIDIR reference design.

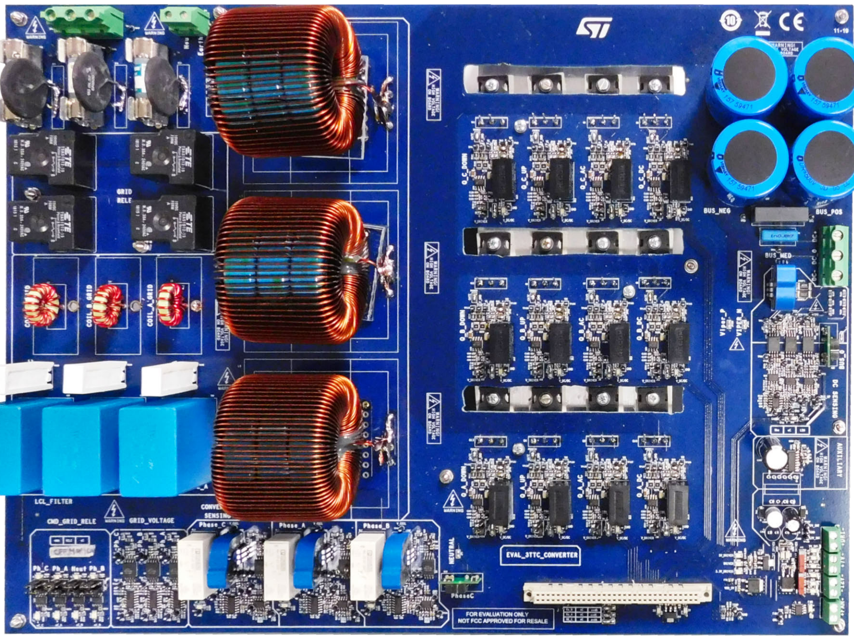


Figure 5. STDES-PFCBIDIR reference design - power board

The following figure shows the main sections of the power board.

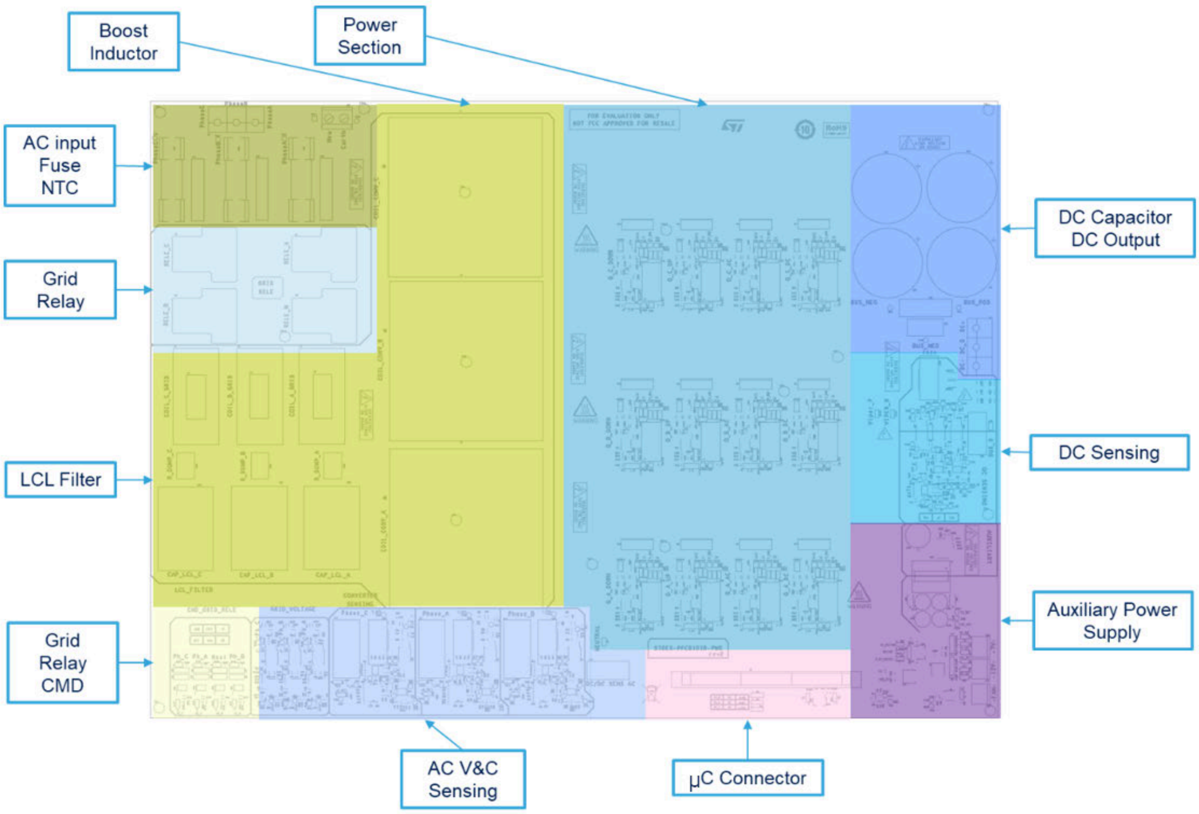


Figure 6. STDES-PFCBIDIR power board sections

1.5.2 Power stage

1.5.2.1 Boost inductor

Boost inductors are part of the LCL-R AC side filter. They allow obtaining the converter PFC operation by controlling the inductor current using a proper conduction pattern in the power device section.

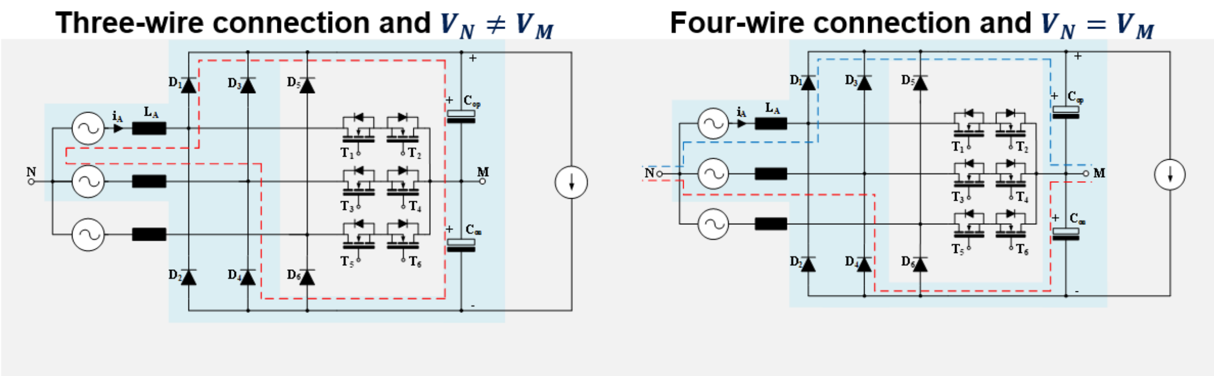
Continuous conduction mode (CCM) performs the PFC operation of this reference design. The inductance value is related to several parameters: the current ripple, the available converter voltage levels, the switching frequency, and the rated DC-AC operation voltages.

Table 3. Boost inductor parameters

Parameter	Symbol	Value
DC voltage (V)	V_0	800
Switching frequency (kHz)	fsw	70
Rated AC voltage (V_{RMS})	V_{AC}	230
Max. ripple current (%)	$\Delta_{iLppmax}$	10
Boost inductance (H)	L	470e-6

1.5.2.2 Inrush current limiter

Figure 7. Three and four-wire connections



$$V_{DC} = \sqrt{2} V_{AC_{rms}} \sqrt{3}$$

$$V_{DC} = \sqrt{2} V_{AC_{rms}} * 2$$

Figure 8. Passive NTC

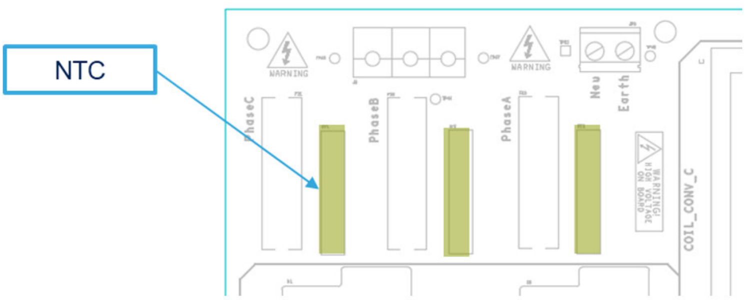


Figure 9. **STDES-PFCBIDIR NTC specifications**

Min. Resistance [Ω]	$R_{NTC_{min}} = \frac{\hat{V}_{AC}}{I_{max}}$	$e.g.\ \ R_{NTC} = \frac{\sqrt{2} \cdot 230}{60} = 5.42\ [\Omega]$
Steady State Current [A]	$I_{NTC_{SS}} = \frac{P_{OUT}}{V_{AC_{rms}}} \cdot \eta$	$e.g. I_{NTC_{SS}} = \frac{4k}{230} \cdot 98\% = 17\ [A]$
Maximum Energy [J]	$E_{NTC} = \frac{C\ \hat{V}_{AC}^{\ 2}}{2}$	$e.g.\ \ E_{NTC} = \frac{313\mu F\ (\sqrt{2} \cdot 230)^2}{2} = 16\ [A]$

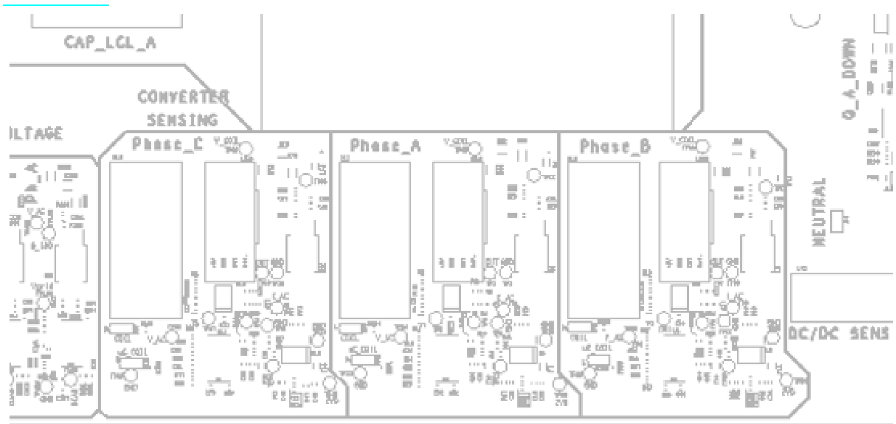


Figure 10. **Active relays**

1.5.2.3 Sensing

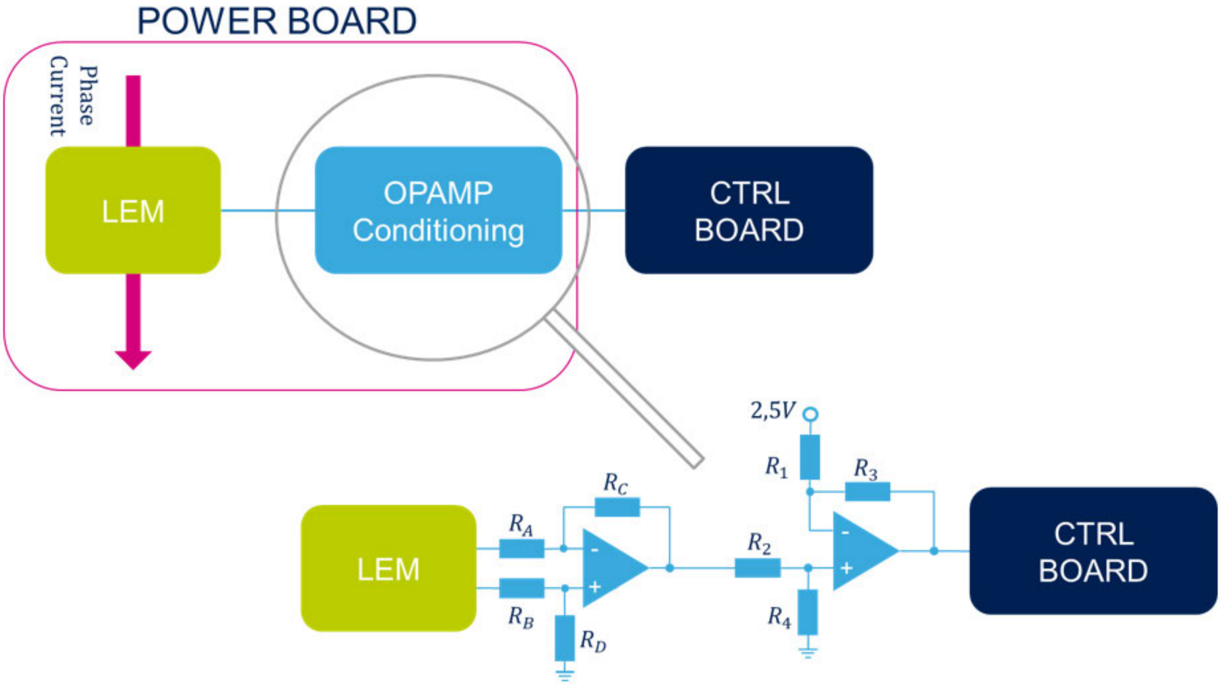
1.5.2.3.1 AC current

An isolated sensor measures the AC input current. It represents the boost inductor current to be controlled for the proper operation of the PFC behavior of the power converter.

The output voltage of the Hall effect transducer is not in scale and contains a DC component of 2.5 V with respect to the ADCs.

A conditioning circuit allows obtaining the correct value for the ADCs. The circuit shown below is replicated for each phase.

Figure 11. **AC current sensing block diagram**



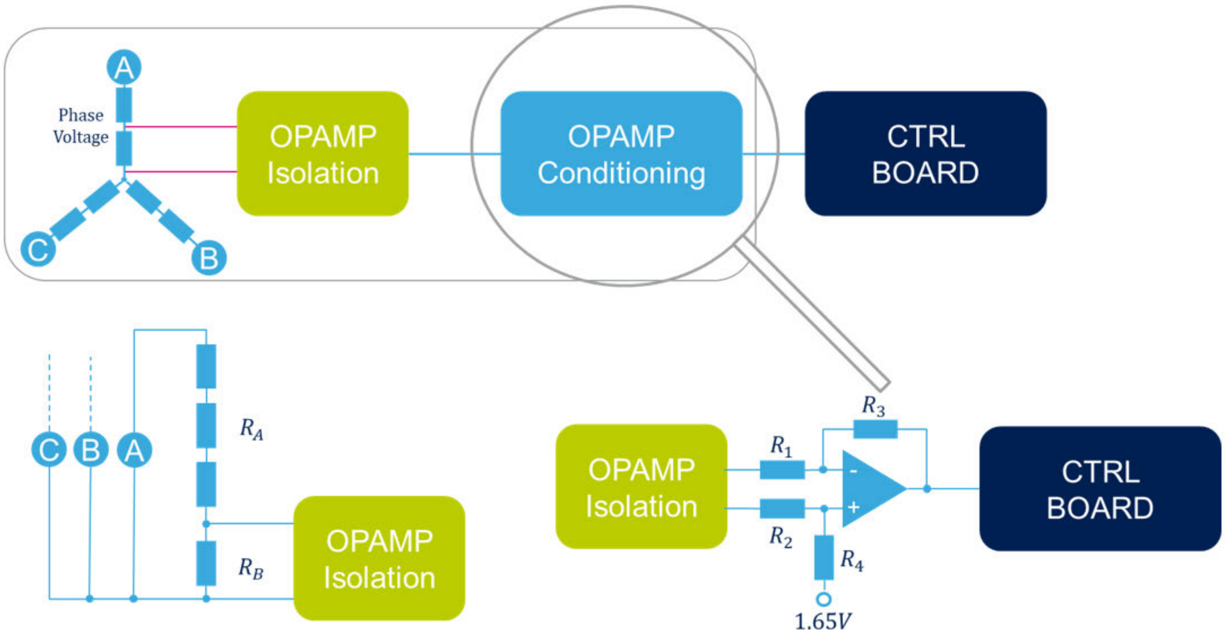
1.5.2.3.2 AC voltage

The three-phase AC voltages are obtained using a two-stage sensor circuit. The first part represents an isolated op-amp that allows measuring the HV through a voltage divider with an isolation barrier.

`Isol-Op-AMP` output is limited in volts and is scaled with a second stage of op-amps with a proper gain and bias.

This circuit allows measuring an AC voltage referenced by a virtual or grid neutral point. The circuit is replicated for each phase.

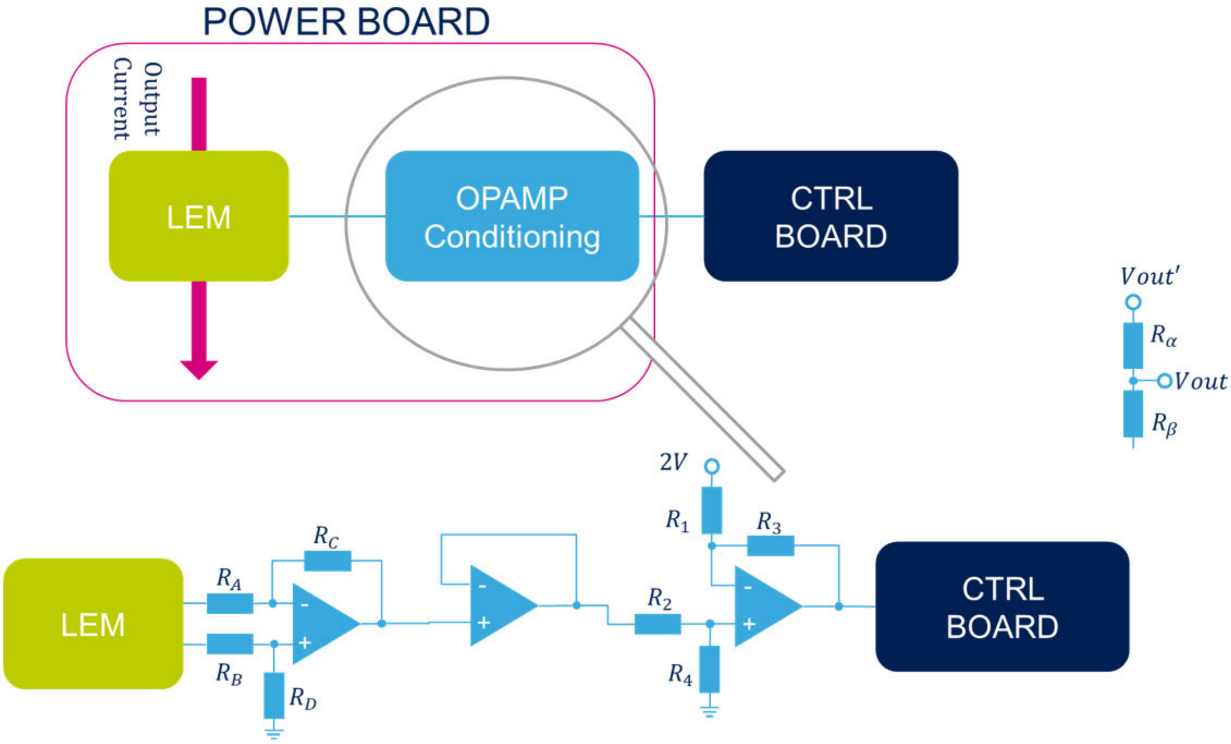
Figure 12. **AC voltage sensing block diagram**



1.5.2.3.3 DC current

An isolated sensor measures the DC output current. Hall sensors are taken into consideration. A conditioning circuit allows obtaining the correct value for the ADCs.

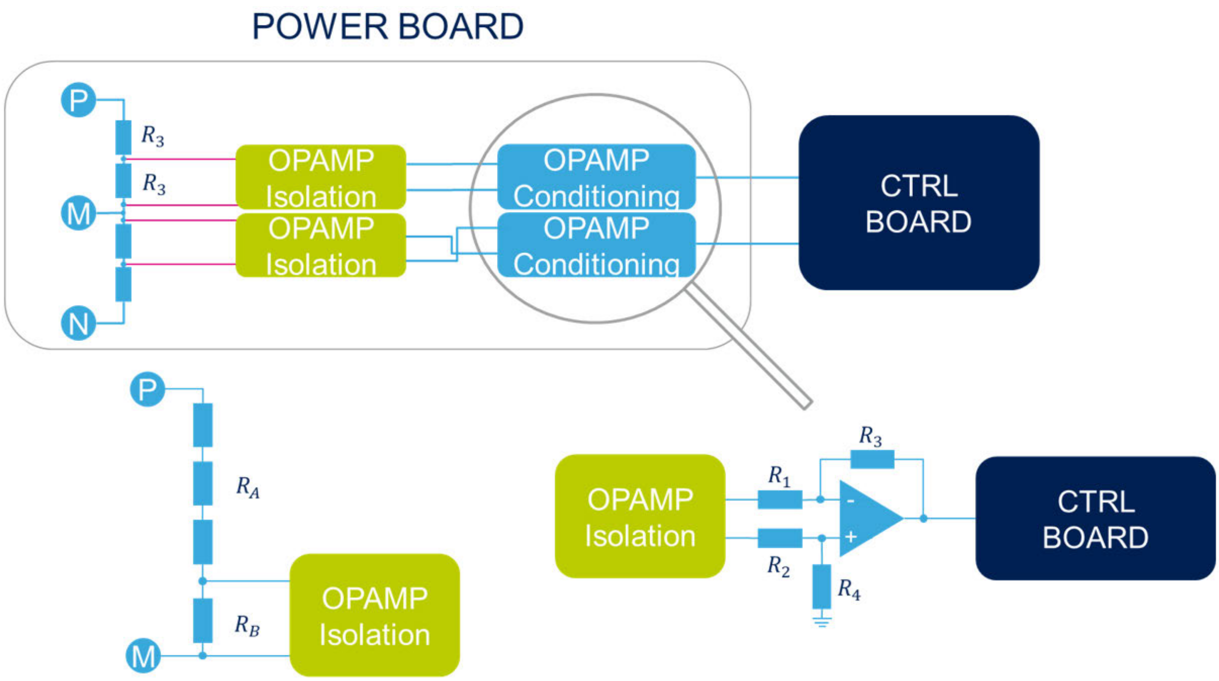
Figure 13. DC current sensing block diagram



1.5.2.3.4 DC voltage

The DC voltages are obtained using two-stage sensing. The total DC bus voltage is split exploiting two voltage dividers. Both voltages are needed to obtain the monitoring of each capacitor to avoid overvoltage, offering independent DC voltages for the control.

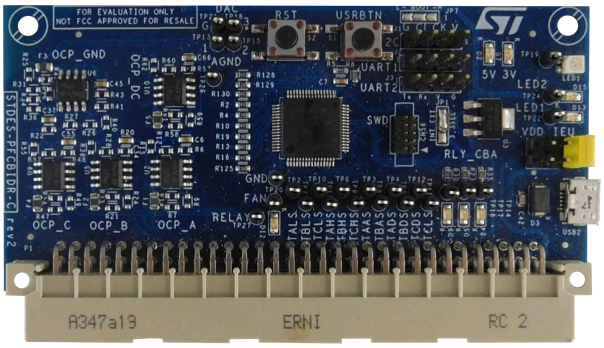
Figure 14. **DC voltage sensing block diagram**



1.5.3 Control board

The figure below shows the control board of the STDES-PFCBIDIR reference design.

Figure 15. **STDES-PFCBIDIR reference design - control board**



The following figure shows the main sections of the control board.

Figure 16. **STDES-PFCBIDIR control board sections**

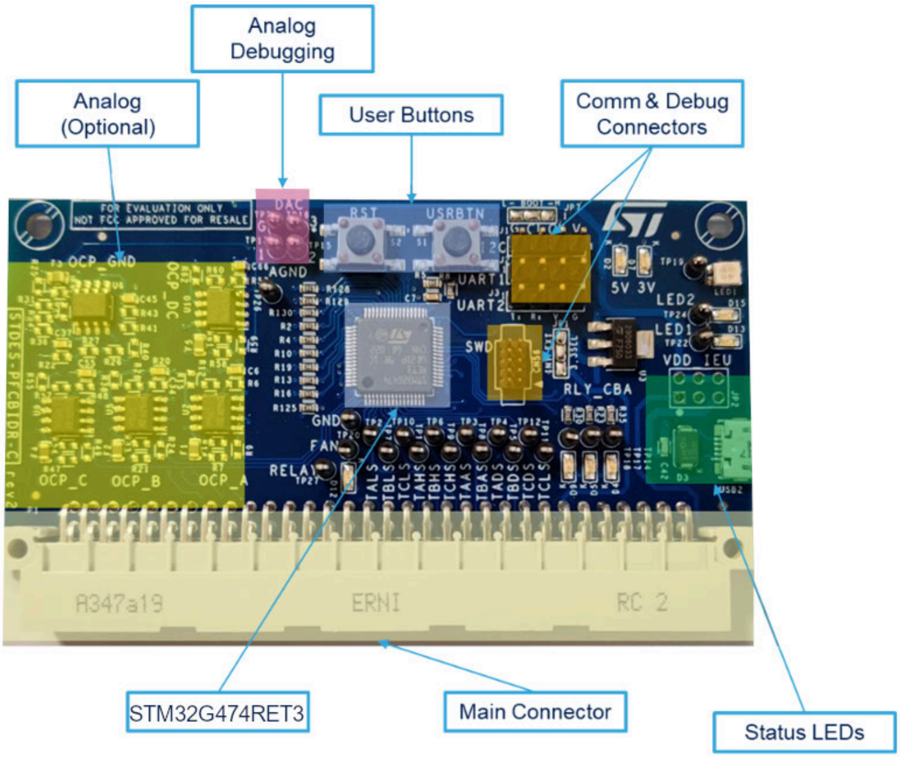
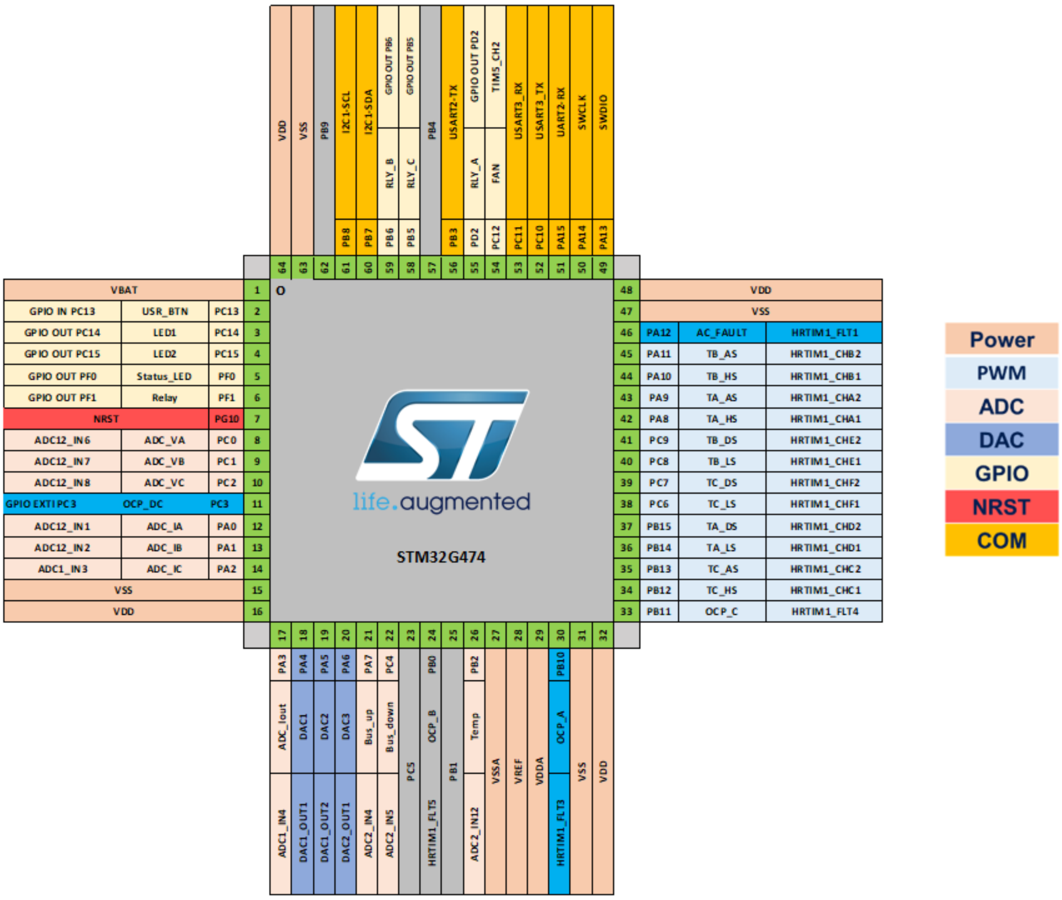


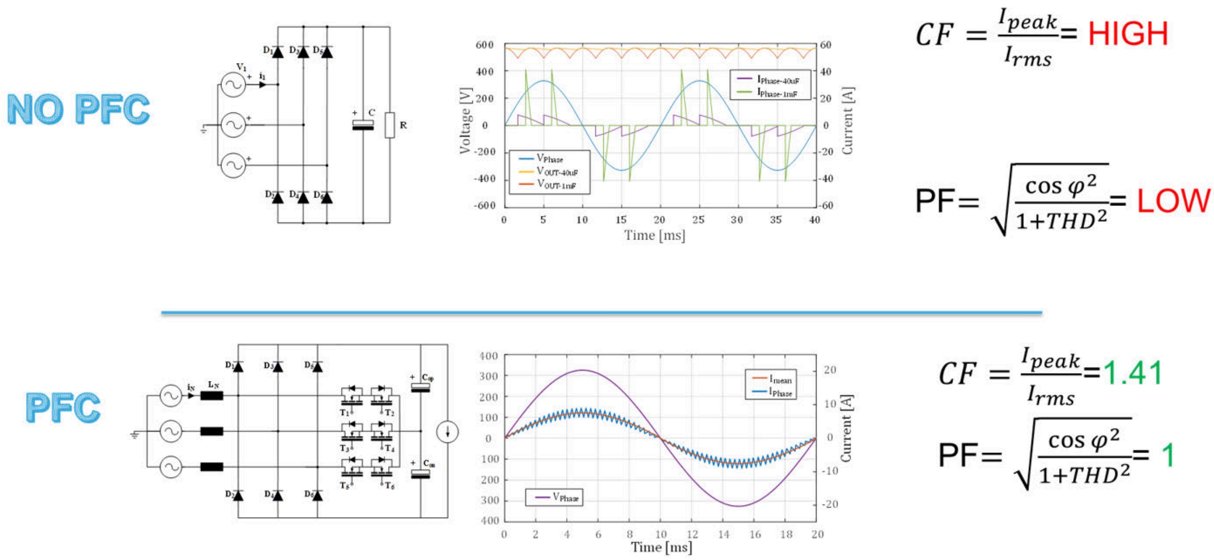
Figure 17. **STDES-PFCBIDIR MCU pin assignment**



1.6 Power factor correction (PFC) benefits

The figure below highlights the PFC benefits in terms of rest factor and power factor.

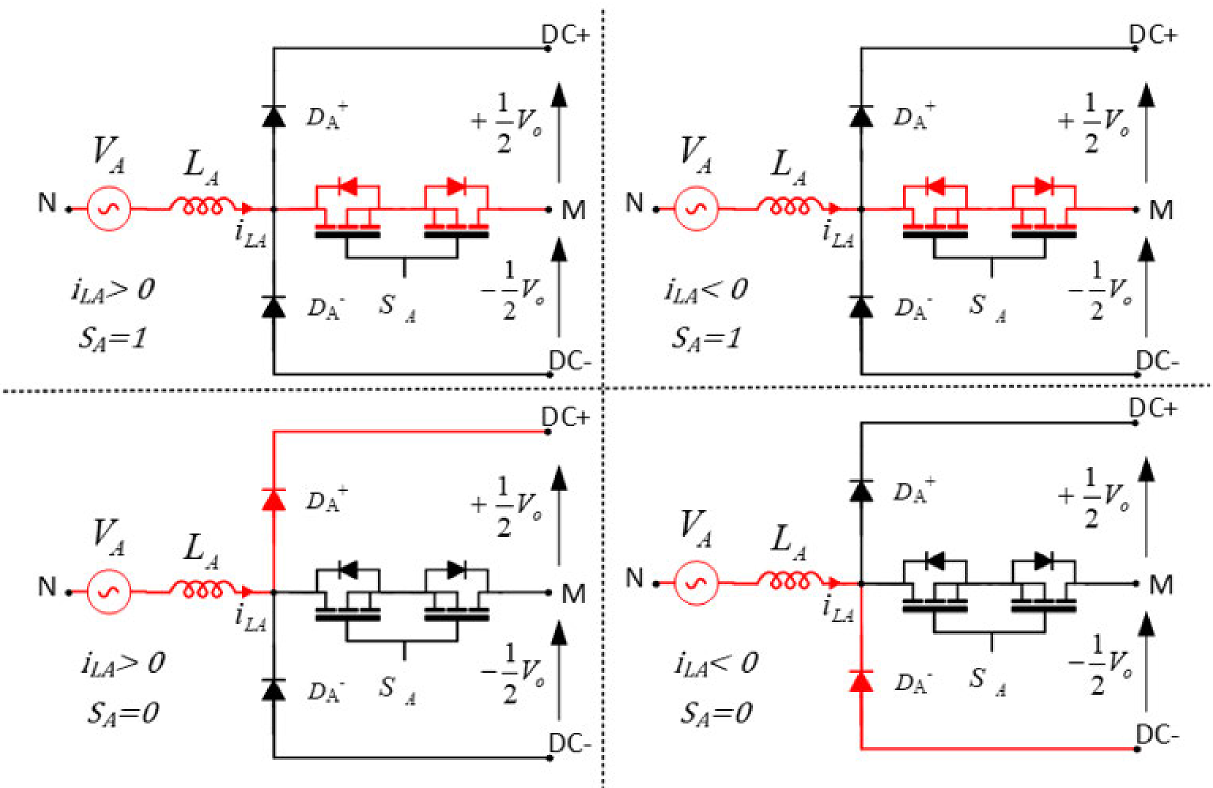
Figure 18. PFC benefits



1.7 Converter operation

The figure below shows the current paths of the Vienna topology. To simplify the scheme, we considered the single phase representation.

Figure 19. Switching paths of the Vienna topology



2 How to use the STDES-PFCBIDIR reference design

2.1 System setup

To use the STDES-PFCBIDIR, you need:

- a programmable AC emulator or a programmable AC source;
- a DC electronic load;
- a power analyzer;
- a digital oscilloscope.

You can test the STDES-PFCBIDIR up to 15 kW at 230 V_{AC} RMS and 6 kW at 110 V_{AC} RMS in a frequency between 47 and 63 Hz.

2.2 How to connect the reference design

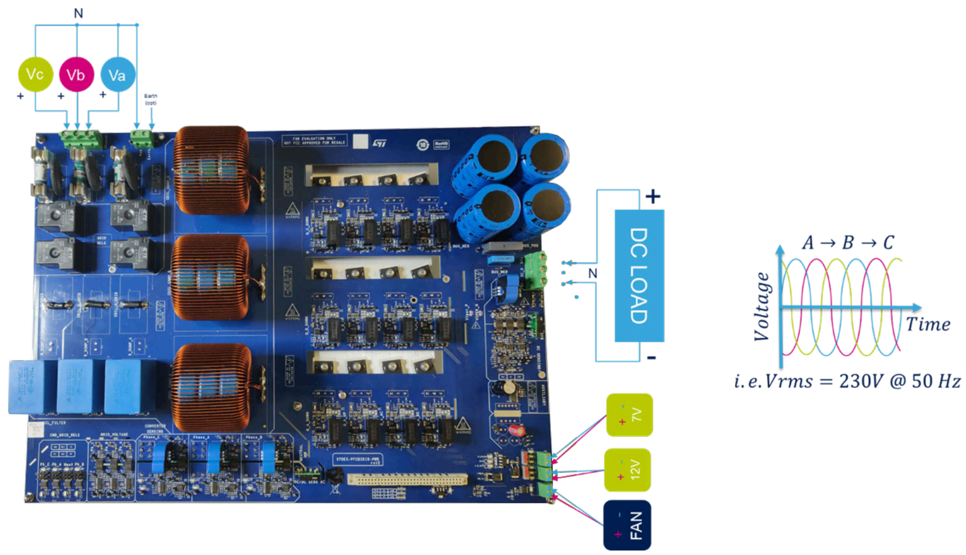
To operate the reference design power converter properly, consider the operating limits shown below.

Table 4. Operation condition limits

Description	Value	Unit
Three-phase input voltage range	208-400	V_{AC}
Line frequency range	47-63	Hz
Maximum output power at 230 V_{AC}	15	kW
Voltage limit of the bulk capacitors	500	V

Step 1. Connect the power board as shown in the figure below.
The figure shows the three-phase connection sequence (A-B-C). The neutral connection is optional.
The power board handles the input connection exploiting the four input relays. The polarity influences the DC load connection.

Figure 20. STDES-PFCBIDIR connection



Step 2. The auxiliary power supply can be externally provided. Connect an external fan to manage the thermal dissipation.

2.3 MCU programming and debugging

You can program and debug the microcontroller unit (MCU) through different tools.

Step 1. Use ST-LINK/V2 and a 20- to 10-pin JTAG adapter to connect the platform to the PC.

Figure 21. **ST-LINK/V2 and adapter**

Figure 22. **ST-LINK/V2 connected to the control board**

Step 2. Select the main.c file in the project/Application/User path.

Step 3. Click on the [**Download and debug**] button to start programming and debugging.

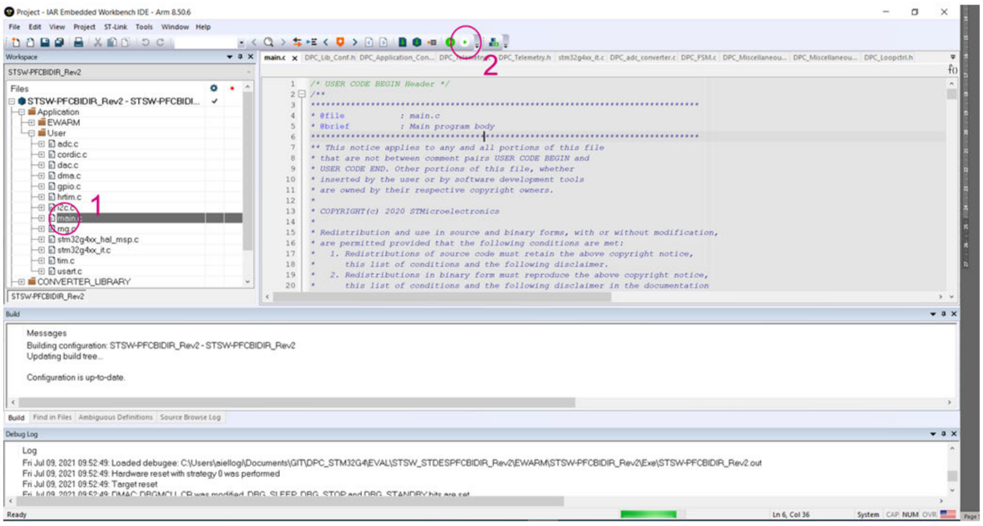


Figure 23. IAR EWARM program procedure

Step 4. Click on the [**Run**] button to start the code execution.

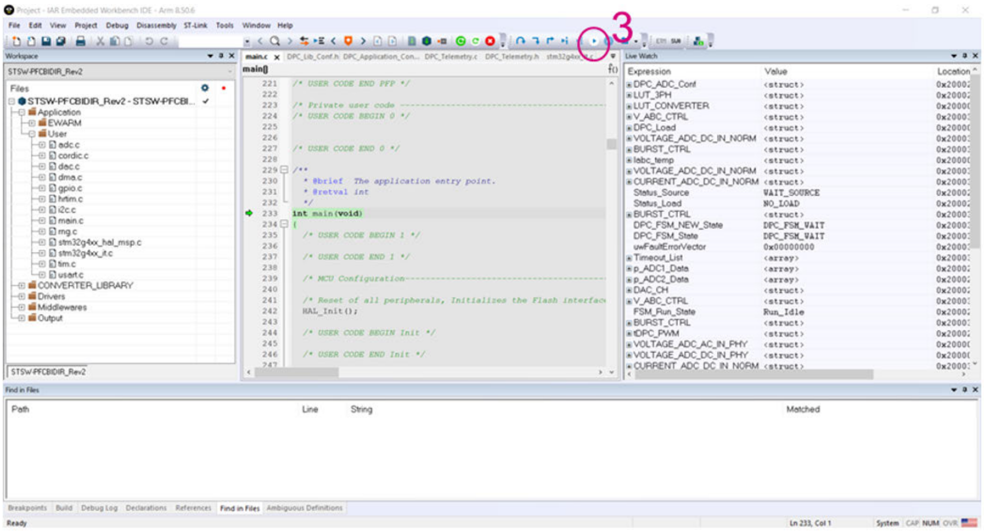


Figure 24. IAR EWARM debug procedure

2.4 Board configuration

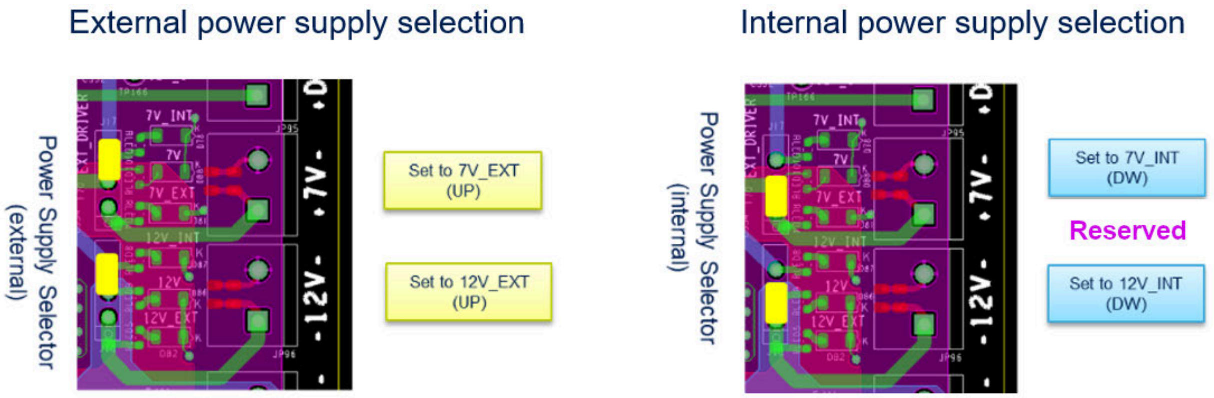
The STDES-PFCBIDIR is a customizable reference design. You can customize the power supply, the driving section, the grid relays, the inrush current limiter, and the DC current sensing technique.

2.4.1 Power supply section

Two different input voltages are required for the power supply. An embedded SMPS based on the VIPER26HD provides self-powering from the DC-link.

As shown in the figure below, you can select either an internal or external connection. Specific LEDs allow identifying the selected configuration.

Figure 25. **Example of power supply configuration**



2.4.2 Driver section

The driving section allows configuring the driving voltage.

Figure 26. **Example of driver configuration**

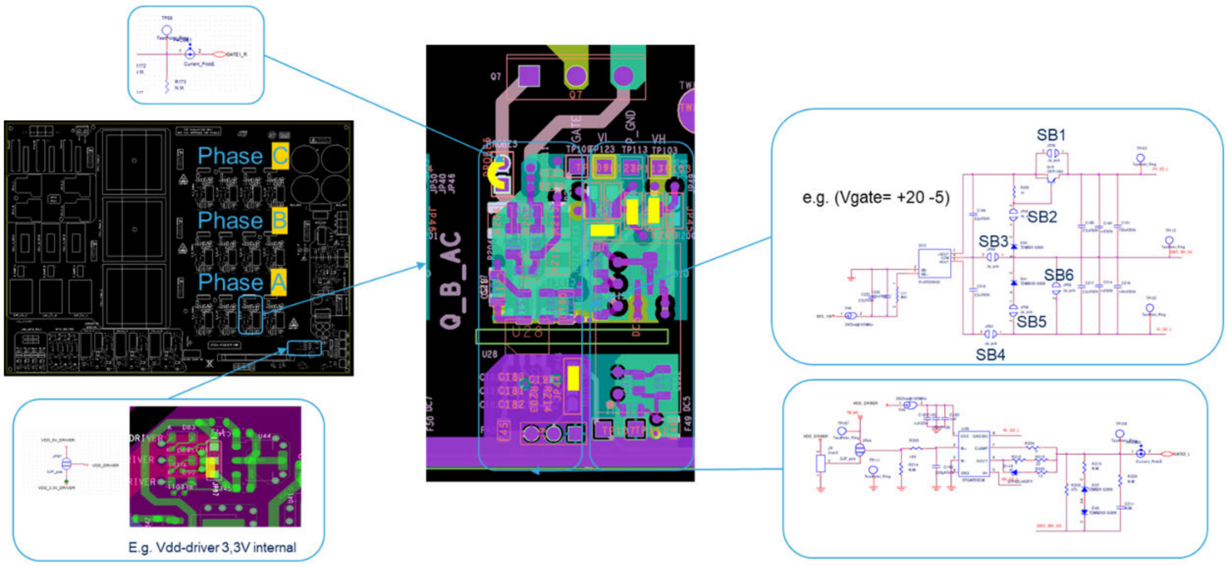


Table 5. **Example of driving section configuration**

Configuration	SB1	SB2	SB3	SB4	SB5	SB6
+20 V -5 V	Closed	Open	Closed	Closed	Open	Open

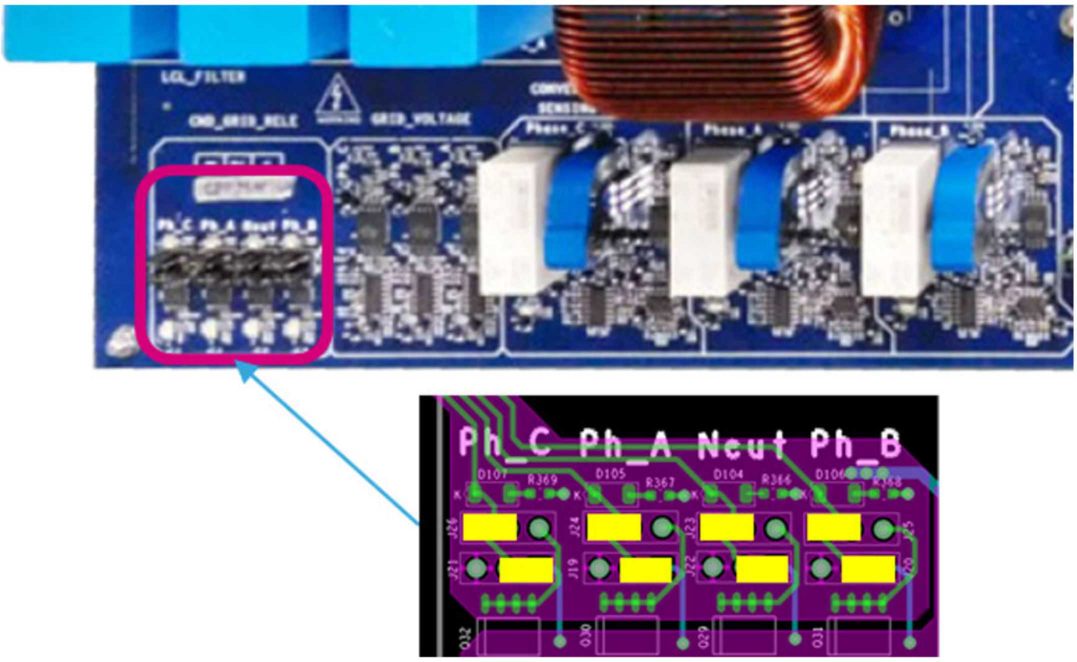
2.4.3 Relay section

The STDES-PFCBIDIR allows managing the power in both directions (AC-DC rectifier mode a DC-AC inverter mode).

To customize the AC side connection with the power converter, we considered four relays. Three of them are for the three-line connection and one is for the neutral.

You can manually manage each relay (on|off state). The MCU can manage the relays for the grid connection or if a fault occurs.

Figure 27. **Example of relay configuration**



2.5 Preliminary test procedure

2.5.1 AC sensing

To verify the proper operation of the AC sensing, analyze some test points for voltages and currents as shown in the figures below.

Figure 28. **AC sensing section**

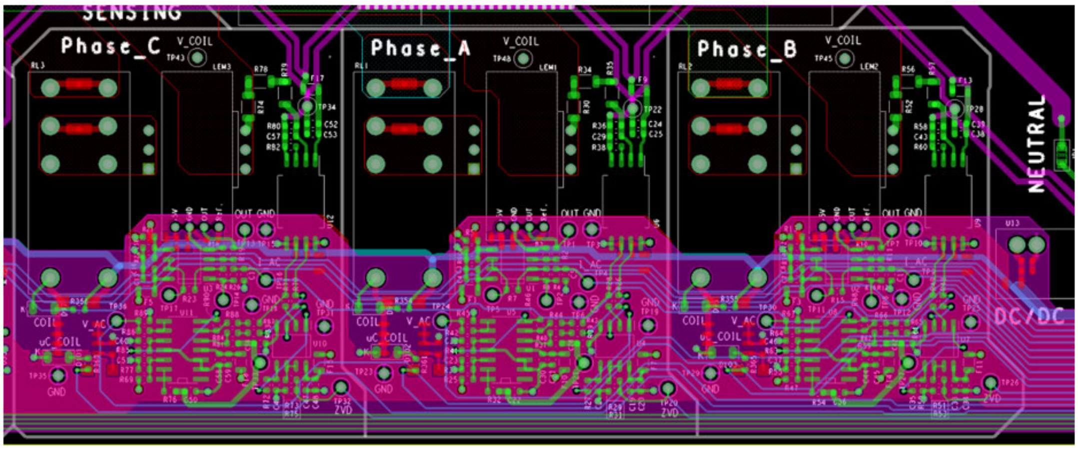


Figure 29. **AC voltage sensing test procedure**

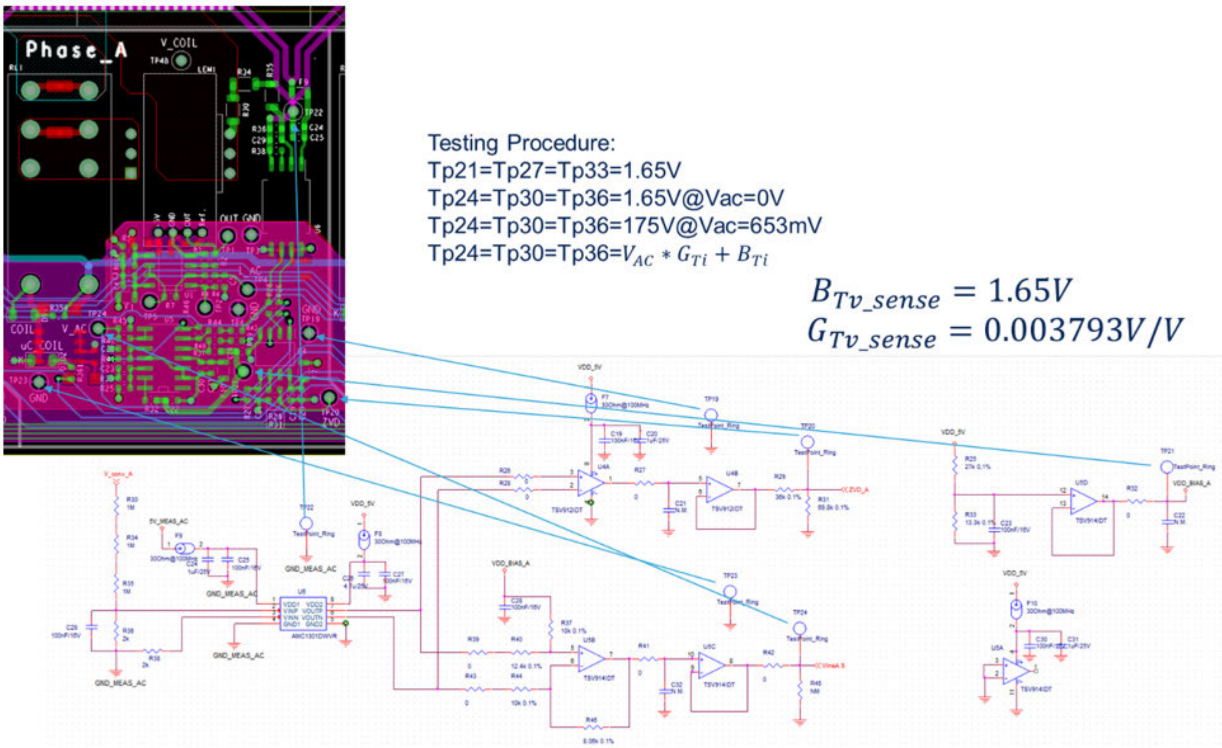


Figure 30. **AC grid voltage sensing test procedure**

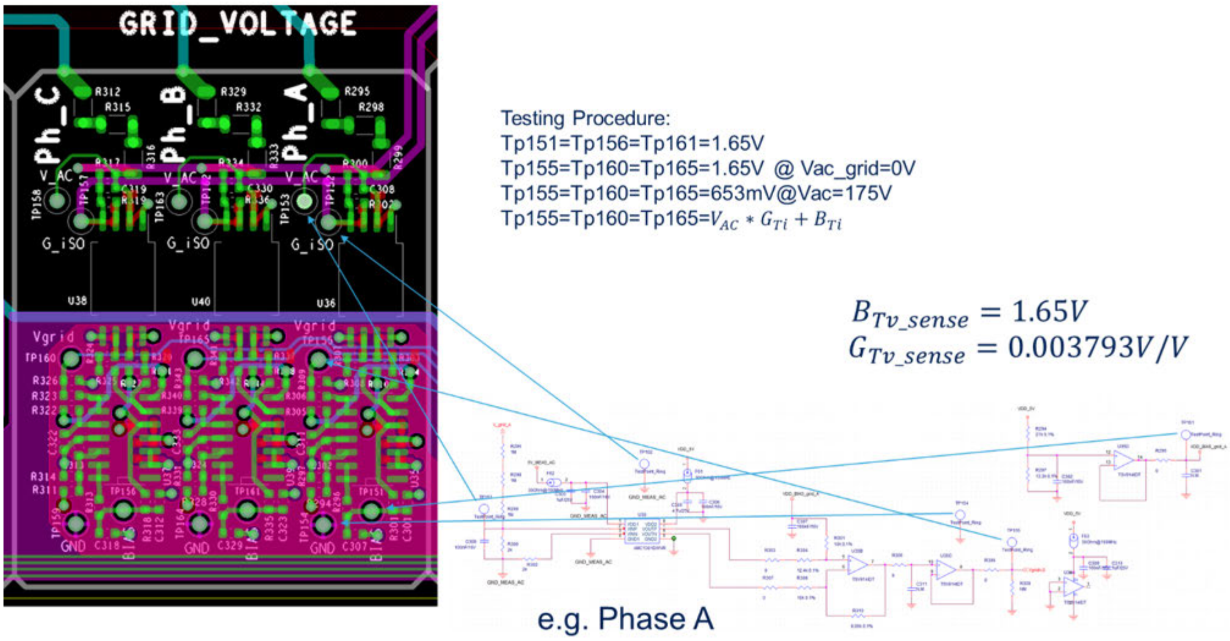
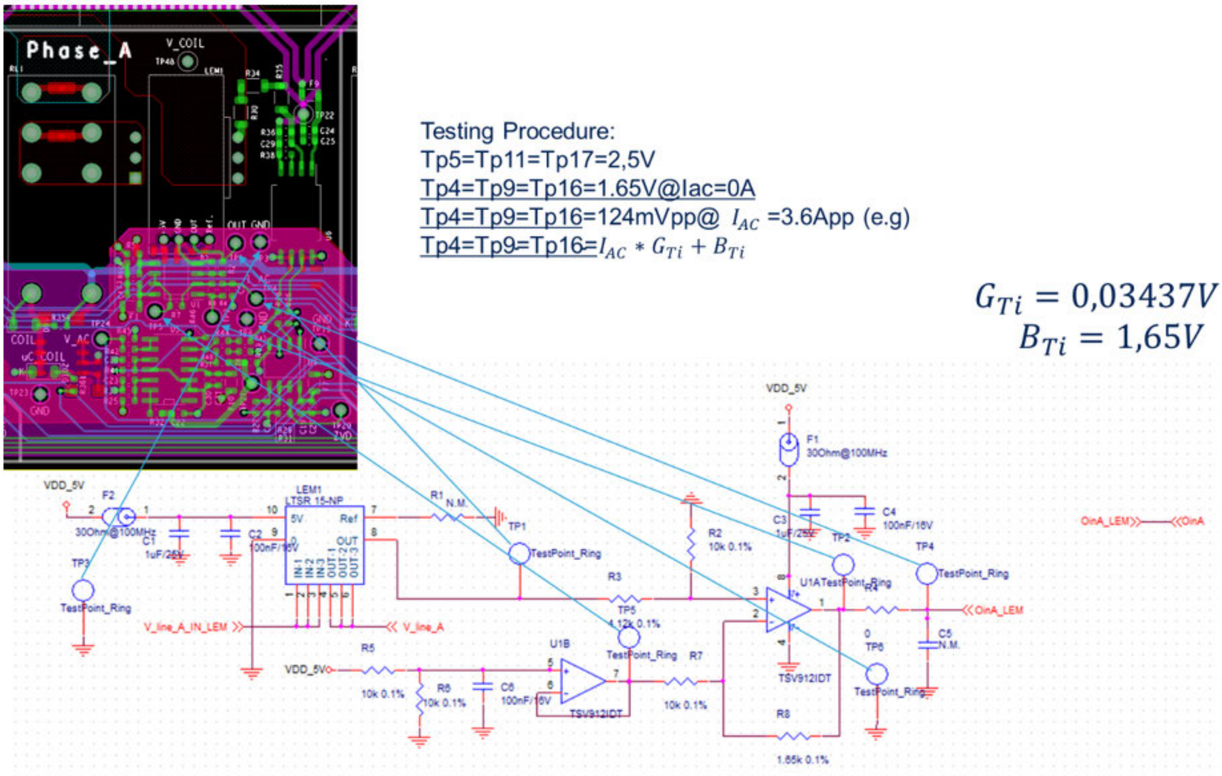


Figure 31. AC grid current sensing test procedure



2.5.2 DC sensing

To verify the proper operation of the DC sensing, analyze the test points for voltages and currents as shown in the figures below.

Figure 32. DC voltage sensing test procedure (1 of 2)

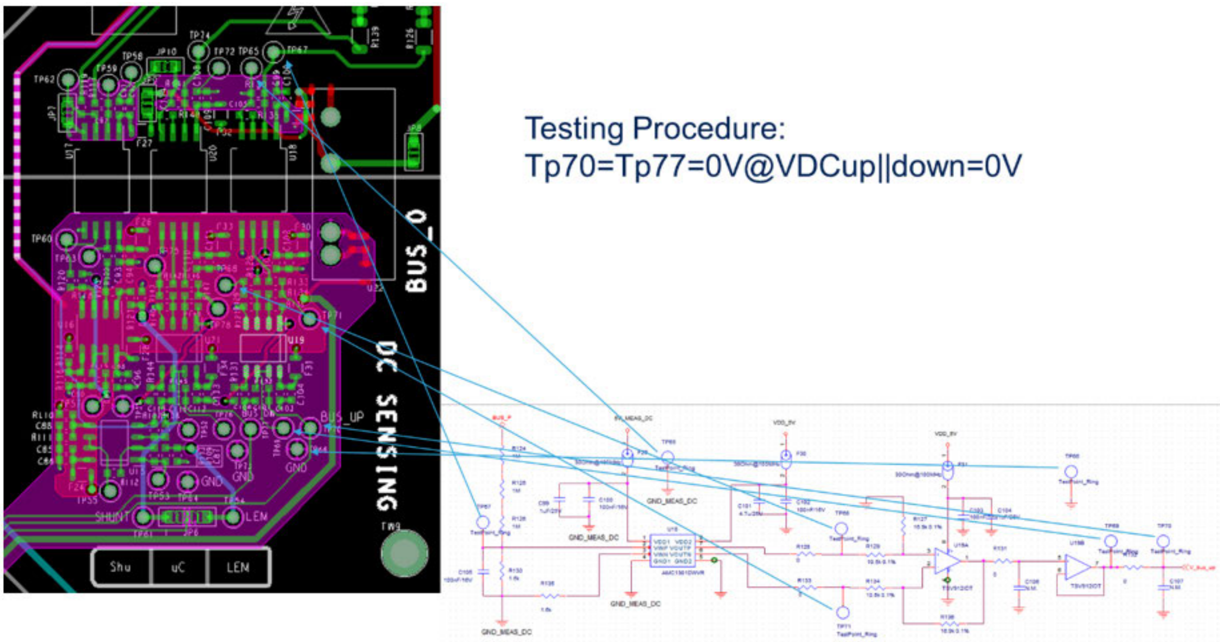
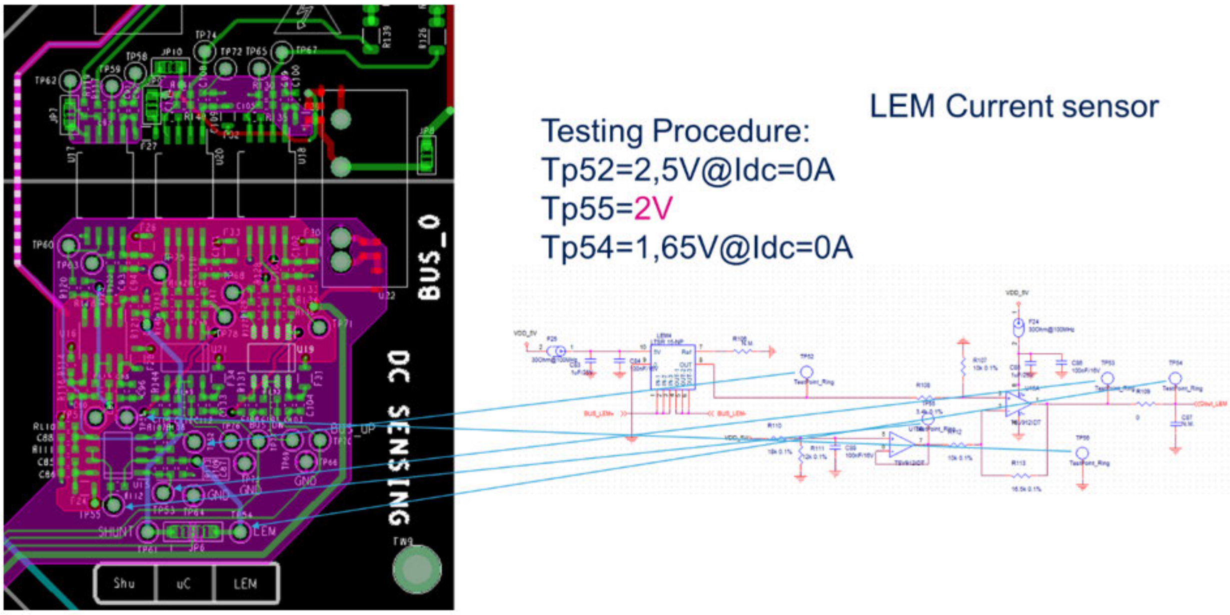


Figure 33. **DC voltage sensing test procedure (2 of 2)**

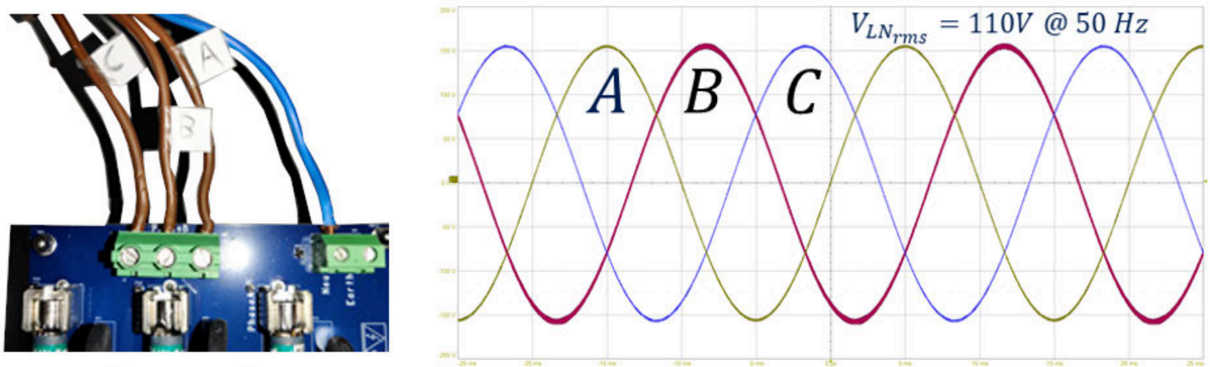


2.5.3 AC connection

Connect the STDES-PFCBIDIR AC main as shown below.

A correct ABC sequence is mandatory for the proper operation of the power converter.

Figure 34. **AC main connection and sequence**



AC connection AC sequence

2.5.4 DC connection

The figure below shows the output DC connection. Ensure to apply the correct polarity.

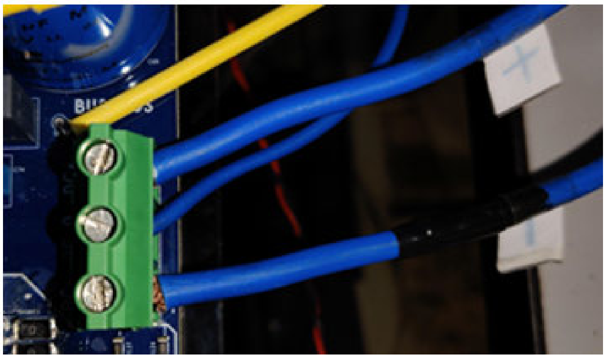


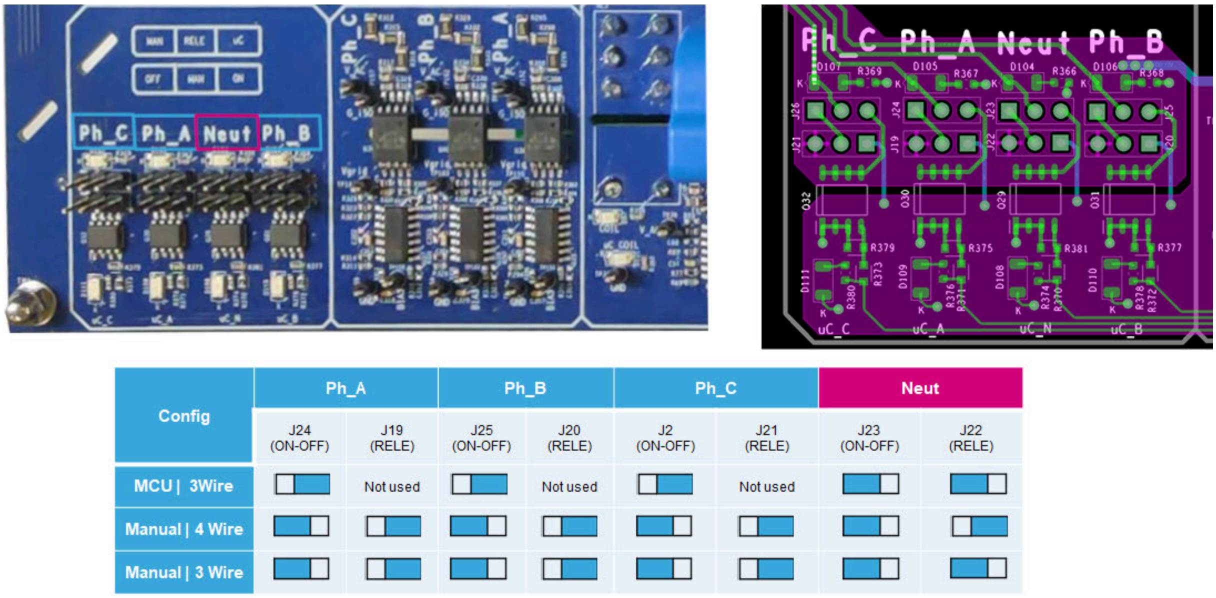
Figure 35. DC side load connection

2.5.5 Relay section

The STDES-PFCBIDIR reference design uses two groups of relays to manage the AC side connection and ICL.

Step 1. To verify the functionality, configure the power board as shown below.

Figure 36. Relay jumper configuration



Step 2. Connect the first row of the selector to the left side to set the manual mode.

Step 3. Close or open the second row in the right or left jumper position.

Step 4. Check the relay impedance with a multimeter according to the configuration (three-phase and neutral).

2.6 Startup procedure

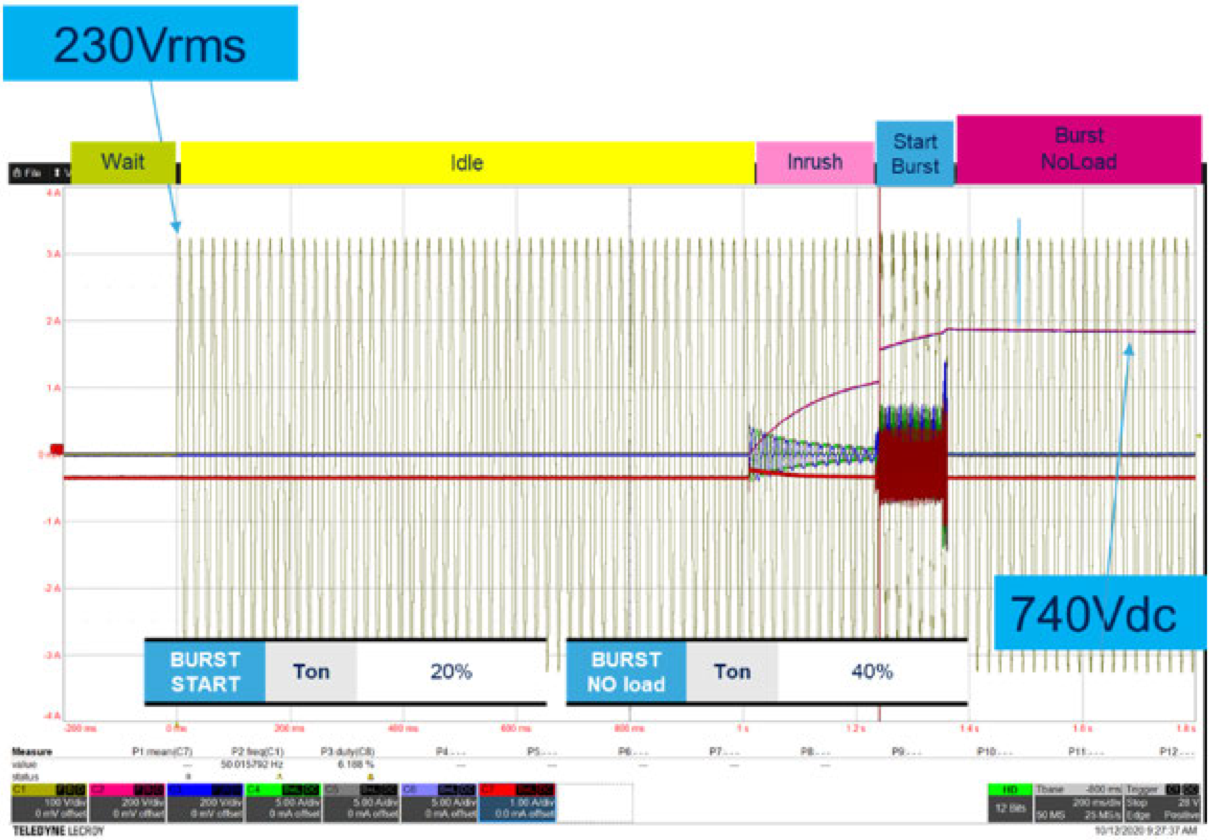
After connection and debugging initialization, you can perform the startup procedure.

An embedded finite state machine handles this procedure. It consists of different states that perform a preliminary check of the converter and the precharge of the capacitor. Then the burst operation boosts the output voltage.

The STDES-PFCBIDIR reference design allows managing the complete startup procedure.

However, a controlled step-by-step procedure is available. It is useful during the preliminary test or after hardware/software modification.

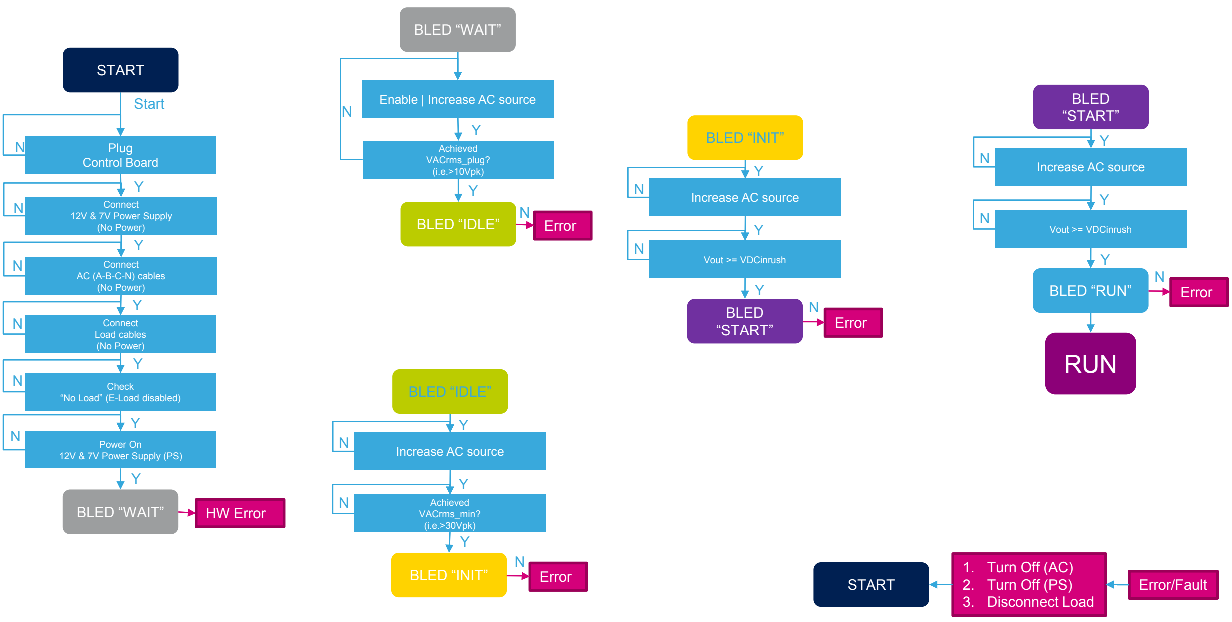
Figure 37. Typical startup procedure



2.6.1 Controlled startup procedure

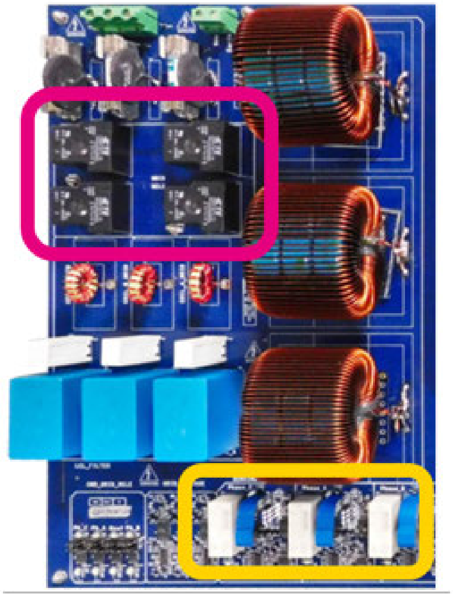
The AC power supply is slowly increased to verify the procedure step-by-step as shown below.

Figure 38. Connection and power-on procedure



This procedure takes the below grid relays (pink box) and the inrush relays (yellow box) into consideration.

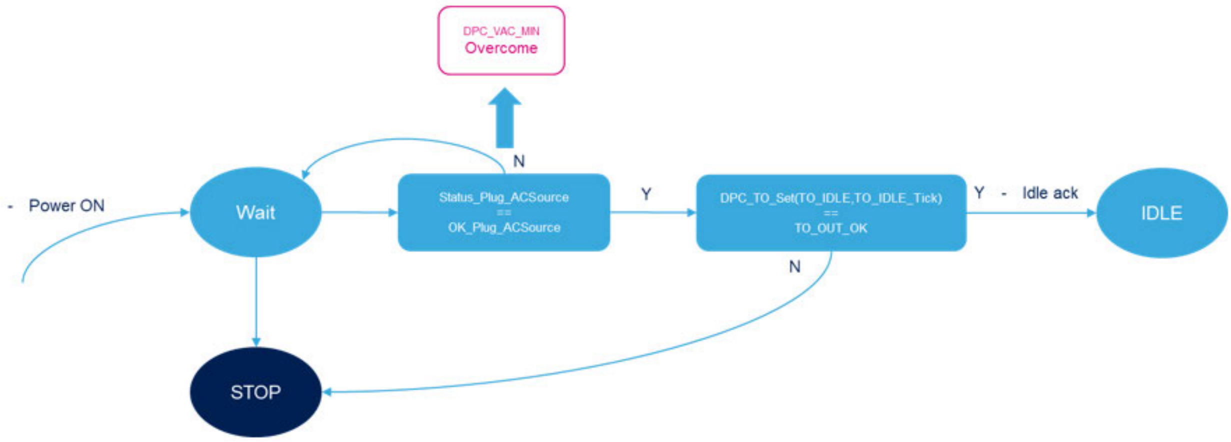
Figure 39. **STDES-PFCBIDIR relays**



The procedure consists of the following steps.

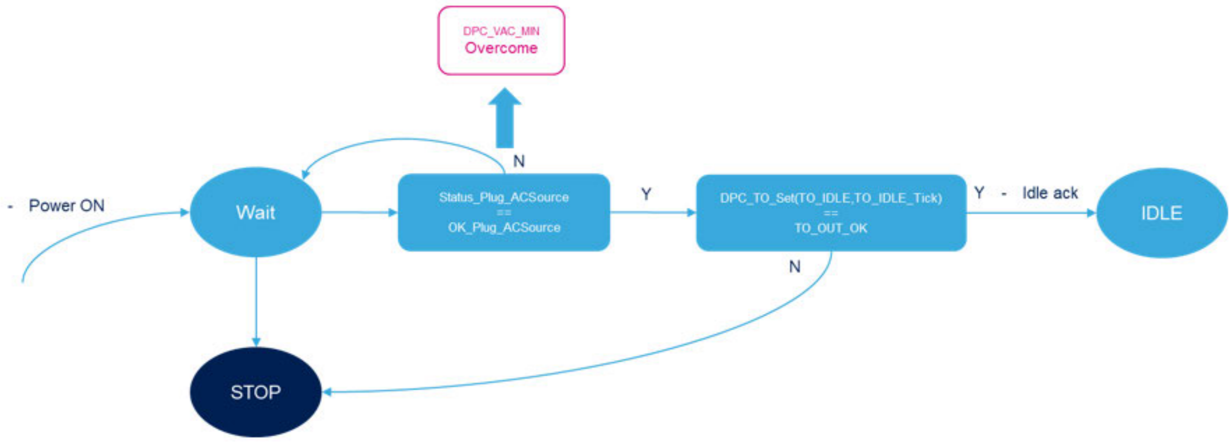
1. `FSM Wait`: PWM signals are in IDLE state, configured in low state, to force all the MOSFETs in off state. The AC main voltage is already under monitoring. This state is maintained until AC main reaches a lower AC voltage threshold (`OK_Plug_ACSource`), that is 30 V_{AC}. After that, an internal timeout (`TO_IDLE`) is activated to prevent power converter connection during the first-phase synchronization procedure. FSM moves on to `FSM Idle`.

Figure 40. **FSM_Wait block diagram**



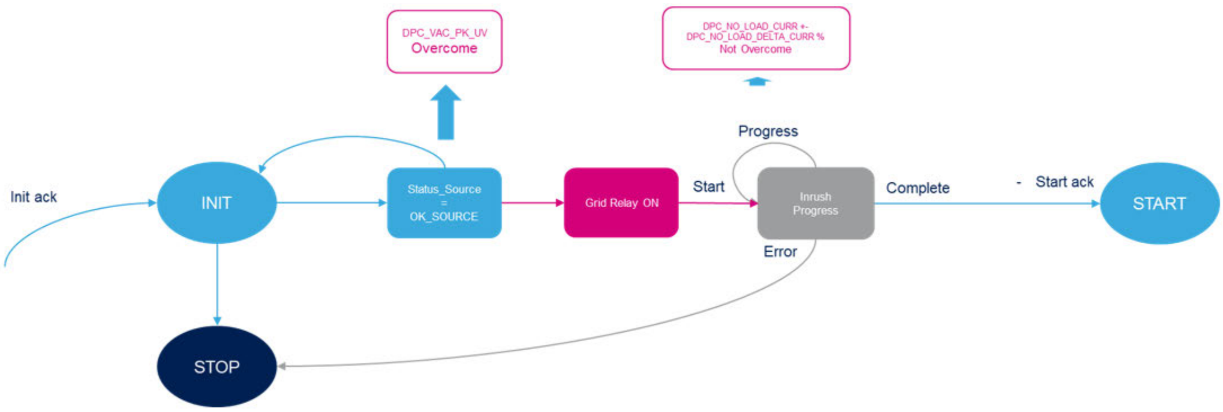
2. `FSM_Idle`: after `TO_IDLE` time elapses, wait for the AC mains to reach the uvAC value (`OK_SOURCE`). After checking the load current, a new timeout is set (`TO_INIT`) to prevent PLL instability. FSM moves to `FSM_Init`. All relays are maintained in the off state.

Figure 41. FSM_Idle block diagram



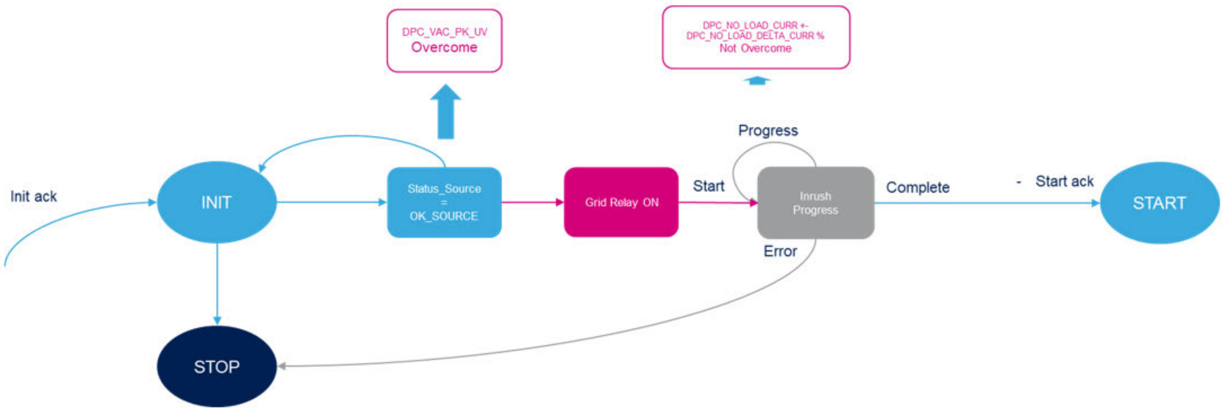
3. `FSM_Init`: handles the inrush current control. If the grid voltage is correct, the status source is equal to `OK_SOURCE`. The bulk capacitors are at low voltage and the inrush current must be limited. For this reason, during this state, the inrush relays are considered in series with a high resistance. On the basis of their values, the inrush is completed. The state machine state is still maintained to stabilize the output voltage according to the grid amplitude. After a configurable time, the FSM moves to start state (`FSM_Start`).

Figure 42. FSM_Init block diagram



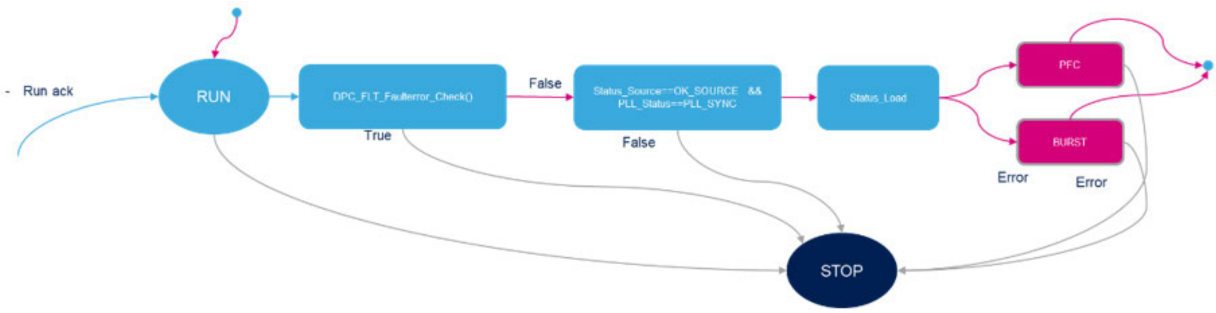
4. `FSM_Start`: is related to the burst mode operation of the power converter. During this procedure, the PWM is activated. The pulse sequence at a fixed duty cycle allows boosting the input voltage and increasing the DC output voltage at a reference voltage. The state machine then moves to `FSM_Run` state.

Figure 43. FSM_Start block diagram



5. `FSM_Run`: if the startup procedure is completed without any issue, `FSM_Start` manages the PFC operation of the power converter. The burst operation still maintains the DC voltage. If a DC load occurs, the PFC modulation and the control loop are activated to handle the load power demand.

Figure 44. FSM_Run block diagram



2.6.2 Direct startup procedure

The finite state machine manages a direct startup procedure. The AC source takes the nominal voltage into consideration. The inrush current limitation and the burst mode operation must be completed after the DC load connection.

3 Control

The voltage-oriented control allows controlling the PFC behavior of the converter in the dq-axis synchronous reference frame.

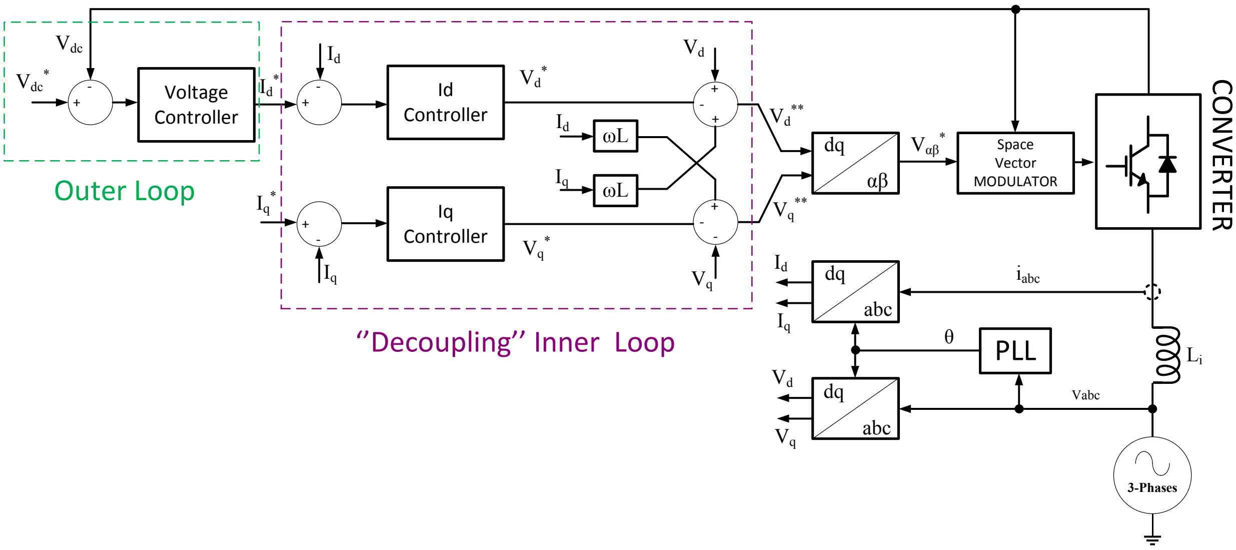
Table 6. Control strategy comparison

Reference frame	Pros	Cons
3-axis stationary reference frame (abc)	• Simple implementation with PI • Avoids effort in the reference transformation • Best results with the PR regulator (no analog) • Best choice for the analog version	• Poor in transient • Phase shifting (lag) • Needs three regulators (three-phase) • Necessary high bandwidth (noise) • Steady state error
2-axis stationary reference frame (αβ)	• Use two regulators instead of three • Simple implementation with PI • Best results with the PR regulator (no analog)	• Poor in transient • Phase shifting (lag) • Digital version only • Necessary high bandwidth (noise)
2-axis synchronous reference frame (dq)	• Zero steady state error (DC reference) • Use of a simple PI (simple structure of the regulator) • Low bandwidth is allowed (robust) • Best in transient (first order behavior)	• Effort frame transformation • Digital version only • Necessary high bandwidth (noise) • Implementation

3.1 Control strategy

This reference design power converter can be represented as a second order dynamic system, which consists of inductors and capacitors. The theoretical different dynamic behavior of this two-system element allows considering two fully decoupling first order systems. For this reason, a current control and a voltage control are taken into account.

Figure 45. Cascaded control



3.1.1 Current control strategy

A continuous conduction mode controls the reference design current.

Figure 46. **Continuous conduction mode in current control**

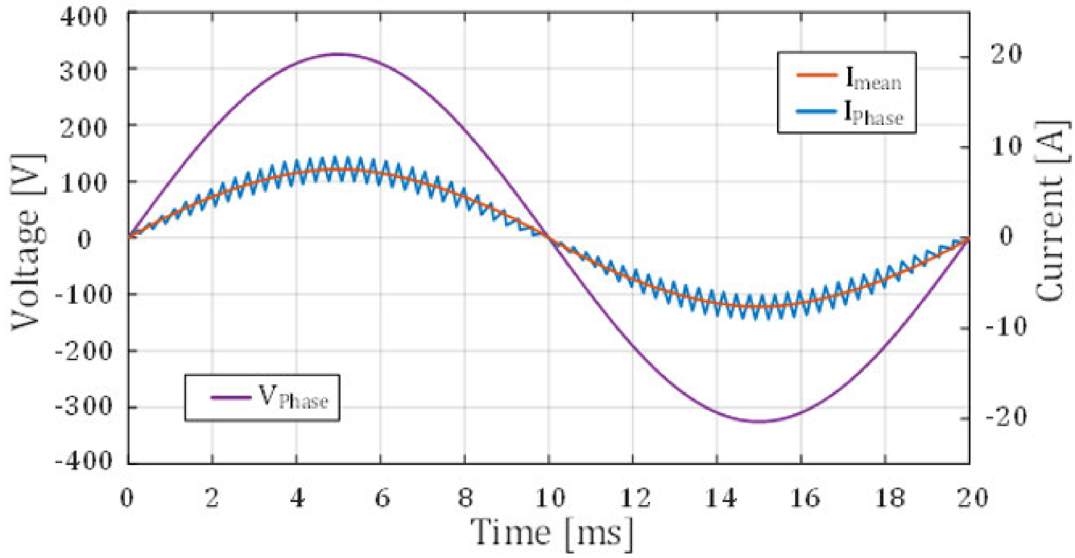


Figure 47. **Current decoupling control of the reference design converter model**

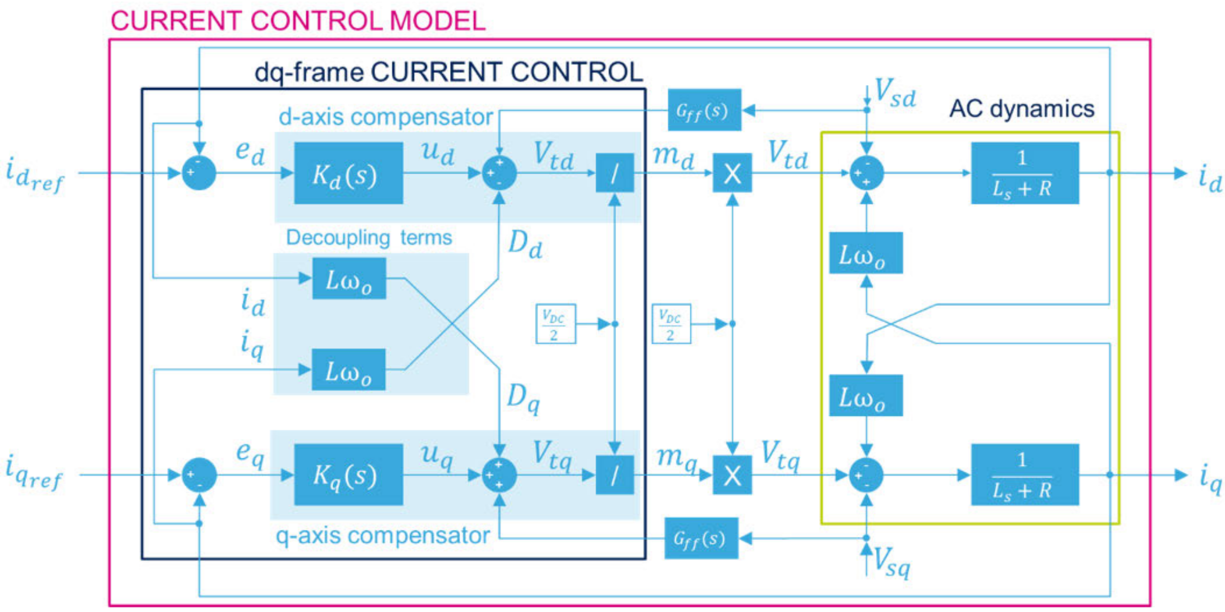
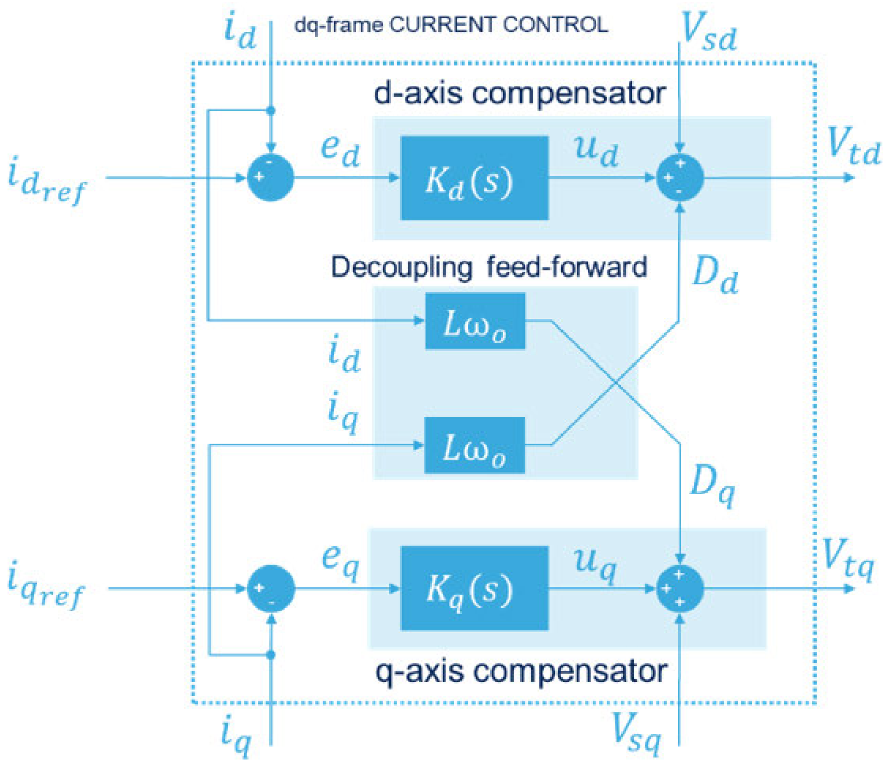


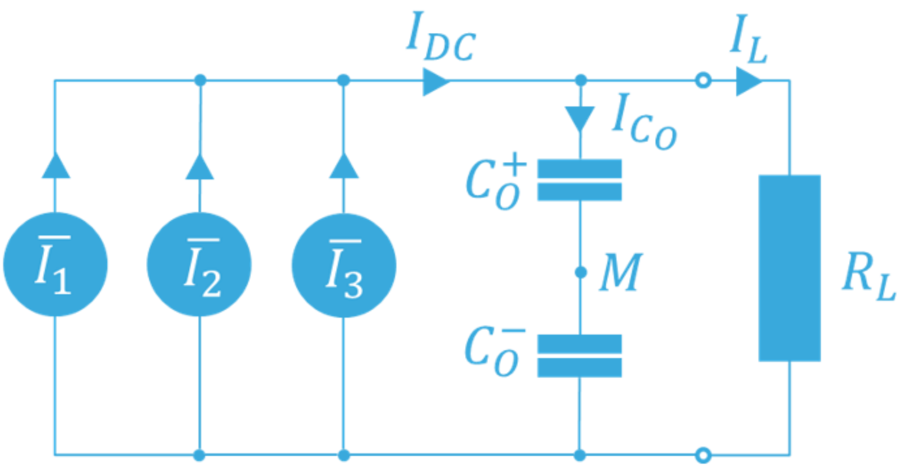
Figure 48. **CDC**



3.1.2 Voltage control strategy

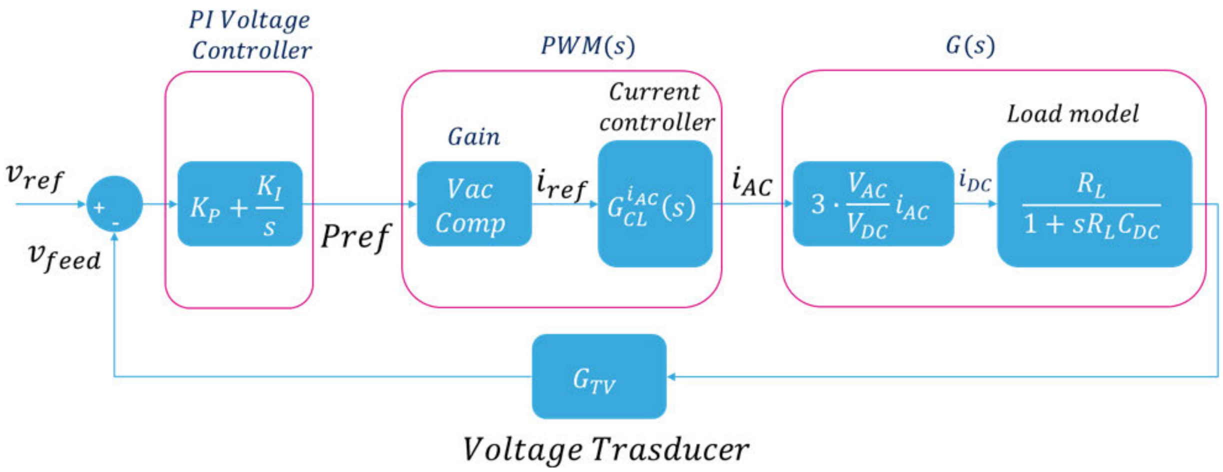
The outer loop of the PFC operation is a voltage control.

Figure 49. **Converter DC side model**



The figure below shows the closed loop representation of the above model.

Figure 50. Voltage control diagram



3.2 Phase locked loop

In converter control, the PI regulators are usually used. This kind of regulator gets the best results when using a DC reference term.

Figure 51. PLL internal regulator loop

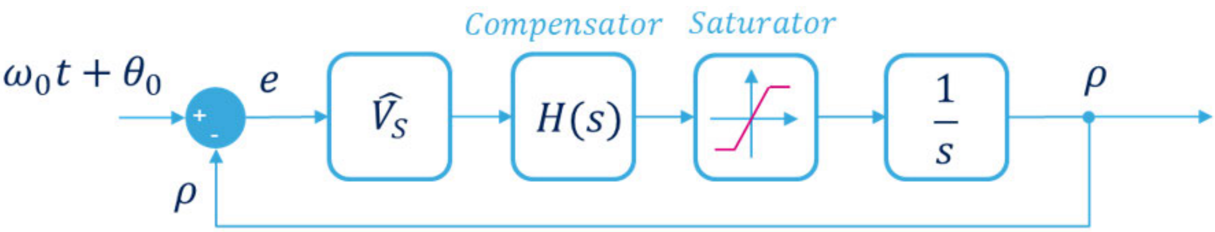
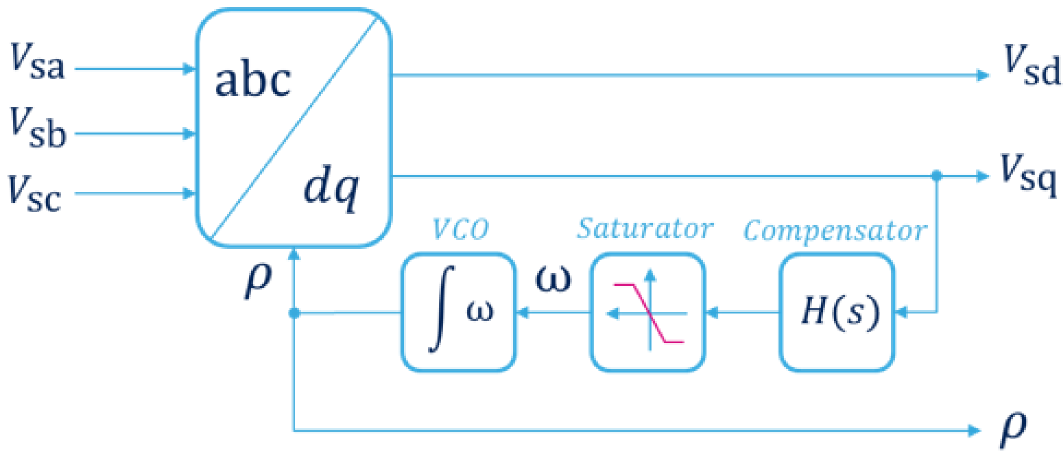


Figure 52. PLL in AC main voltage



4 Software implementation

The STM32G474RET3 MCU controls the STDES-PFCBIDIR.

The firmware package is based on the STM32Cube ecosystem. Starting from the STM32CubeMX, all the peripherals and pins used are activated and configured according to the basic project.

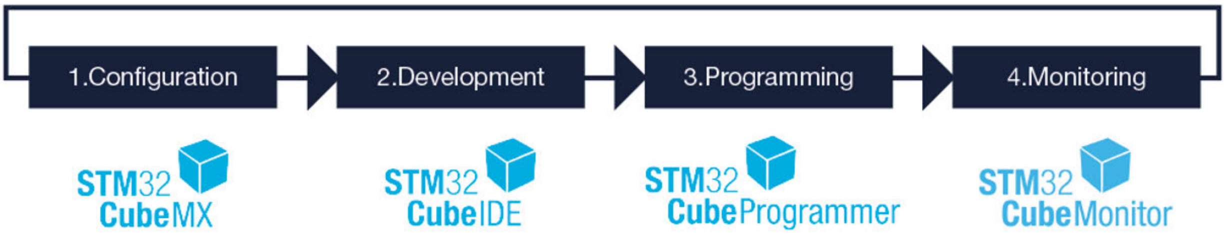
The application firmware is supported and tested using STM32CubeIDE, IAR, and Keil development environments.

After the development, the MCU can be programmed through the IDE or STM32CubeProgrammer.

To monitor and control the application, you can use a GUI based on STM32CubeMonitor.

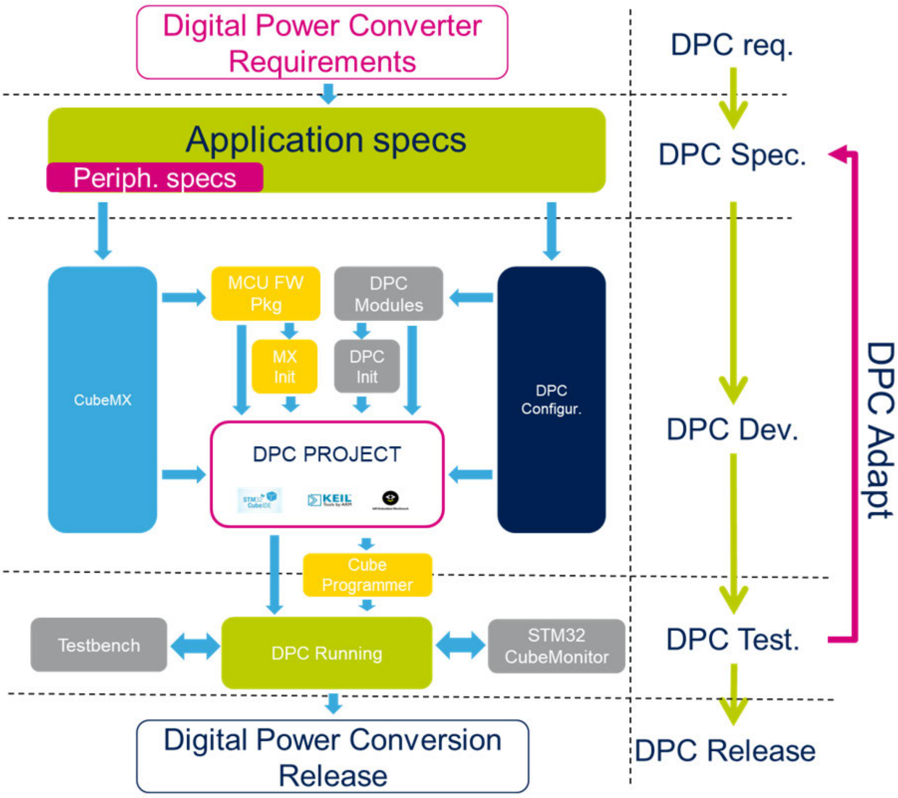
The firmware described in this documentation development is based on the STM32CubeG4 firmware package v1.3.0.

Figure 53. STM32Cube ecosystem development flow



An extensive range of generic and specific firmware modules is available to support the digital power conversion. The figure below shows the generic development flow to get the power conversion used for the STDES-PFCBIDIR firmware development.

Figure 54. DPC development flow



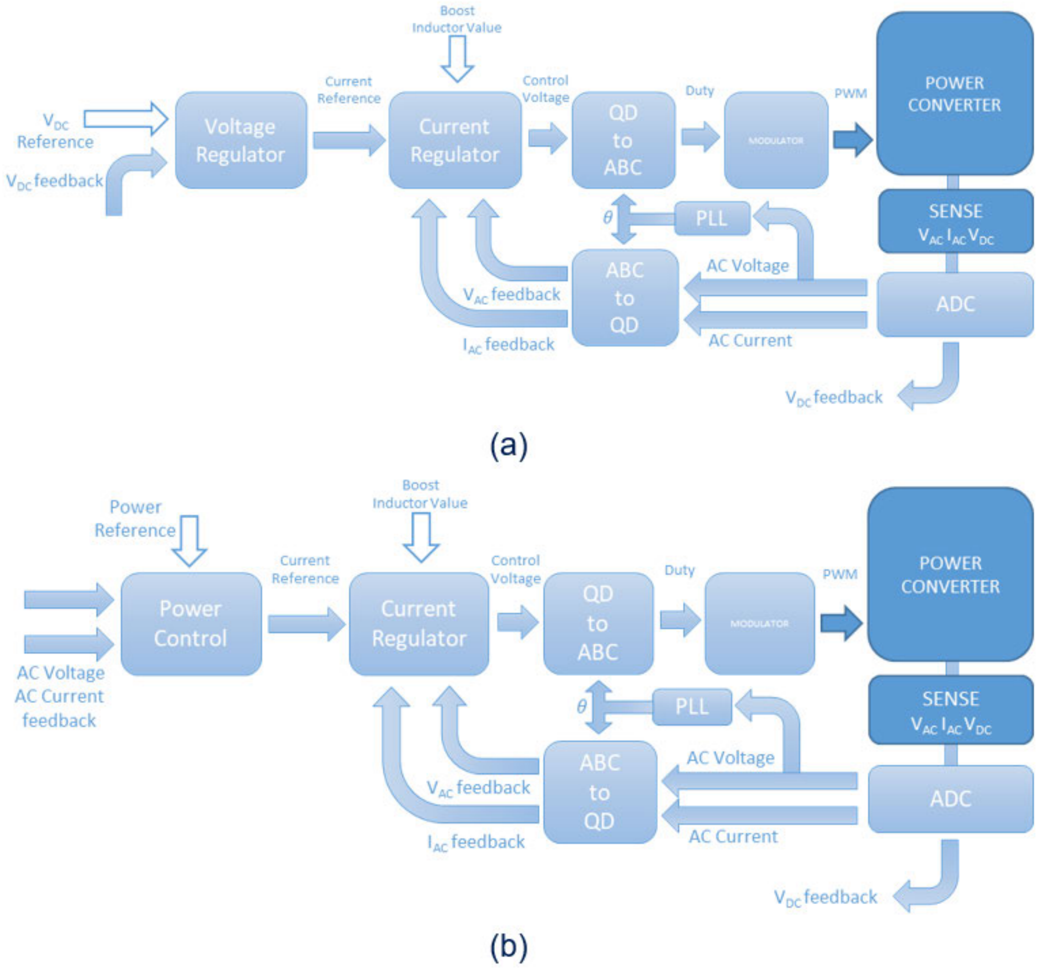
This workflow starts from power conversion requirements. This information is then reinterpreted in the application specs that contain information linked to the MCU peripheral and the DPC application configuration.

On the basis of this information, an STM32CubeMX project, properly configured and initialized, is provided. Then, the needed DPC module is included and configured.

The STM32CubeMX generates the development IDE project. The MCU is directly flashed through the IDE or STM32CubeProgrammer. At the end of this operation, the DPC application is tested and debugged through STM32CubeMonitor. The digital power converter firmware is then released, if compliant, and the DPC is adapted.

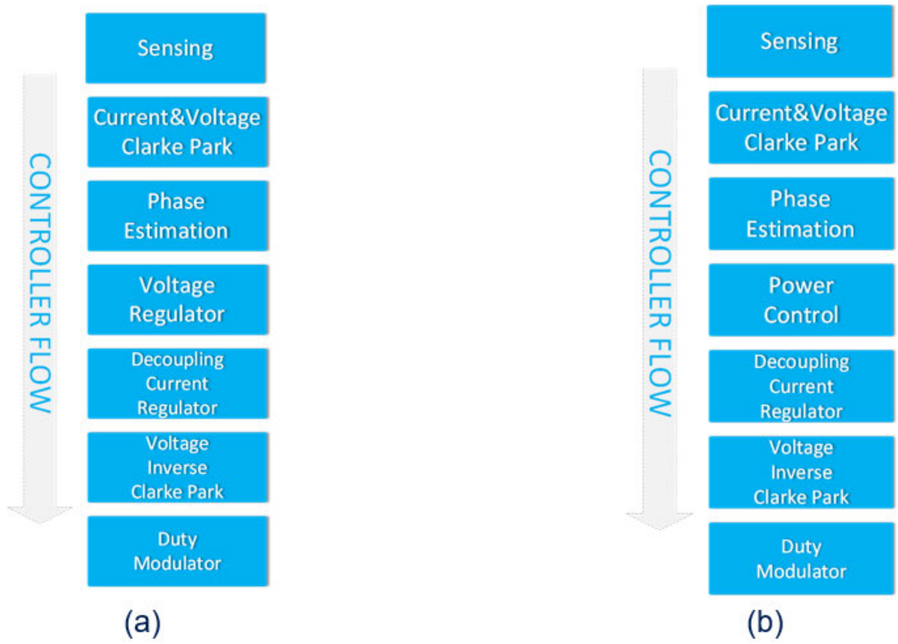
The STDES-PFCBIDIR reference design power converter allows managing the two-direction energy flow. The figure below shows the algorithm schematic diagram of the implementation in the AC-DC rectifier application and DC-AC inverter application.

Figure 55. **AC-DC rectifier application (a) and DC-AC inverter application schematic diagram (b)**



The figure below shows the basic representation of the execution flow. A current decoupling control well fitted for this application is used. This allows managing the bidirectional energy flow in terms of AC current without discontinuity in the operation of the high dynamic inner loop. Only the outer loop is adapted to ensure the correct operation for both loops.

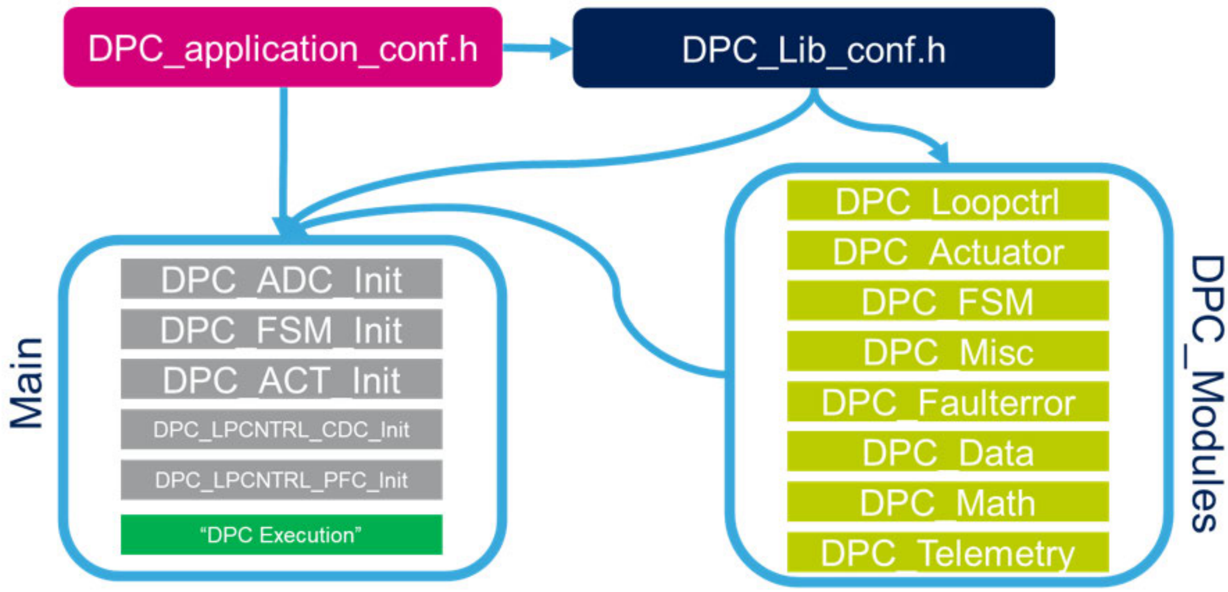
Figure 56. **Simplified execution task of the control in AC-DC (a) and DC-AC (b)**



4.1 Configuration files

The STDES-PFCBIDIR power converter configuration is based on two main configuration files.

Figure 57. **STDES-PFCBIDIR configuration files**



"DPC_application_conf.h" contains the application specific `DEFINE` (that is the ADC gain factor PI regulator gain, FSM configuration, control reference value, etc.).

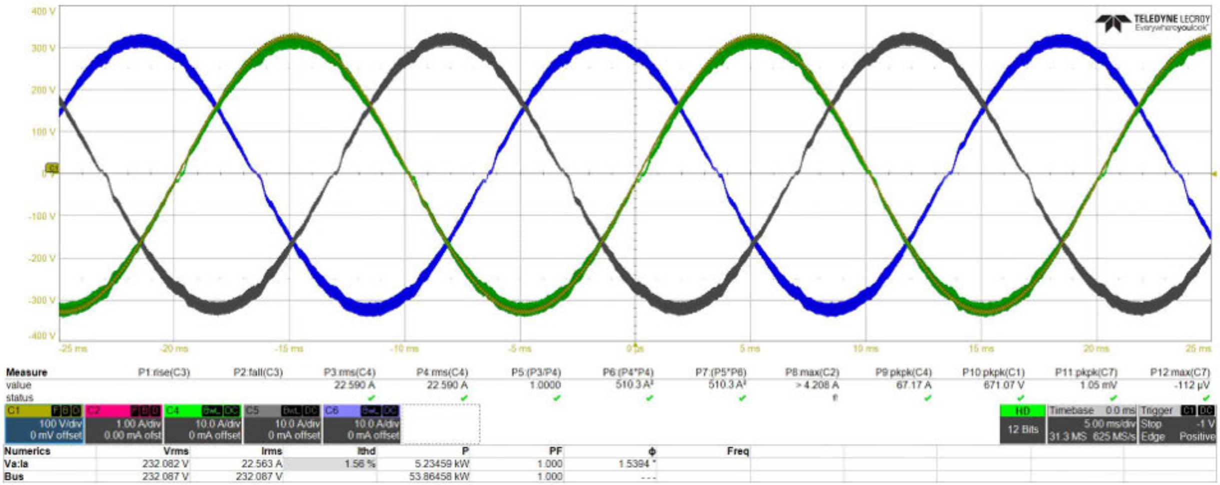
"DPC_Lib_conf.h" contains the configuration parameters linked to the MCU peripherals configuration.

5 Measurements

5.1 PFC operation

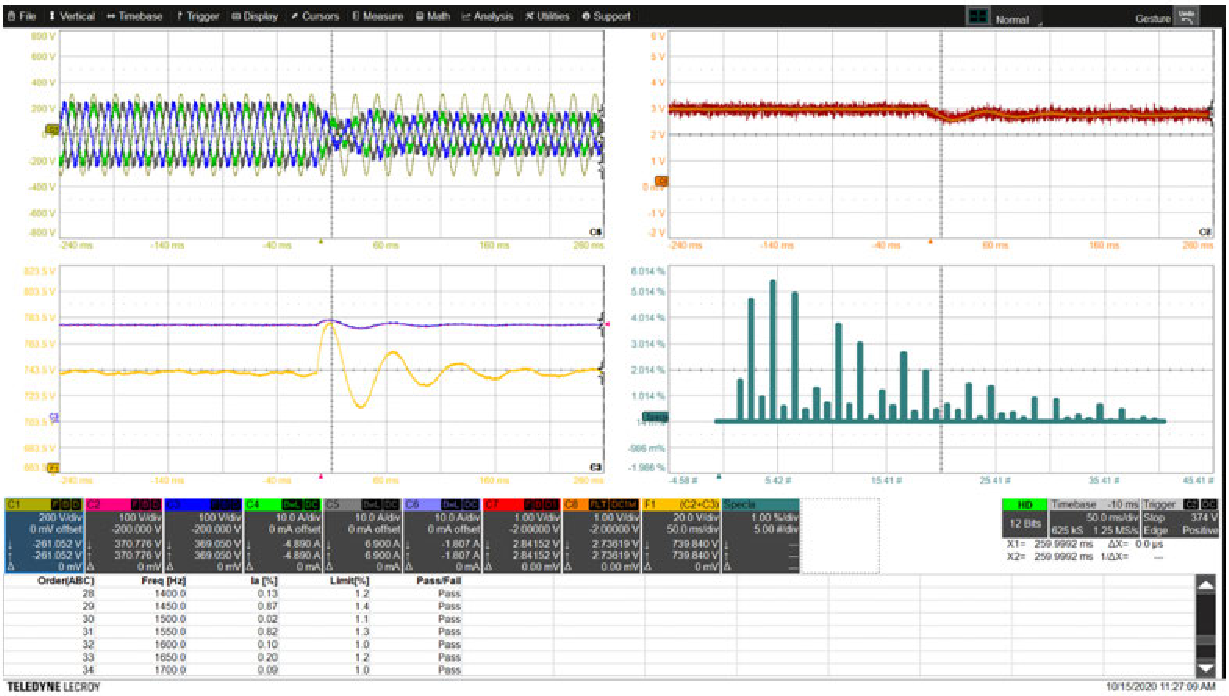
The figure below shows a steady state condition test considering 800 V DC voltage and 220 Vrms AC voltage with 15 kW DC load (constant current). This test represents the PFC operation with the DC voltage regulation active.

Figure 58. PFC operation



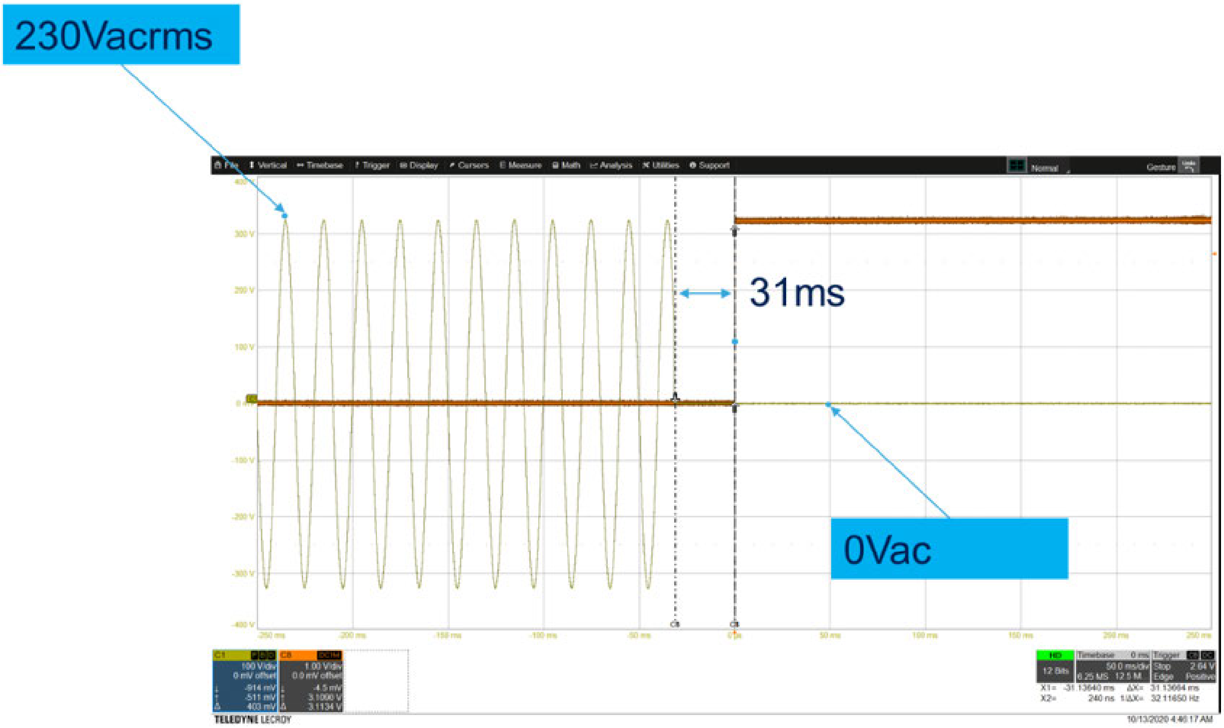
5.2 Step load

Figure 59. Step load



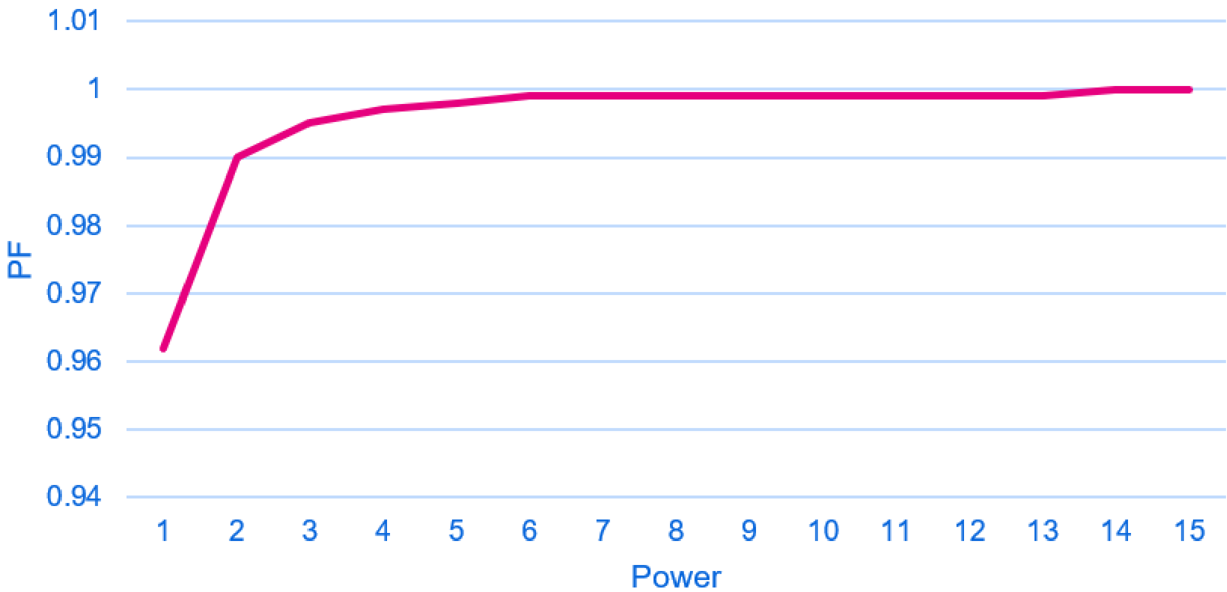
5.3 UVP AC

Figure 60. UVP AC



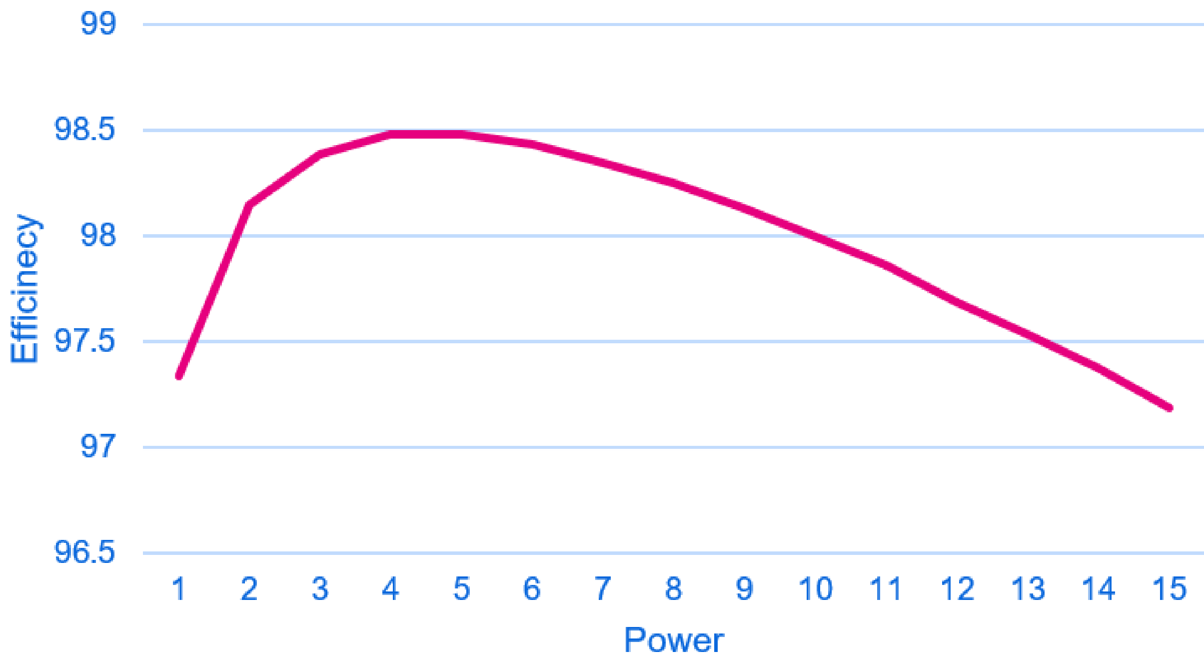
5.4 Power factor

Figure 61. Power factor



5.5 Efficiency

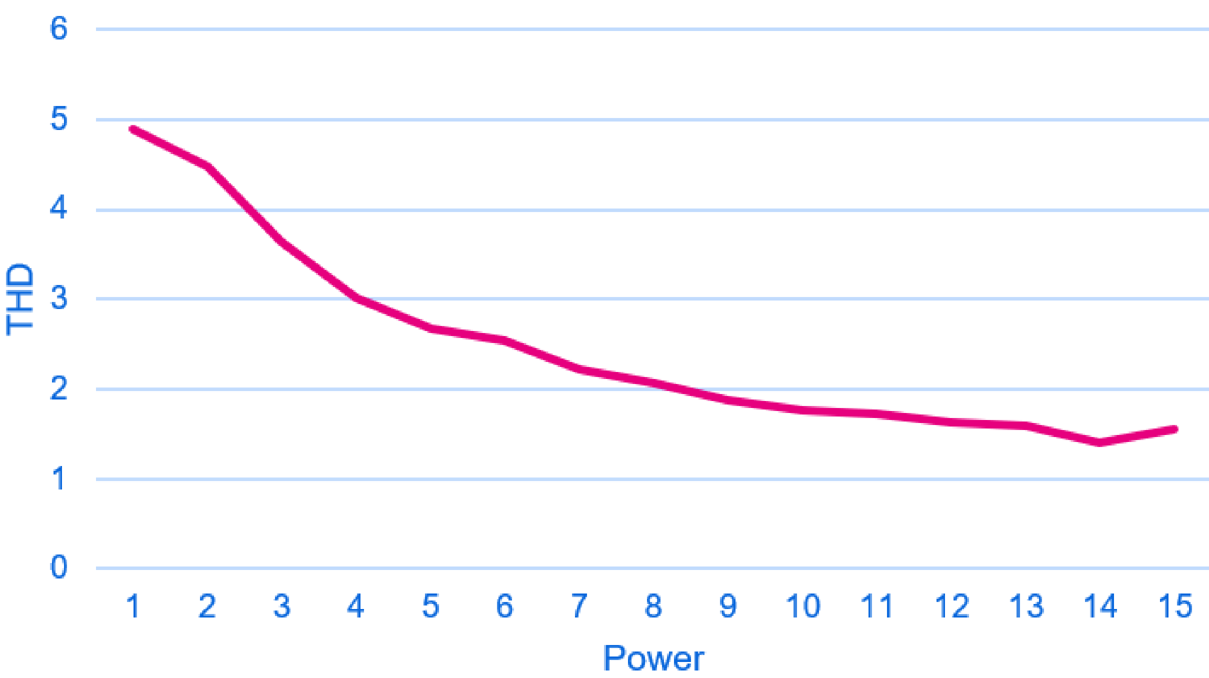
Figure 62. **Efficiency**



5.6 THD

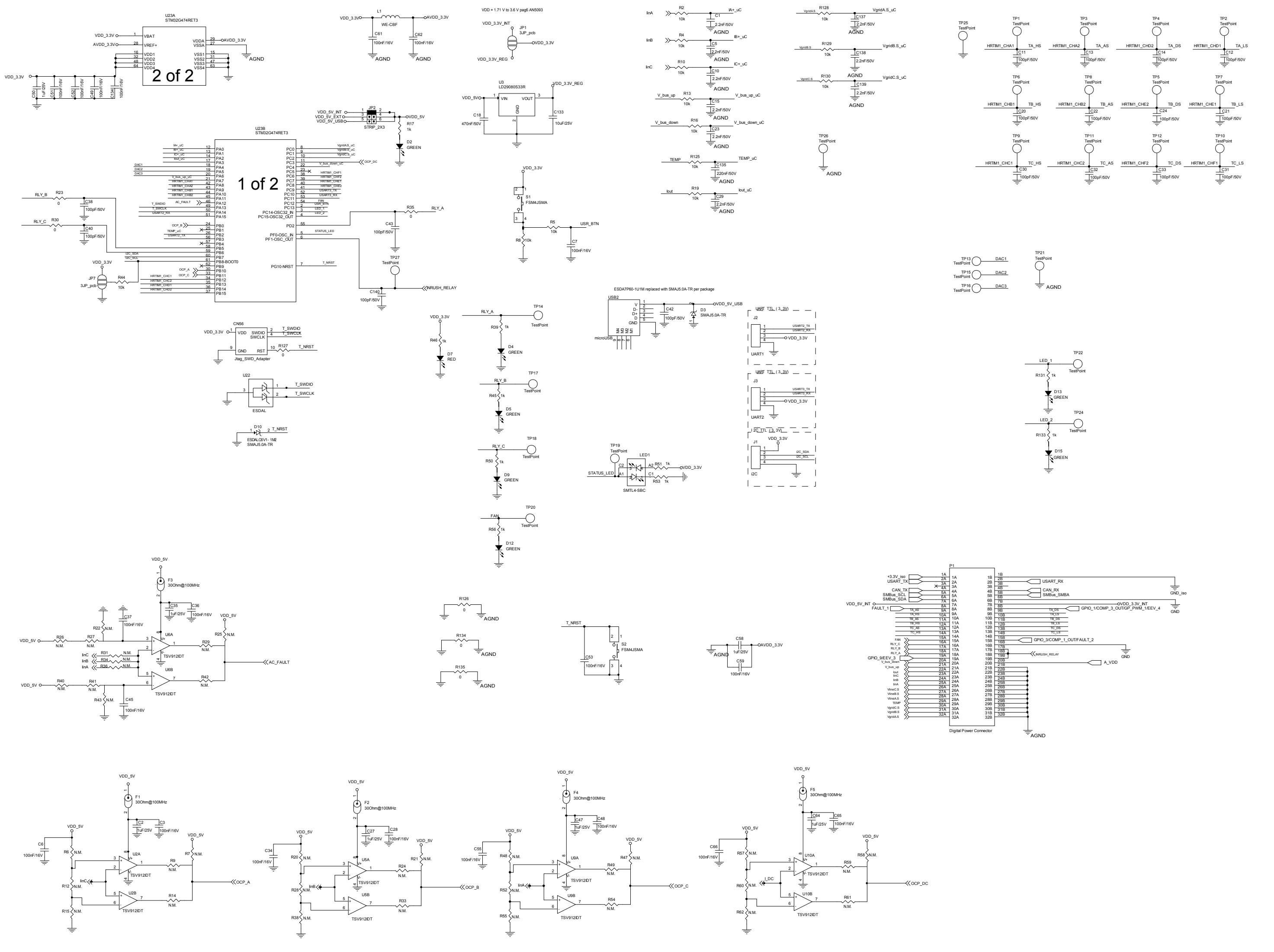
The figure below shows the current THD measurements. Test conditions are V_{AC} = 230 Vrms, V_{DC} = 800 V. According to the specification, THD is lower than 5% starting from 10% of the full load.

Figure 63. **THD**



6 Schematic diagrams

Figure 64. STDES-PFCBIDIR schematic diagram - control board



-Refer to datasheet for PCB orientation of the LED1
-Solder a 22µF / 10V electrolytic capacitor in parallel to C133
-32A-28A | 31A-27A | 30A-26A of P1 connector must be shorted.

Figure 65. STDES-PFCBIDIR schematic diagram - power board: AC current sensing

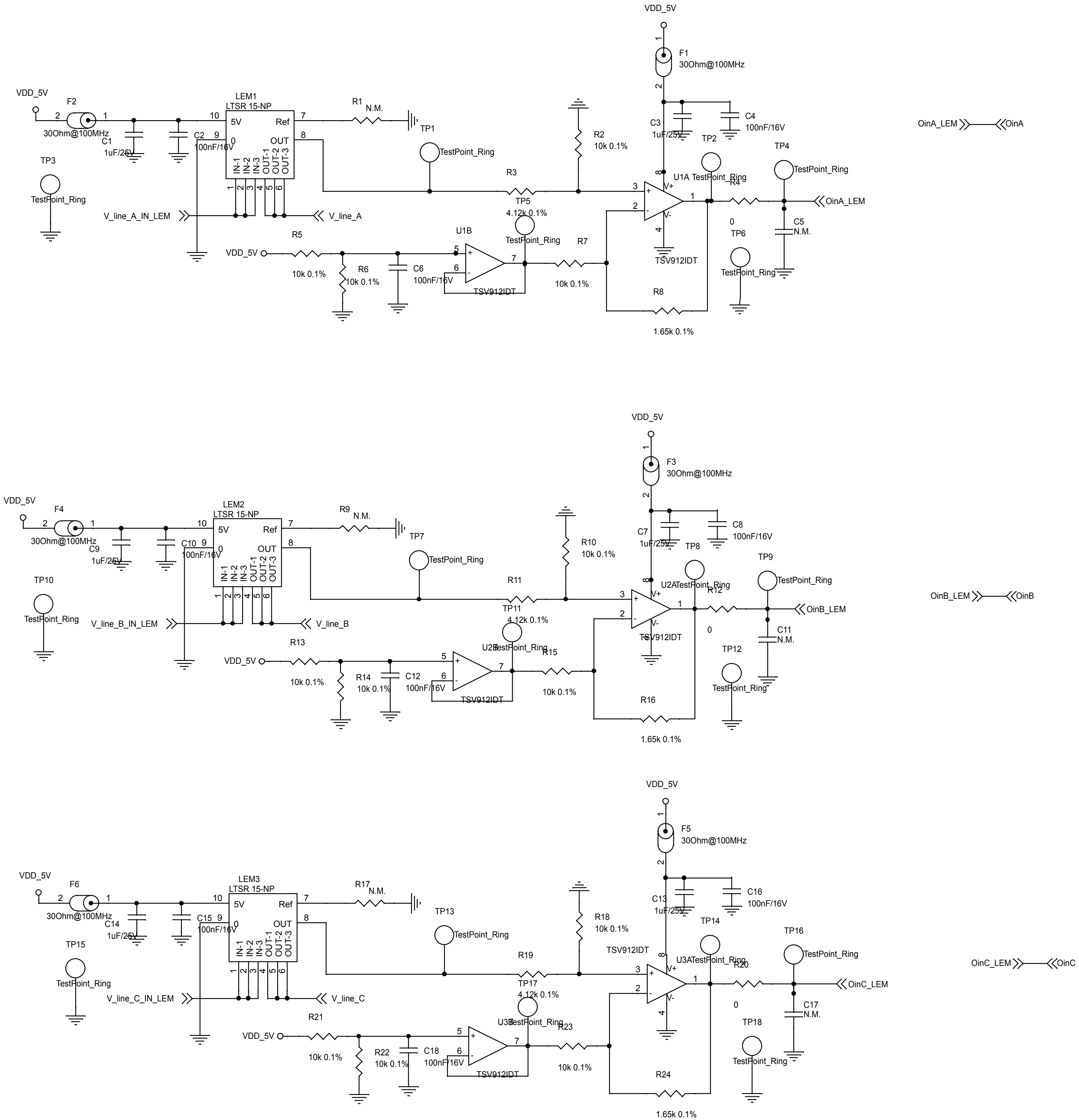


Figure 66. STDES-PFCBIDIR schematic diagram - power board: AC voltage sensing

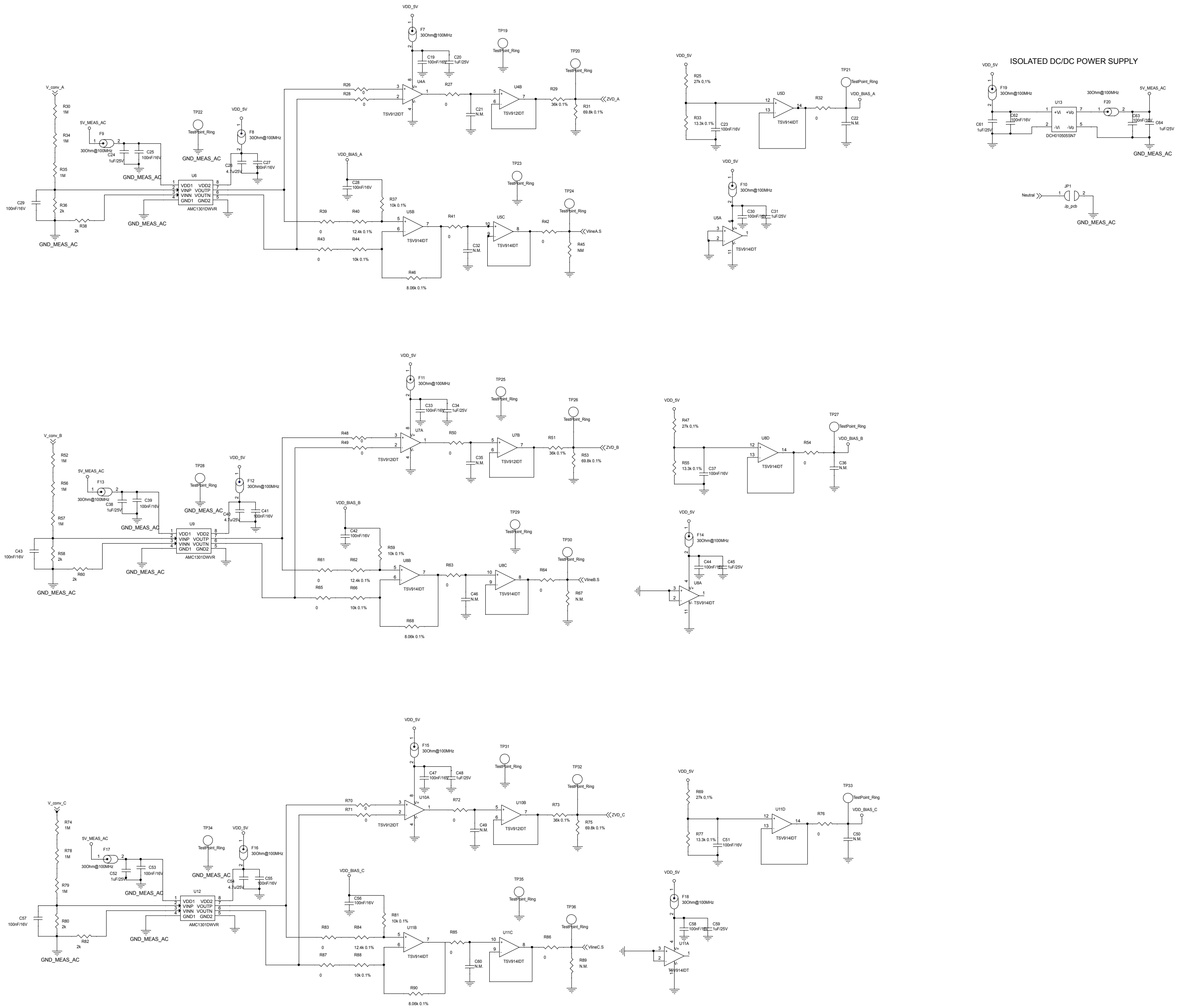


Figure 67. STDES-PFCBIDIR schematic diagram - power board: aux power DC-DC

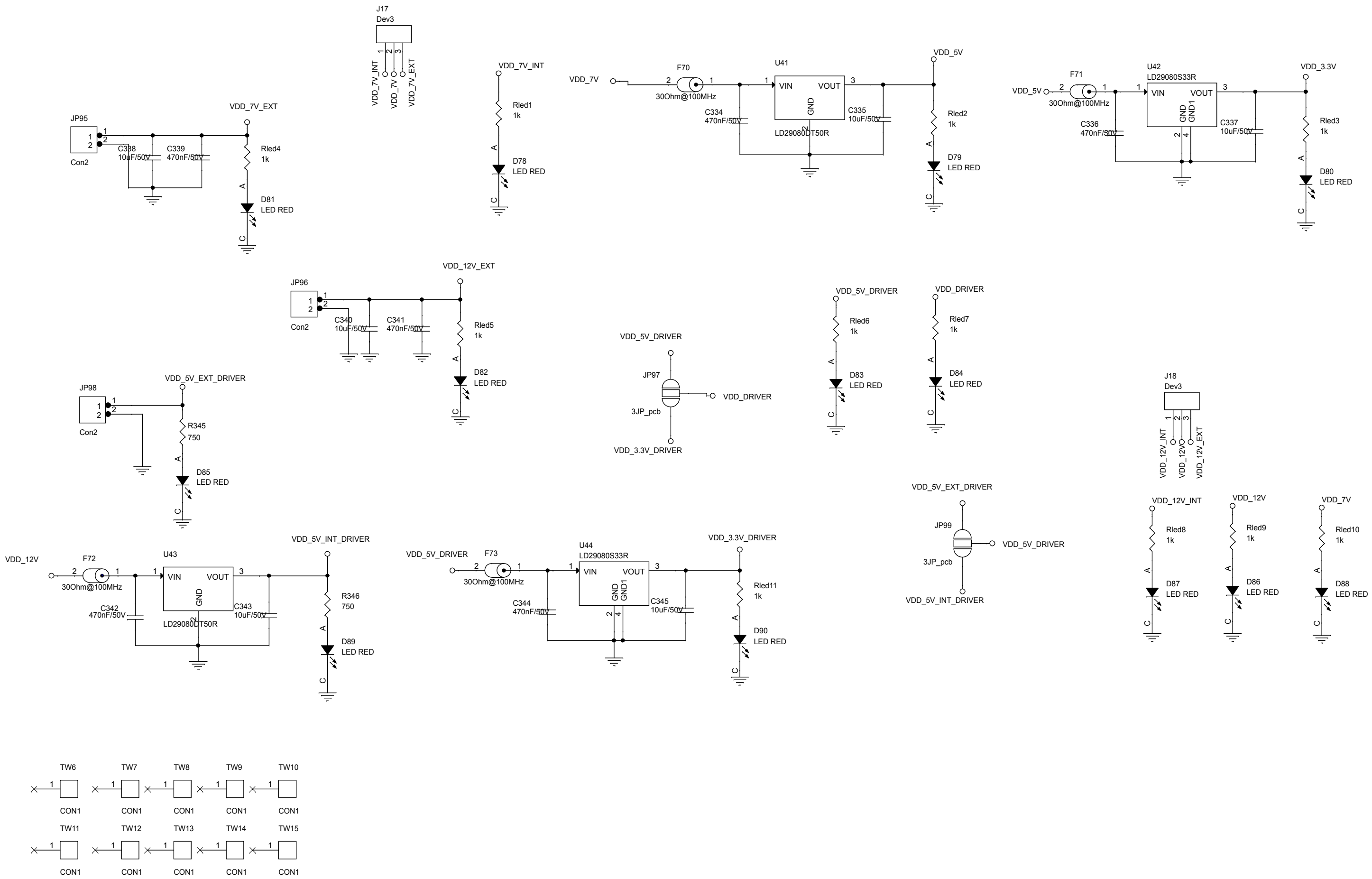


Figure 68. STDES-PFCBIDIR schematic diagram - power board: aux power VIPER

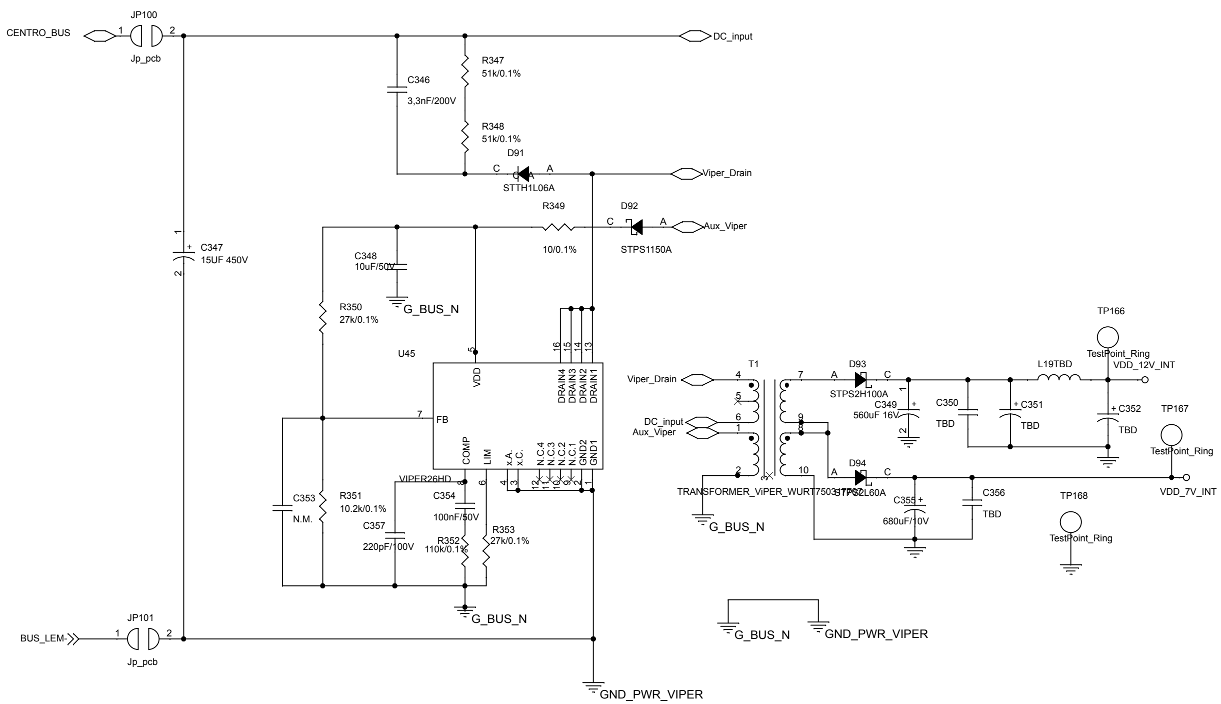


Figure 69. STDES-PFCBIDIR schematic diagram - power board: connector

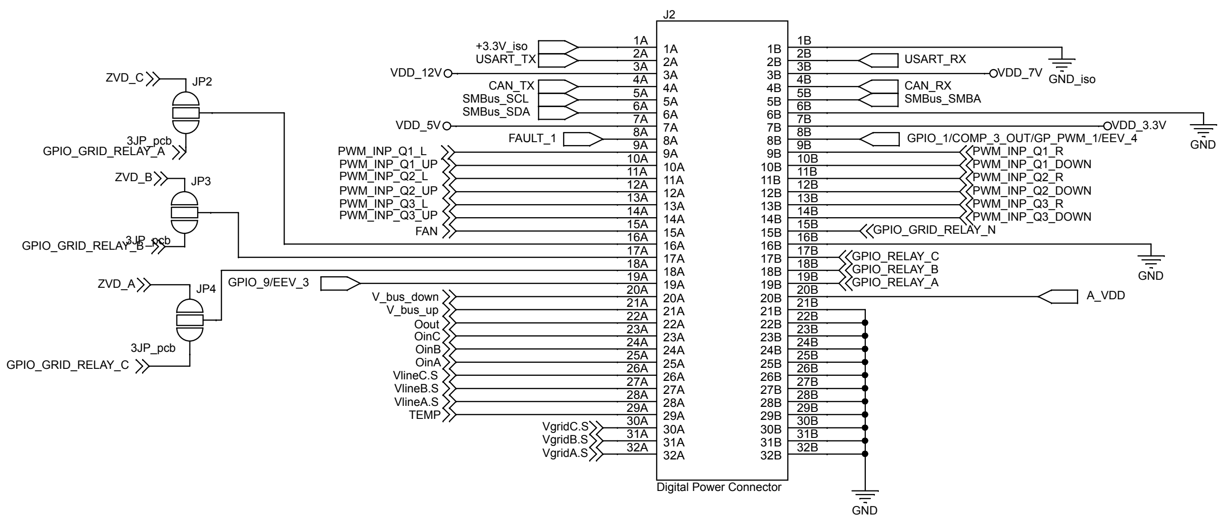


Figure 70. STDES-PFCBIDIR schematic diagram - power board: DC current sensing

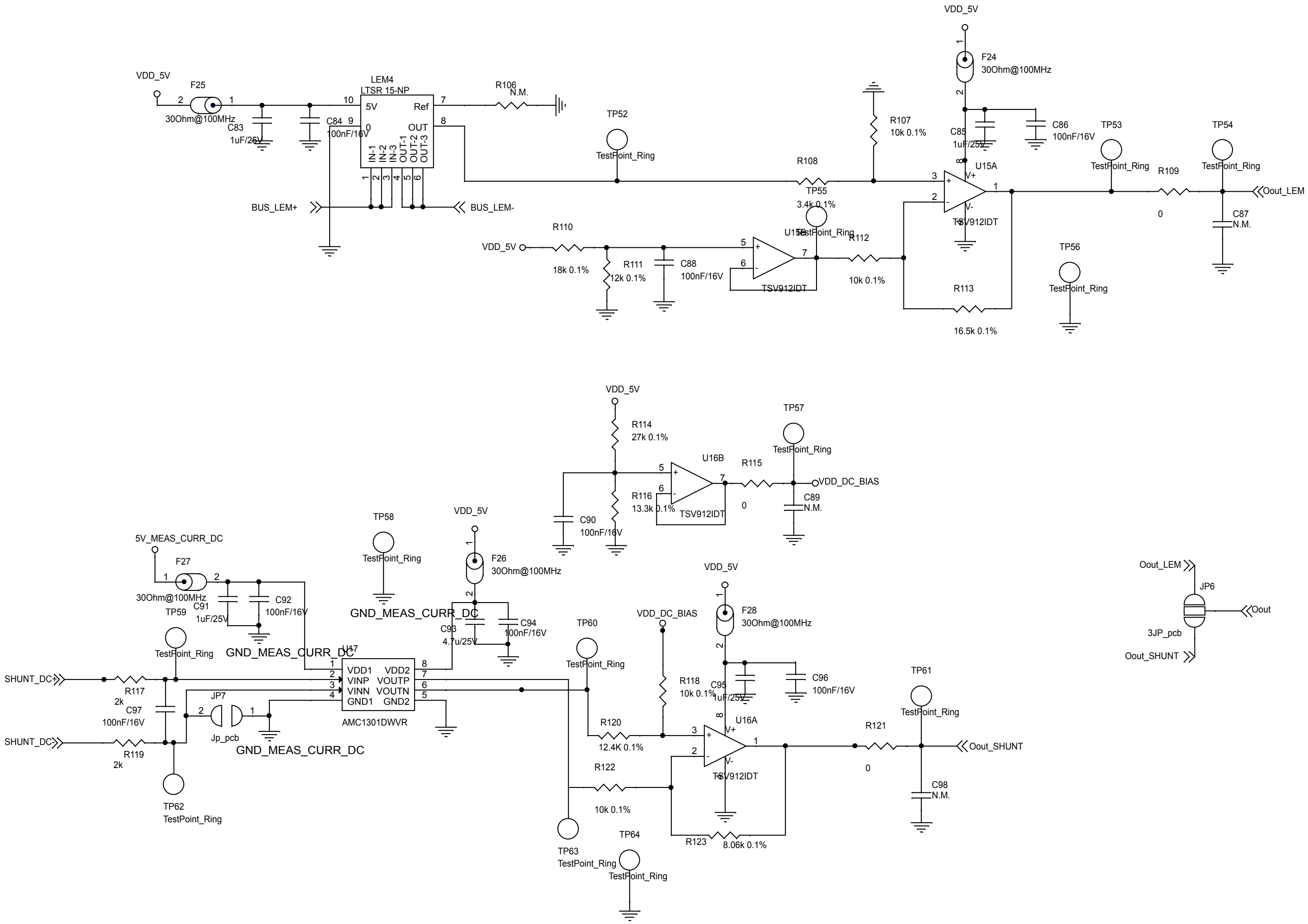


Figure 71. STDES-PFCBIDIR schematic diagram - power board: DC voltage sensing

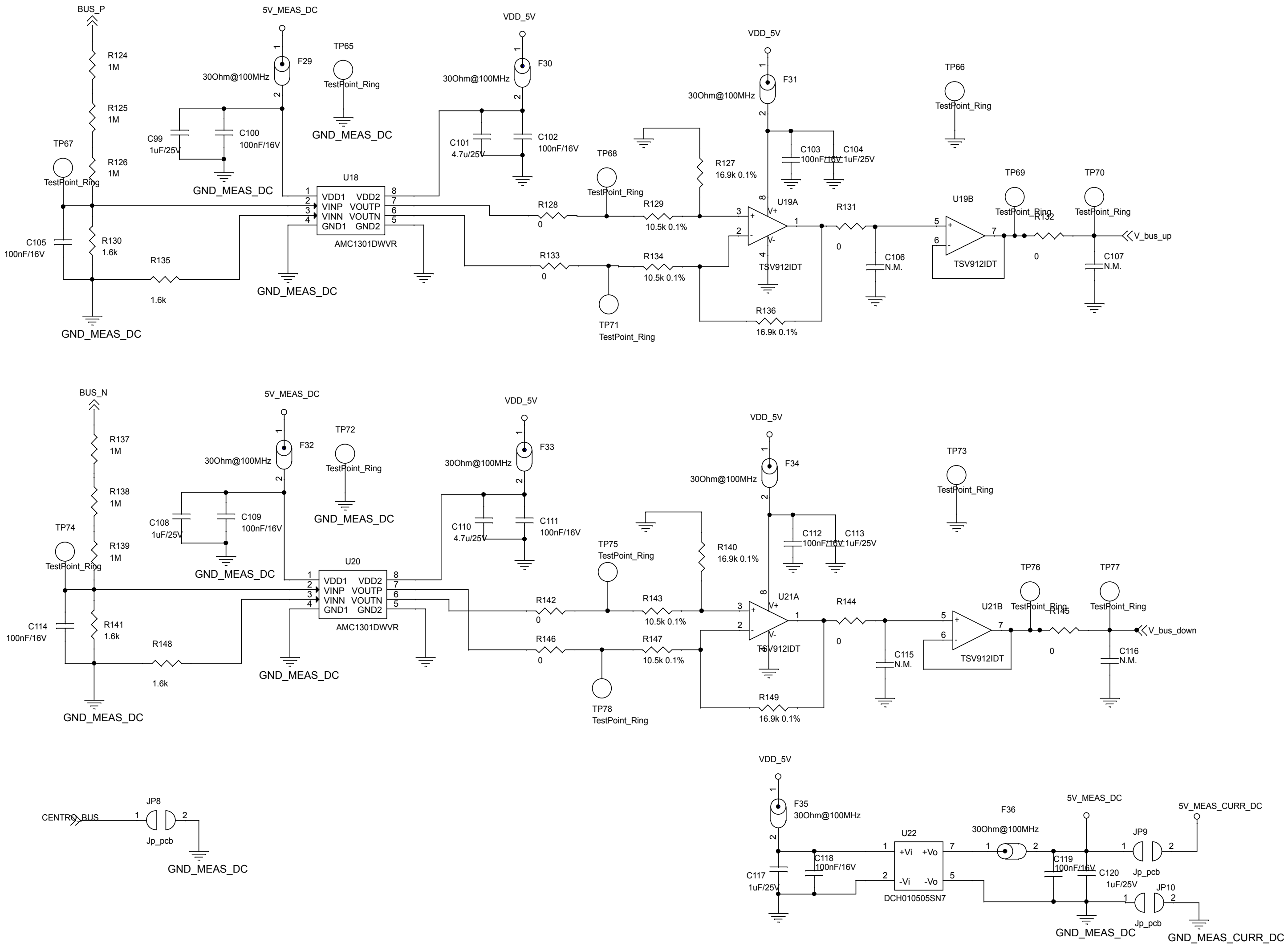


Figure 72. STDES-PFCBIDIR schematic diagram - power board: gate drivers (x12)

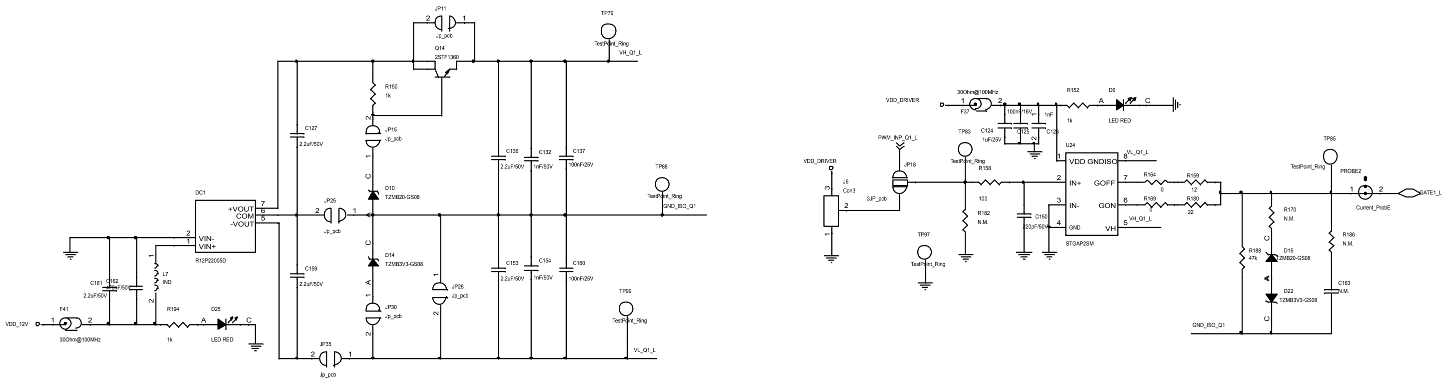


Figure 73. STDES-PFCBIDIR schematic diagram - power board: grid voltage sensing

Figure 74. STDES-PFCBIDIR schematic diagram - power board: power section

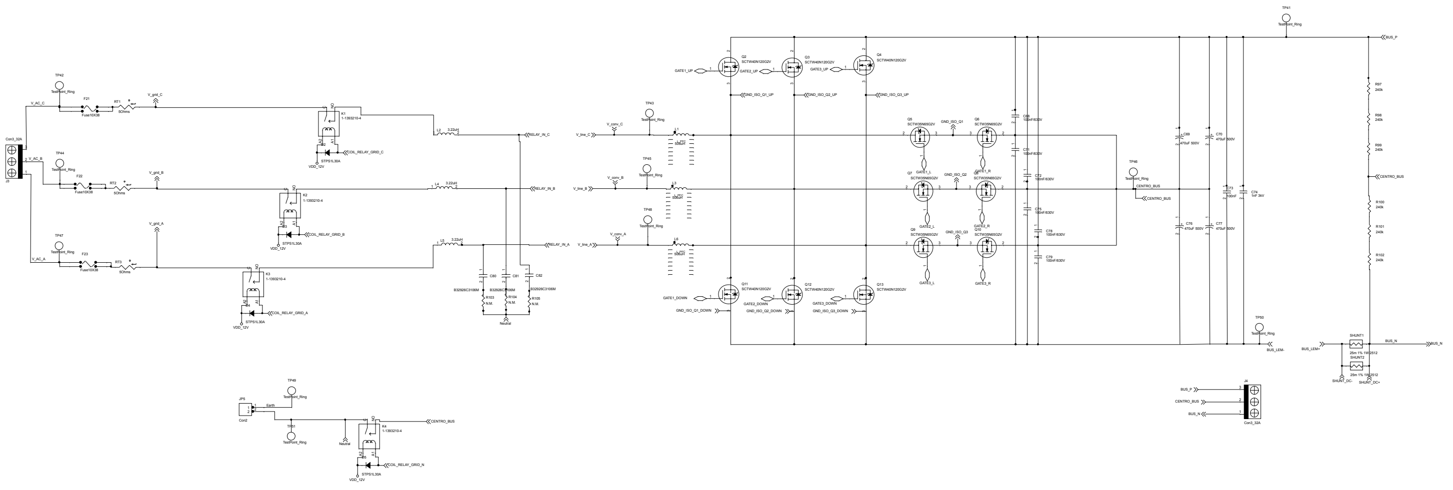


Figure 75. STDES-PFCBIDIR schematic diagram - power board: active inrush current and AC grid connection management

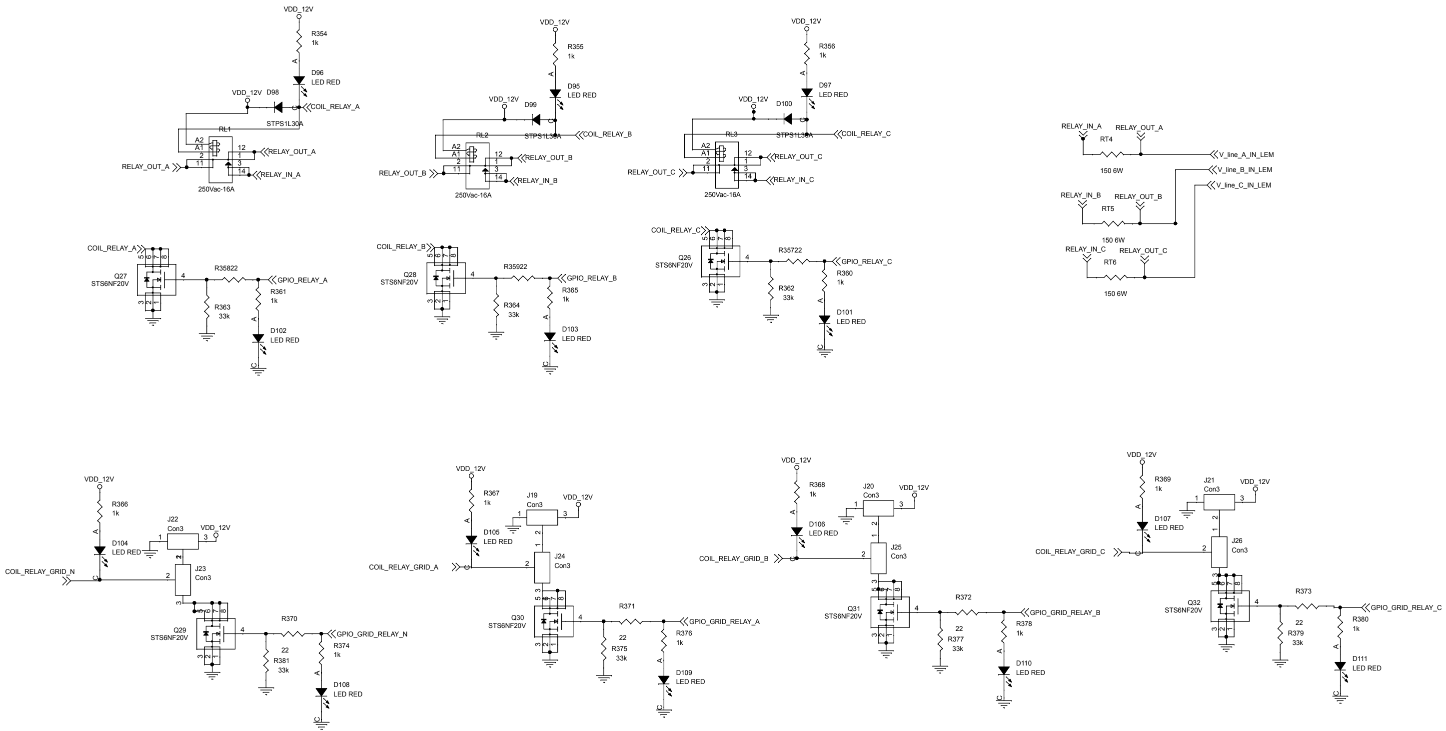
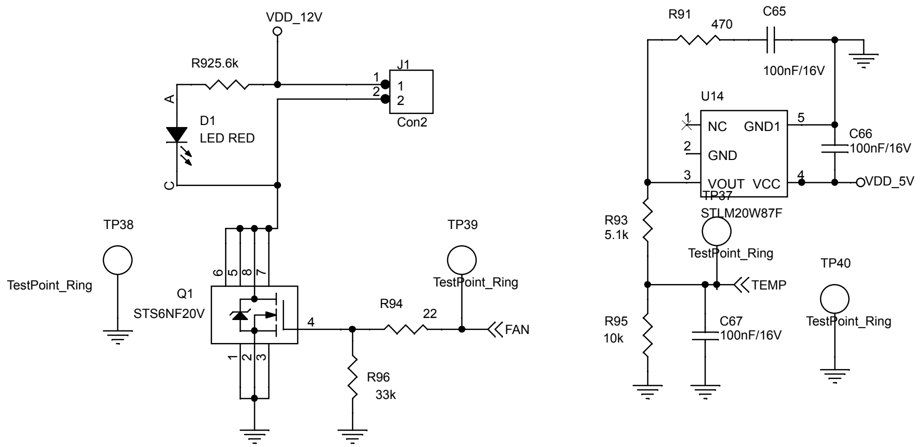


Figure 76. STDES-PFCBIDIR schematic diagram - power board: temp control



7 Bill of materials

Table 7. STDES-PFCBIDIR bill of materials

Item	Q.ty	Ref.	Part/value	Description	Manufacturer	Order code
1	1	Table 8. STDES-PFCBIDIR control board	-	Control board	ST	Not available for separate sale
2	1	Table 9. STDES-PFCBIDIR power board	-	Power board	ST	Not available for separate sale

Table 8. STDES-PFCBIDIR control board

Item	Q.ty	Ref.	Value	Description	Manufacturer	Order code
1	1	CN56	Jtag_SWD_Adapter,	10-way, 2-row, vertical pin header	Wurth	62201021121
2	20	C3,C6, C7,C28,C34, C36,C37,C45,C48,C49,C51,C52,C53,C55,C59,C61,C62,C65,C66,C134	100 nF, 603, 16 V, ±10 %,	Multilayer ceramic capacitors	Wurth	885012206046
3	7	C2,C27,C35, C47,C50,C58,C64	1 µF, 603, 25 V	Multilayer ceramic capacitors	Wurth	885012206076
4	17	C11,C12,C13,C14,C20,C21,C22,C24,C30,C31,C32,C33,C38,C40,C42,C43,C140	100 pF, 603, 50 V	Multilayer ceramic capacitors	Wurth	885012006057
5	1	C135	220nF, 603, 50 V	Multilayer ceramic capacitor	ANY	ANY
6	1	C18	470 nF, 805, 50 V	Multilayer ceramic capacitor	Wurth	885012207102
7	3	C15,C23,C29	2.2 nF, 603, 50 V, ±5 %	Multilayer ceramic capacitors	KEMET	C0603C222J5GACTU
8	1	C133	10 µF, 805, 25 V	Multilayer ceramic capacitor	ANY	ANY
9	7	D2,D4, D5,D9, D12,D13,D15	GREEN, SMD 0805, 2.8 V	Green LED	Wurth	150080GS75000

Item	Q.ty	Ref.	Value	Description	Manufacturer	Order code
10	2	D3,D10	SMAJ5.0A-TR, SMA, 400 W	Uni-directional TVS Diode,	ST	SMAJ5.0A-TR
11	1	D7	RED, SMD 0805, 2.4 V	Red LED	Wurth	150080RS75000
12	5	F1,F2, F3,F4, F5	22 Ohm@100 MHz, 6 A	Ferrite beads	Wurth	742792021
13	2	JP1,JP7 N.A.	3JP_pcb	Solder jumper selectors (not assembled)	ANY	ANY
14	1	JP2 N.A.	STRIP_2X3	Solder jumper selector (not assembled)	ANY	ANY
15	1	J1	i2C, strip4_100m_v	4-way, 1-row, straight pin header	Wurth	61300411121
16	2	J2,J3	CON4, strip4_100m_v,	4-way, 1 row, straight pin header	Wurth	61300411121
17	1	LED1	SMTL4-SBC, 2 V, SMD	LED	BIVAR	SMTL4-SBC
18	1	L1	WE-CBF, 603, 500 m A, ±25 %	Ferrite bead	Wurth	74279262
19	1	P1	CON 64 male	Multipole plug	ERNI	533406
20	13	R2,R4, R5,R8, R10,R13,R16,R19,R44,R125,R128,R129, R130	10 k, 603, 0.1 W, ±1 %	Thick film SMD resistors	ANY	ANY
21	36	R6,R7, R9,R12,R14, R15,R20,R21,R22,R24,R25,R26,R27,R28,R29,R31,R33,R34,R36,R38,R40,R41,R42,R43,R47,R48,R49,R52,R54,R55,R57,R58,R59,R60,R61,R62 N.A.	N.M., 603	Resistors (not mounted)	ANY	ANY

Item	Q.ty	Ref.	Value	Description	Manufacturer	Order code
22	10	R17,R39,R45,R46,R50,R51,R53,R56,R131,R133	1 k, 603, 0.1 W, ±1%	Thick film SMD resistors	ANY	ANY
23	7	R23,R30,R35,R126,R127,R134,R135	0, 603, 0.1 W, ±1%	Thick film SMD resistors	ANY	ANY
24	2	S1,S2	te_fsm4jsma, None	Button tactile switch, single pole single throw (SPST)	TE Connectivity	FSM4JSMATR
25	26	TP1,TP2,TP3,TP4,TP5,TP6,TP7,TP8,TP9,TP10,TP11,TP12,TP13,TP14,TP15,TP16,TP17,TP18,TP19,TP20,TP21,TP22,TP24,TP25,TP26,TP27	TestPoint	Test terminals	ANY	ANY
26	1	USB2	microUSB	Micro USB connector receptacle	MOLEX	47346-0001
27	5	U2,U5,U6,U9,U10	TSV912IDT, SO-8	Wide-bandwidth (8 MHz) rail-to-rail input/output 5 V CMOS op-amp	ST	TSV912IDT
28	1	U3	LD29080, 3.3 V, 800 mA	800 mA fixed and adjustable output very low drop voltage regulator	ST	LD29080
29	1	U23	STM32G474RET3, LQFP 64	Mainstream Arm Cortex-M4 MCU	ST	STM32G474RET3
30	1	U22	ESDAL, 300 W, SOT23-3L	Dual-Element Uni-Directional TVS Diode	ST	ESDA6V1L
31	1	PCB	FR4 4 LAYER, 98x48x1.6mm	PCB FR4- 4 Layer size 98x48x1.6mm	-	-

Table 9. STDES-PFCBIDIR power board

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
1	33	C1, C3, C7, C9, C13, C14, C83, C85, C91, C95, C99, C104, C108, C113, C117, C120, C124, C130, C140, C181, C186, C197, C202, C241, c245, C251, C265, C303, C310, C314, C321, C325, C332	1µF, 25V, ±10%	Multilayer ceramic capacitor SMD, 0603	ANY	ANY
2	55	C2, C4, C6, C8, C10, C12, C15, C16, C18, C84, C86, C88, C90, C92, C94, C96, C97, C100, C102, C103, C105, C109, C111, C112, C114, C122, C125, C131, C141, C182, C187, C198, C203, C242, c246, C255, C266, C302, C304, C306, C307, C308, C309, C313, C315, C317, C318, C319, C320, C324, C326, C328, C329, C330, C331	100nF, 16V, ±10%	Multilayer ceramic capacitor SMD, 0603	ANY	ANY
3	28	C5, C11, C17, C87, C89, C98, C106, C107, C115, C116, C163, C166, C178, C180, C211, C213, C238, C240, C271, c279, C291, C300, C301, C311, C312, C322, C323, C333 N.M (NOT Assembly)	N.M.	(not mounted), 0603	ANY	ANY
4	21	C19, C23, C25, C27, C28, C29, C30, C33, C37, C39, C41, C42, C43, C44, C47, C51, C53, C55, C56, C57, C58	100nF, 16V, ±10%	Multilayer ceramic capacitor SMD, 0603	ANY	ANY

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
5	11	C20, C24, C31, C34, C38, C45, C48, C52, C59, C61, C64	1µF, 25V, ±10%	Multilayer ceramic capacitor SMD, 0603	ANY	ANY
6	9	C21, C22, C32, C35, C36, C46, C49, C50, C60 N.M (NOT Assembly)	N.M.	(not mounted), 0603	ANY	ANY
7	3	C26, C40, C54	4.7µF, 25V, ±10%	Multilayer ceramic capacitor SMD, 0603	ANY	ANY
8	2	C62, C63	100nF, 16V, ±10%	Multilayer ceramic capacitor SMD, 0603	ANY	ANY
9	3	C65, C66, C67	100nF, 16V, ±10%	Multilayer ceramic capacitor SMD, 0603	ANY	ANY
10	6	C68, C71, C72, C75, C78, C79	100nF, 630V, ±10%	Multilayer ceramic capacitor SMD, 1812	Murata	GRM43DR72J104KW01 L
11	4	C69, C70, C76, C77	470µF, 500V	Electrolytic Capacitor Through Hole	Vishay BC Components	MAL215759471E3
12	1	C73	100nF, 3kV, ±5%	Polypropylene Capacitor	KEMET	R474N310050A1K
13	1	C74	1nF, 3kV, ±5%	Polypropylene Capacitor	KEMET	PHE450XB4100JB04R1 7
14	3	C80, C81, C82	10µF, 305V, ±20%	Polypropylene Capacitor through hole	EPCOS	B32926C3106M000
15	6	C93, C101, C110, C305, C316, C327	4.7µF, 25V, ±10%	Multilayer ceramic capacitor SMD, 0603	ANY	ANY
16	2	C118, C119	100nF, 16V, ±10%	Multilayer ceramic capacitor SMD, 0604	ANY	ANY
17	1	C121	1µF, 25V, ±10%	Multilayer ceramic capacitor SMD, 0605	ANY	ANY
18	12	C123, C126, C129, C142, C183, C185, C193, C204, C243, C247, C256, C267	1nF, 25V, ±10%	Ceramic Capacitor X7R	Samsung Electro-Mechanics	CL10B102KA8NNNC
19	60	C127, C128, C133, C135, C136, c143, C145, c146, C153, C155, C156, C159, C161, C164, c167, C170, C171, c174, C176, c179, C184, C188, C189, C194, C196, C201,	2.2µF, 50V, ±10%	Multilayer ceramic capacitor SMD, 1206	ANY	ANY

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
		C205, C210, C216, C217, C221, C222, C225, C227, C228, C230, C231, C234, C235, C239, C244, C248, C253, C254, C259, C261, C264, C268, C274, C275, C278, C281, C283, C286, C287, C289, C292, C294, C295, C298				
20	24	C132, C138, C144, c148, C154, C157, c168, C172, C190, C199, C206, C208, C214, C219, C223, C232, C249, C258, C262, C269, C272, C280, C284, C296	1nF, 50V, ±10%	Multilayer ceramic capacitor SMD, 1206	ANY	ANY
21	24	C134, C137, C139, c147, C158, C160, c169, c173, C191, C195, C207, C209, C218, C220, C224, C233, C250, C257, C260, C270, C276, C285, C288, C297	100nF, 25V, ±5%	Multilayer ceramic capacitor SMD, 1206	ANY	ANY
22	12	C149, C150, C151, C152, C192, C200, C212, C215, C252, c263, C273, C282	220pF, 50V, ±5%	Multilayer ceramic capacitor SMD, 0603	ANY	ANY
23	18	C162, C165, c175, C177, C226, C229, C236, C237, C277, C290, C293, C299, C334, C336, C339, C341, C342, C344	470nF, 50V, ±10%	Multilayer ceramic capacitor SMD, 0805	Murata	ANY
24	6	C335, C337, C338, C340, C343, C345	10µF, 50V, ±10%	Multilayer ceramic capacitor SMD, 0805	Murata	ANY
25	1	C346	3,3nF, 200V, ±10%	Multilayer ceramic capacitor SMD	ANY	ANY

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
26	1	C347	15µF, 450V	Electrolytic Capacitor Through Hole	Panasonic Electronic Components	EEU-EE2W150
27	1	C348	10µF, 50V, ±10%	Multilayer ceramic capacitor SMD, 0805	Murata	ANY
28	1	C349	560µF, 16V	Polypropylene Capacitor through hole	Panasonic Electronic Components	16SEPF560M
29	2	C350, C356 N.M.	N.M.	(not mounted)	-	-
30	2	C351, C352 N.M.	N.M.	(not mounted)	-	-
31	1	C353	N.M.	(not mounted)	-	-
32	1	C354	100nF, 50V, ±10%	Multilayer ceramic capacitor SMD, 0805	ANY	ANY
33	1	C355	680µF, 10V	Polypropylene Capacitor through hole	ANY	ANY
34	1	C357	220pF, 100V, ±5%	Multilayer ceramic capacitor SMD, 0805	ANY	ANY
35	12	DC1, DC2, DC3, DC4, DC5, DC6, DC7, DC8, DC9, DC10, DC11, DC12	Vin 10.8 - 13.2V dc, Vout -5V dc, 20, 2W	Isolated DC-DC Converter Through Hole, R24P22005D	Recom Power	R12P22005D
36	1	D1	RED, 2.4V, 20mA	LED SMD, 3216 (1206)	Lumex Opto/ Components Inc.	SML-LX1206SIC-TR
37	7	D2, D3, D4, D5, D98, D99, D100	30V, 1A	Schottky Diode, 2-Pin, DO-214AC, SMA	ST	STPS1L30A
38	51	D6, D7, D8, D9, D25, D26, D28, D29, D30, D31, D32, D33, D48, D50, D51, D53, D54, D55, D56, D58, D70, D74, D75, D77, D78, D79, D80, D81, D82, D83, D84, D85, D86, D87, D88, D89, D90, D95, D96, D97, D101, D102, D103, D104, D105, D106, D107, D108, D109, D110, D111	RED, 20mA	LED SMD, 3216 (1206)	Lumex Opto/ Components Inc.	SML-LX1206SIC-TR

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
39	24	D10, D11, D12, D13, D15, D17, D18, D19, D34, D35, D36, D37, D38, D39, D45, D47, D57, D59, D60, D61, D64, D65, D67, D73	20V, 500mW	Zener Diode SMT 2-Pin MiniMELF	Vishay Semiconductor Diodes Division	TZMB20-GS08
40	24	D14, D16, D20, D21, D22, D23, D24, D27, D40, D41, D42, D43, D44, D46, D49, D52, D62, D63, D66, D68, D69, D71, D72, D76	3.3V, 500mW	Zener Diode SMT 2-Pin MiniMELF	Vishay Semiconductor Diodes Division	TZMB3V3-GS08
41	1	D91	600V, 1A	Silicon Junction Diode, 2-Pin DO-214AC	ST	STTH1L06A
42	1	D92	150V, 1A	Silicon Junction Diode, 2-Pin DO-214AC	ST	STPS1150A
43	1	D93	100V, 2A	Silicon Junction Diode, 2-Pin DO-214AC	ST	STPS2H100A
44	1	D94	60V, 2A	Silicon Junction Diode, 2-Pin DO-214AC	ST	STPS2L60A
45	70	F1, F2, F3, F4, F5, F6, F7, F8, F9, F10, F11, F12, F13, F14, F15, F16, F17, F18, F19, F20, F24, F25, F26, F27, F28, F29, F30, F31, F32, F33, F34, F35, F36, F37, F38, F39, F40, F41, F42, F43, F44, F45, F46, F47, F48, F49, F50, F51, F52, F53, F54, F55, F56, F57, F58, F59, F60, F61, F62, F63, F64, F65, F66, F67, F68, F69, F70, F71, F72, F73	30Ω@100MHz, 6A	Ferrite Beads 10mΩ Ferrite Chip, 0805	TDK Corporation	MPZ2012S300AT000
46	3	F21, F22, F23	Fuse10X38	Fuse Clips TRON FUSE CLIP	Eaton	BK/1A3400-09-R
47	1	JP1 N.M (NOT Assembly)	Jp_pcb	Solder jumper (not mounted)	-	-

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
48	16	JP2, JP3, JP4, JP6, JP18, JP20, JP21, JP24, JP43, JP44, JP51, JP52, JP72, JP75, JP76, JP82 N.M (NOT Assembly)	3JP_pcb	Solder jumper selector (not mounted)	-	-
49	1	JP5	Con2	Fixed Terminal Blocks GMKDS 3/2-7.62	Phoenix Contact	1731721
50	77	JP7, JP9, JP10, JP11, JP12, JP13, JP14, JP15, JP16, JP17, JP19, JP22, JP23, JP25, JP26, JP27, JP28, JP29, JP30, JP31, JP32, JP33, JP34, JP35, JP36, JP37, JP38, JP39, JP40, JP41, JP42, JP45, JP46, JP47, JP48, JP49, JP50, JP53, JP54, JP55, JP56, JP57, JP58, JP59, JP60, JP61, JP62, JP63, JP64, JP65, JP66, JP67, JP68, JP69, JP70, JP71, JP73, JP74, JP77, JP78, JP79, JP80, JP81, JP83, JP84, JP85, JP86, JP87, JP88, JP89, JP90, JP91, JP92, JP93, JP94, JP100, JP101 N.M (NOT Assembly)	Jp_pcb	Solder jumper (not mounted)	-	-
51	1	JP8	Jp_pcb	Solder jumper	-	-
52	3	JP95, JP96, JP98	Con2	Fixed Terminal Blocks 2P 5.08mm 90DEG	Phoenix Contact	1729128
53	2	JP97, JP99	3JP_pcb	Solder jumper selector	-	-
54	1	J1	Con2	Fixed Terminal Blocks 2P 5.08mm 90DEG	Phoenix Contact	1729128

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
55	1	J2	Digital Power Connector	DIN 41612 Connectors 64P 2.54MM VERT FML TYPE B 4MM SLDR	ERNI	284166 32X2
56	2	J3, J4	Con3_32A	Phoenix Contact MKDS 5/3-9.5, 3 Way PCB Terminal Strip	Phoenix Contact	1714984
57	20	J5, J6, J7, J8, J9, J10, J11, J12, J13, J14, J15, J16, J19, J20, J21, J22, J23, J24, J25, J26	Con3	HARWIN M20, 3 Way, 1 Row, Straight Pin Header	Harwin Inc.	M20-9990345
58	2	J17, J18	Dev3, 500mA (DC)	Through Hole Slide Switch Single Pole Double Throw (SPDT) Latching 100 mA@ 42V dc Slide	Wurth Electronics Inc.	450301014042
59	4	K1, K2, K3, K4	1-1393210-4	General Purpose Relay SPST-NO (1 Form A) 15VDC Coil Through Hole	TE Connectivity Potter & Brumfield Relays	T9AS1D12-15
60	4	LEM1, LEM2, LEM3, LEM4	LTSR 15-NP, 0 - ±48A nom	LEM LTSR Series Closed Loop Current Sensor, LTSR 25-NP	LEM USA Inc.	LTSR 15-NP
61	3	L1, L3, L6	514µH	Boost Inductor	Wurth Electronics Inc.	750344313
62	3	L2, L4, L5	3.22µH, 20.5 A	Fixed Inductors Inductors, Coils, Chokes Fixed - INDUCTOR POWER TOROID TH	Pulse Electronics	PA0431LNL
63	12	L7, L8, L9, L10, L11, L12, L13, L14, L15, L16, L17, L18	22µH, 4810mΩ, 130Ma, ±20%	Fixed Inductors, 0805 (2012 Metric)	Taiyo Yuden	LBC2012T220M
64	1	L19	N.M.	(not mounted), SMD 4.5x4mm	-	-
65	12	PROBE1, PROBE2, PROBE3, PROBE4, PROBE5, PROBE6, PROBE7, PROBE8, PROBE9, PROBE10, PROBE11, PROBE12 N.M (NOT Assembly)	Current_ProbE	Solder Current Probe	-	-
66	1	Q1	20V, 6A	MOSFET N-CH 8SOIC	ST	STS6NF20V

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
67	6	Q5, Q6, Q7, Q8, Q9, Q10, N.M (NOT Assembly)	650V, 45A	Silicon Carbide HIP247 (not mounted)	ST	SCTW35N65G2V
68	12	Q14, Q15, Q16, Q17, Q18, Q19, Q20, Q21, Q22, Q23, Q24, Q25	60V, 3A	NPN Transistor, 3-Pin SOT-89	ST	2STF1360
69	7	Q26, Q27, Q28, Q29, Q30, Q31, Q32	20V, 6A	N-Channel MOSFET, 8-Pin SOIC, SO8	ST	STS6NF20V
70	3	RL1, RL2, RL3	250Vac-16A, 12V dc coil, 16A	Phoenix Contact REL-MR- 12DC/ 21HC SPDT Non-Latching Relay PCB Mount, TRH	Phoenix Contact	2961309
71	3	RT1, RT2, RT3	5Ω, 32mm, 20A	Inrush Current Limiters KINK INRSH CURR LIMITER	Ametherm	SL32 5R020-B
72	3	RT4, RT5, RT6	150Ω, 6W, ±0.1%	Thin Film SMD Resistor, 2512 (6432M)	Vishay	PCAN2512E1500BST3
73	60	Rled1, Rled2, Rled3, Rled4, Rled5, Rled6, Rled7, Rled8, Rled9, Rled10, Rled11, R150, R151, R152, R153, R154, R155, R156, R157, R194, R195, R196, R197, R198, R199, R200, R201, R202, R206, R207, R211, R242, R243, R244, R245, R246, R247, R248, R249, R251, R254, R259, R262, R287, R291, R292, R293, R354, R355, R356, R360, R361, R365, R366, R367, R369, R374, R376, R378, R380	1k, 0.1W, ±1%	Thick Film SMD Resistor, 0603	ANY	ANY
74	40	R1, R9, R17, R106, R170, R171, R172, R173, R182, R183, R184, R185, R186, R187, R190, R191, R214, R215, R218, R219, R220,	N.M.	(not mounted), 0603	-	-

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
		R221, R232, R235, R236, R237, R238, R240, R255, R256, R266, R270, R271, R275, R276, R278, R281, R286, R288, R289 N.M (NOT Assembly)				
75	22	R2, R5, R6, R7, R10, R13, R14, R15, R18, R21, R22, R23, R107, R112, R118, R122, R301, R308, R318, R325, R335, R342	10k, 0.1W, ±0.1%	Thin Film SMD Resistor, 0603	ANY	-
76	3	R3, R11, R19	4.12k, 0.1W, ±0.1%	Metal Film SMD Resistor, 0603	ANY	-
77	16	R4, R12, R20, R109, R115, R121, R131, R132, R144, R145, R296, R305, R313, R322, R330, R339	0Ω, 0.1W, ±1%	Thick Film SMD Resistor, 0603	ANY	-
78	3	R8, R16, R24	1.65k, 0.1W, ±0.1%	Metal Film SMD Resistor, 0603	ANY	-
79	3	R25, R47, R69	27k, 0.1W, ±0.1%	Thin Film SMD Resistor, 0603	ANY	ANY
80	15	R26, R27, R28, R32, R41, R48, R49, R50, R54, R63, R70, R71, R72, R76, R85	0Ω, 0.1W, ±1%	Thick Film SMD Resistor, 0603	ANY	ANY
81	3	R29, R51, R73	36k, 0.1W, ±0.1%	Thin Film SMD Resistor, 0603	ANY	ANY
82	9	R30, R34, R35, R52, R56, R57, R74, R78, R79	1M, 0.25W, ±0.1%	Thin Film SMD Resistor, 1206	ANY	ANY
83	3	R31, R53, R75	69.8k, 0.063W, ±0.1%	Thin Film SMD Resistor, 0603	ANY	ANY
84	3	R33, R55, R77	13.3k, 0.1W, ±0.1%	Metal Film SMD Resistor, 0603	ANY	ANY
85	6	R36, R38, R58, R60, R80, R82	2k, 0.1W, ±0.1%	Thin Film SMD Resistor, 0603	ANY	ANY
86	6	R37, R44, R59, R66, R81, R88	10k, 0.1W, ±0.1%	Thin Film SMD Resistor, 0603	ANY	ANY
87	6	R39, R43, R61, R65, R83, R87	0, 0.1W, ±1%	Thick Film SMD Resistor, 0603	ANY	ANY
88	3	R40, R62, R84	12.4k, 0.1W, ±0.1%	Metal Film SMD Resistor, 0603	ANY	ANY
89	3	R42, R64, R86	0Ω, 0.1W, ±1%	Thick Film SMD Resistor, 0603	ANY	ANY

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
90	1	R45	N.M.	(not mounted), 0603	ANY	ANY
91	3	R46, R68, R90	8.06k, 0.1W, ±0.1%	Thin Film SMD Resistor, 0603	ANY	ANY
92	2	R67, R89	N.M.	(not mounted), 0603	ANY	ANY
93	1	R91	470Ω, 0.1W, ±1%	Thick Film SMD Resistor, 0603	ANY	ANY
94	1	R92	5.6k, 0.1W, ±1%	Thick Film SMD Resistor, 0603	ANY	ANY
95	1	R93	5.1k, 0.25W, ±1%	Thick Film SMD Resistor, 0603	ANY	ANY
96	1	R94	22Ω, 0.25W, ±1%	Thick Film SMD Resistor, 1206	ANY	ANY
97	1	R95	10k, 0.1W, ±1%	Thick Film SMD Resistor, 0603	ANY	ANY
98	1	R96	33k, 0.1W, ±1%	Thick Film SMD Resistor, 0604	ANY	ANY
99	6	R97, R98, R99, R100, R101, R102	240k, 0.25W, ±1%	Thick Film SMD Resistor, 1206	ANY	ANY
100	3	R103, R104, R105	220mΩ, 7W, ±5%	Wire Wound Resistor	ANY	ANY
101	1	R108	3.4k, 0.1W, ±0.1%	Metal Film SMD Resistor, 0603	ANY	ANY
102	1	R110	18k, 0.1W, ±0.1%	Thin Film SMD Resistor, 0603	ANY	ANY
103	1	R111	12k, 0.1W, ±0.1%	Thin Film SMD Resistor, 0603	ANY	ANY
104	1	R113	16.5k, 0.1W, ±0.1%	Metal Film SMD Resistor, 0603	ANY	ANY
105	1	R114	27k, 0.1W, ±0.1%	Thin Film SMD Resistor, 0603	ANY	ANY
106	1	R116	13.3k, 0.1W, ±0.1%	Metal Film SMD Resistor, 0603	ANY	ANY
107	8	R117, R119, R300, R302, R317, R319, R334, R336	2k, 0.1W, ±0.1%	Thin Film SMD Resistor, 0603	ANY	ANY
108	4	R120, R304, R321, R338	12.4k, 0.1W, ±0.1%	Metal Film SMD Resistor, 0603	ANY	ANY
109	1	R123	8.06k, 0.1W, ±0.1%	Metal Film SMD Resistor, 0603	ANY	ANY
110	15	R124, R125, R126, R137, R138, R139, R295, R298, R299, R312, R315, R316, R329, R332, R333	1M, 0.25W, ±0.1%	Thin Film SMD Resistor, 1206	ANY	ANY
111	4	R127, R136, R140, R149	16.9k, 0.063W, ±0.1%	Thin Film SMD Resistor, 0603	ANY	ANY

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
112	4	R128, R133, R142, R146	0, ±1%	Thick Film SMD Resistor, 0603	ANY	ANY
113	4	R129, R134, R143, R147	10.5k, 0.063W, ±0.1%	Thin Film SMD Resistor, 0603	ANY	ANY
114	4	R130, R135, R141, R148	1.6k, 0.063W, ±0.1%	Metal Film SMD Resistor, 0603	ANY	ANY
115	12	R158, R160, R163, R181, R203, R208, R223, R227, R250, R261, R263, R282	100Ω, 0.1W, ±1%	Thick Film SMD Resistor, 0603	ANY	ANY
116	12	R159, R162, R166, R179, R205, R210, R224, R229, R253, R265, R272, R280	12Ω, 0.5W, ±1%	Thick Film SMD Resistor	ANY	ANY
117	24	R161, R164, R165, R167, R169, R174, R176, R178, R204, R209, R212, R216, R225, R228, R230, R233, R252, R257, R264, R268, R269, R273, R279, R284	0Ω, 0.5W, ±0%	Thick Film SMD Resistor	ANY	ANY
118	12	R168, R175, R177, R180, R213, R217, R231, R234, R258, R260, R274, R285	22Ω, 0.5W, ±1%	Thick Film SMD Resistor	ANY	ANY
119	12	R188, R189, R192, R193, R222, R226, R239, R241, R267, R277, R283, R290	47k, 0.25W, ±1%	Thick Film SMD Resistor, 1206	ANY	ANY
120	3	R294, R311, R328	27k, 0.1W, ±0.1%	Metal Film SMD Resistor, 0603	ANY	ANY
121	3	R297, R314, R331	13.3k, 0.063W, ±0.1%	Metal Film SMD Resistor, 0603	ANY	ANY
122	6	R303, R307, R320, R324, R337, R341	0Ω, 0.1W, ±0.1%	Thin Film SMD Resistor, 0603	ANY	ANY
123	1	R306	0Ω, 0.1W, ±1%	Thick Film SMD Resistor, 0603	ANY	ANY
124	3	R309, R326, R343	N.M.	(not mounted), 0603	ANY	ANY
125	3	R310, R327, R344	8.06k, 0.1W, ±0.1%	Thin Film SMD Resistor, 0603	ANY	ANY
126	2	R323, R340	11.3k, 0.1W, ±1%	Thick Film SMD Resistor, 0603	ANY	ANY

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
127	2	R345, R346	750Ω, 0.25W, ±1%	Thick Film SMD Resistor, 1206	ANY	ANY
128	2	R347, R348	51k, 0.25W, ±0.1%	Thin Film SMD Resistor, 1206	ANY	ANY
129	1	R349	10Ω, 0.1W, ±0.1%	Thin Film SMD Resistor, 0603	-	-
130	2	R350, R353	27k, 0.1W, ±0.1%	Thin Film SMD Resistor, 0603	ANY	ANY
131	1	R351	10.2k, 0.1W, ±0.1%	Metal Film SMD Resistor, 0603	ANY	ANY
132	1	R352	110k, 0.1W, ±0.1%	Thin Film SMD Resistor, 0603	ANY	ANY
133	3	R357, R358, R359	22Ω, 0.25W, ±1%	Thick Film SMD Resistor, 1206	ANY	ANY
134	7	R362, R363, R364, R375, R377, R379, R381	33k, 0.1W, ±1%	Thick Film SMD Resistor, 0603	ANY	ANY
135	1	R368	1k, 0.1W, ±1%	Thick Film SMD Resistor, 0603	ANY	ANY
136	4	R370, R371, R372, R373	22Ω, 0.25W, ±1%	Thick Film SMD Resistor, 0603	ANY	ANY
137	2	SHUNT1, SHUNT2	25m, 1W, ±1%	Metal Strip SMD Resistor, 2512	Vishay	WSL2512R0250FEA
138	164	TP1, TP2, TP3, TP4, TP5, TP6, TP7, TP8, TP9, TP10, TP11, TP12, TP13, TP14, TP15, TP16, TP17, TP18, TP19, TP20, TP21, TP22, TP23, TP24, TP25, TP26, TP27, TP28, TP29, TP30, TP31, TP32, TP33, TP34, TP35, TP36, TP41, TP42, TP43, TP44, TP45, TP46, TP47, TP48, TP49, TP50, TP51, TP52, TP53, TP54, TP55, TP56, TP57, TP58, TP59, TP60, TP61, TP62, TP63, TP64, TP65, TP66, TP67, TP68, TP69, TP70, TP71, TP72, TP73, TP74, TP75, TP76, TP77, TP78, TP79, TP80, TP81,	TestPoint_Ring	RS PRO 1mm Black Test Terminal	ANY	ANY

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
		TP82, TP83, TP84, TP85, TP86, TP87, TP88, TP89, TP90, TP91, TP92, TP93, TP94, TP95, TP96, TP97, TP98, TP99, TP100, TP101, TP102, TP103, TP104, TP105, TP106, TP107, TP108, TP109, TP110, TP111, TP112, TP113, TP114, TP115, TP116, TP117, TP118, TP119, TP120, TP121, TP122, TP123, TP124, TP125, TP126, TP127, TP128, TP129, TP130, TP131, TP132, TP133, TP134, TP135, TP136, TP137, TP138, TP139, TP140, TP141, TP142, TP143, TP144, TP145, TP146, TP147, TP148, TP149, TP150, TP151, TP152, TP153, TP154, TP155, TP156, TP157, TP158, TP159, TP160, TP161, TP162, TP163, TP164, TP165, TP166, TP167, TP168				
139	4	TP37, TP38, TP39, TP40	TestPoint_Ring	RS PRO 1mm Black Test Terminal	ANY	ANY
140	15	TW1, TW2, TW3, TW4, TW5, TW6, TW7, TW8, TW9, TW10, TW11, TW12, TW13, TW14, TW15	CON1	3mm HOLE (not mounted)	-	-
141	1	T1	-	TRANSFORMER_ ViPER_ WURTH 750317707 (not mounted)	-	-
142	10	U1, U2, U3, U15, U19, U21, U4, U10, U7, U16	8MHz, 2.3 - 5.5V	High Speed, Op Amp, RRIO, 8-Pin SOIC	ST	TSV912IDT
143	6	U5, U8, U11, U35, U37, U39,	8MHz, 3V, 5V	High Speed, Op Amp, RRIO, 14-Pin SOIC	ST	TSV914IDT

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
144	9	U6, U9, U12, U17, U18, U20, U36, U38, U40	-	IC OPAMP ISOLATION 1 CIRC 8SOIC, SOIC-8	Texas Instruments	AMC1301DWVR
145	2	U13, U22	-	1-Channel DC-DC Power Supply Module 4-Pin, SIP Module, DCH010505SN7	Texas Instruments	DCH010505SN7
146	1	U14	-55 - +130 °C ±1.5°C	Temperature Sensor Analogue, 5-Pin SOT-323, SOT323-5L	ST	STLM20W87F
147	12	U23, U24, U25, U26, U27, U28, U29, U30, U31, U32, U33, U34	4A	DGTL ISO single Gate Drive	ST	STGAP2SM
148	2	U41, U43	800mA	LDO Voltage Regulators Fixed Adjust output very Lo drop	ST	LD29080DT50R
149	2	U42, U44	0.4 400mV 3.3V, 800mA	LDO Voltage Regulators 800mA VLD Fixed Adj 25c	ST	LD29080S33R
150	1	U45	-	AC-DC Converter 16-Pin, SOIC	ST	VIPER26HD
151	6	Q2, Q3, Q4, Q11, Q12, Q13	1200V	Silicon Carbide 1200V HIP247	ST	SCTW40N120G2VAG

Revision history

Table 10. Document revision history

Date	Revision	Changes
28-Feb-2022	1	Initial release.

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