OPAL-RT TECHNOLOGIES

MMC TEST BENCH
User Manual

www.opal-rt.com

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SYMBOL DEFINITIONS

The following table lists the symbols used in this document to denote certain conditions:

Symbol	Definition
	ATTENTION: Identifies information that requires special consideration
	TIP: Identifies advice or hints for the user, often in terms of performing a task
	REFERENCE _ INTERNAL: Identifies an additional source of information within the bookset.
CAUTION	Indicates a situation which, if not avoided, may result in equipment or work (data) on the system being damaged or lost, or may result in the inability to properly operate the process.
	Indicates a situation where users must observe precautions for handling electrostatic sensitive devices.
	CAUTION: Indicates a potentially hazardous situation which, if not avoided, may result in minor or moderate injury. It may also be used to alert against unsafe practices.
	WARNING: Indicates a potentially hazardous situation which, if not avoided, could result in serious injury or death.
	This symbol indicates a high voltage device or environment. ONLY qualified personnel are permtited to service said device or allowed access to high voltage environments Danger of potential fatal electric shock and fire.

CONTENTS

GETTING STARTED

RECEIVING AND VERIFICATION

Your shipment should include the following equipment and components. Inspect your order to make sure nothing is damaged.

The MMC Test Bench includes the following basic hardware:

Item	Description	Part Number
System Integration binder	RT-LAB software CD O/S CD (Redhat) Documentation CD	N/A
MMC test bench rack	40U rack kit 19” x 36” with rear door, equipped for 240VAC	429-0400-0024
OP1210	MMC Test Bench MMC 10 Cells FB/HB	429-0300-0048
OP1260	Protection Box	429-0300-0050
OP1261	Measurement Box	429-0300-0051
OP1262	Inductance Box	429-0300-0052
OP4510	RCP/HIL system simulator, series 200	429-0107-0017
OP8211/12	Interface connector	429-0201-0008
Fiber optic cables	POF industrial plastic optical fiber patch cords 3M	213-0100-0238
Chassis ground wire		000-0113-0592
DB37 cable	DB37 male/male, serial cable, 37C, 1:1, 5ft - low profile	213-0100-0072
Cable Mounting & Accessories	LiquidTight Cordgrip Diameter 1.12” Black	240-0800-0004
Power cable	1.83 m (6’) power cord, black (10A 125V)	CPC06

OPAL-RT strongly recommends the use of anti-static wrist straps whenever handling any electronic device provided by OPAL-RT. Damage resulting from electrostatic charges will not be convered by the manufacturers warranty.

Disconnect power before servicing

The MMC Test Bench may be subjected to EMI when installed in proximity to other devices. Make sure to connect the MMC Test Bench ground to the rack to prevent any EMI related damage to the simulator.

High voltage wiring operations should always be carried out by qualified personnel.

MMC TEST BENCH INTRODUCTION

The OP1200 Modular Multilevel Converter is a test bench dedicated to the verification and prototyping of new control algorithms for the development of multilevel HVDC interconnections. It consists of a stack of cascaded identical or mixed-topology sub-modules (SM) composing up to 60 switching cells (in the standard configuration).

The OP1200 comes with built-in models designed for use in research or educational or training courses. Using the complete software simulation environment RT-LAB MATLAB/Simulink® and XILINX System Generator, this turnkey test bench is safe, easy-to-use and ideal for implementing (and teaching) control development of Modular Multilevel Converter systems.

APPLICATIONS

The OPAL-RT Lab-Scale MMC Test Bench supports a large number of MMC-based topologies, including:

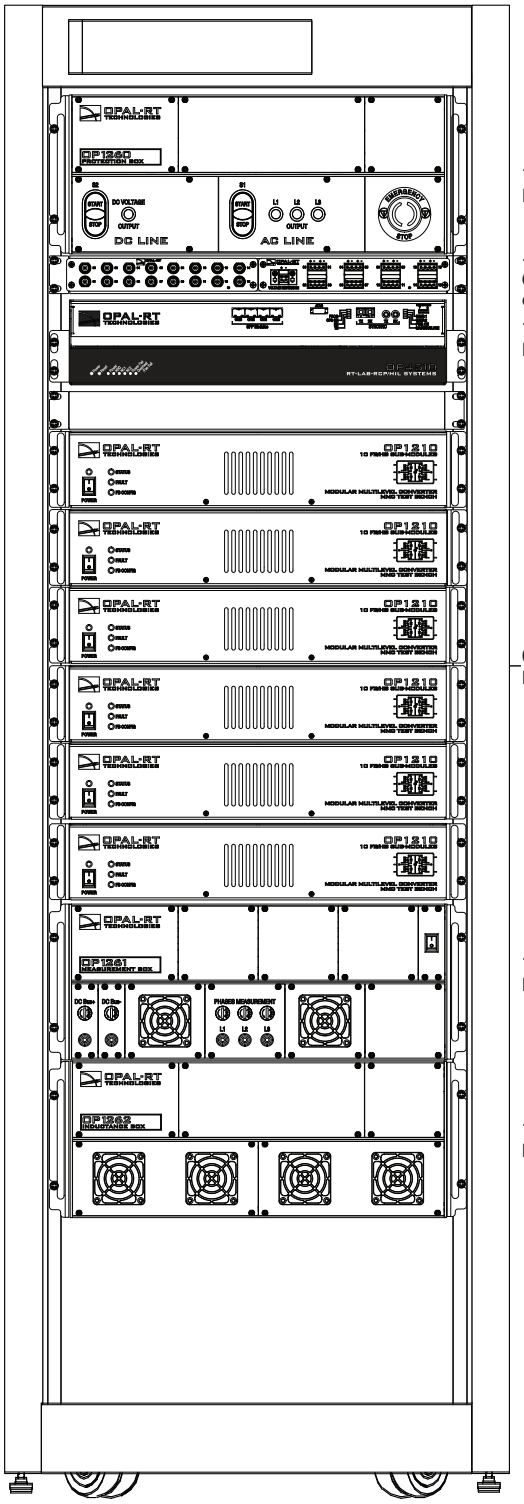
- High voltage DC (HVDC) converters (PHIL, Back-to-Back, Multiterminal)
- Flexible AC transmission systems (FACTS)
- Static Synchronous Compensators (STATCOM)
- Solid State Transformers
- Multilevel Matrix Converters

FEATURES

- OP4510 real-time simulator to perform MMC converter rapid control prototyping and simulation and associated features.
- CPU and FPGA control capability.
- Measurement of all submodule voltages and arm currents.
- Measurement of AC and DC grid voltage and currents.
- AC and DC precharge circuit included.
- Industrial grade power circuit component (contactors, breaker, disconnector).
- Fast low level hardware protection.
- Modular architecture.
- Analog output interface to connect power amplifier for PHIL simulation.

COMPLETE RACK INTERFACE

The standard configuration for the MMC test bench comprises the following units mounted in a rack:



1 x OP1260
Protection Box

1 x OP8210
(OP8211 BNC +
OP8212 panels)

1 x OP4510
HIL/RCP simulator

6 x OP1210
MMC 10 Cells FB/HB

1 x OP1261
Measurement Box

1 x OP1262
Inductance Box

Figure 1: Complete MMC Rack (standard configuration)

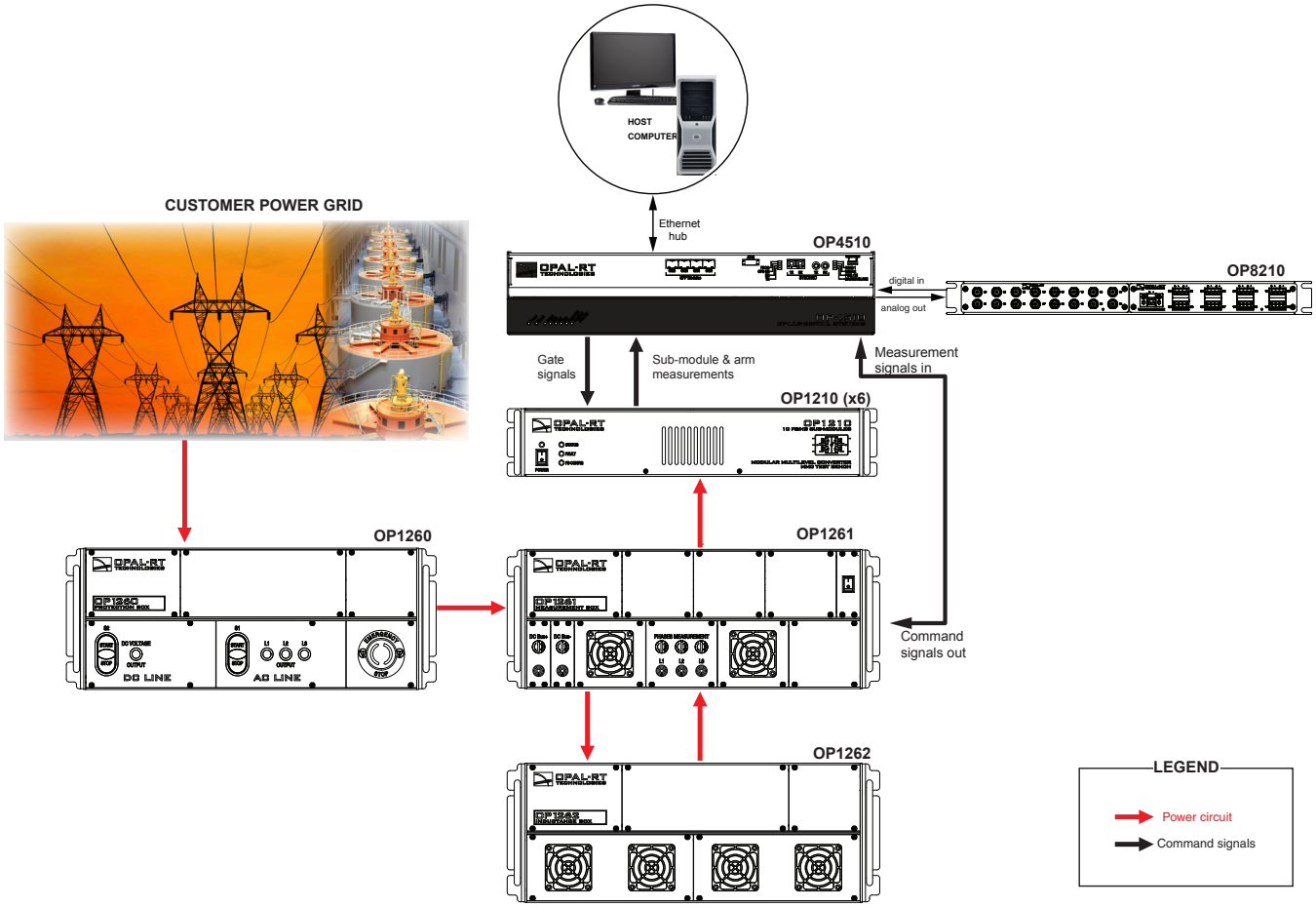


Figure 2: MMC Test Bench system architecture overview (standard configuration)

The image above shows the general connection architecture to and from each part of the test bench and the users, devices. The image on the opposite page, Figure 3, shows a more detailed schematic of how the test bench devices are interconnected (see the System Integration documents for custom schematics, and diagrams).

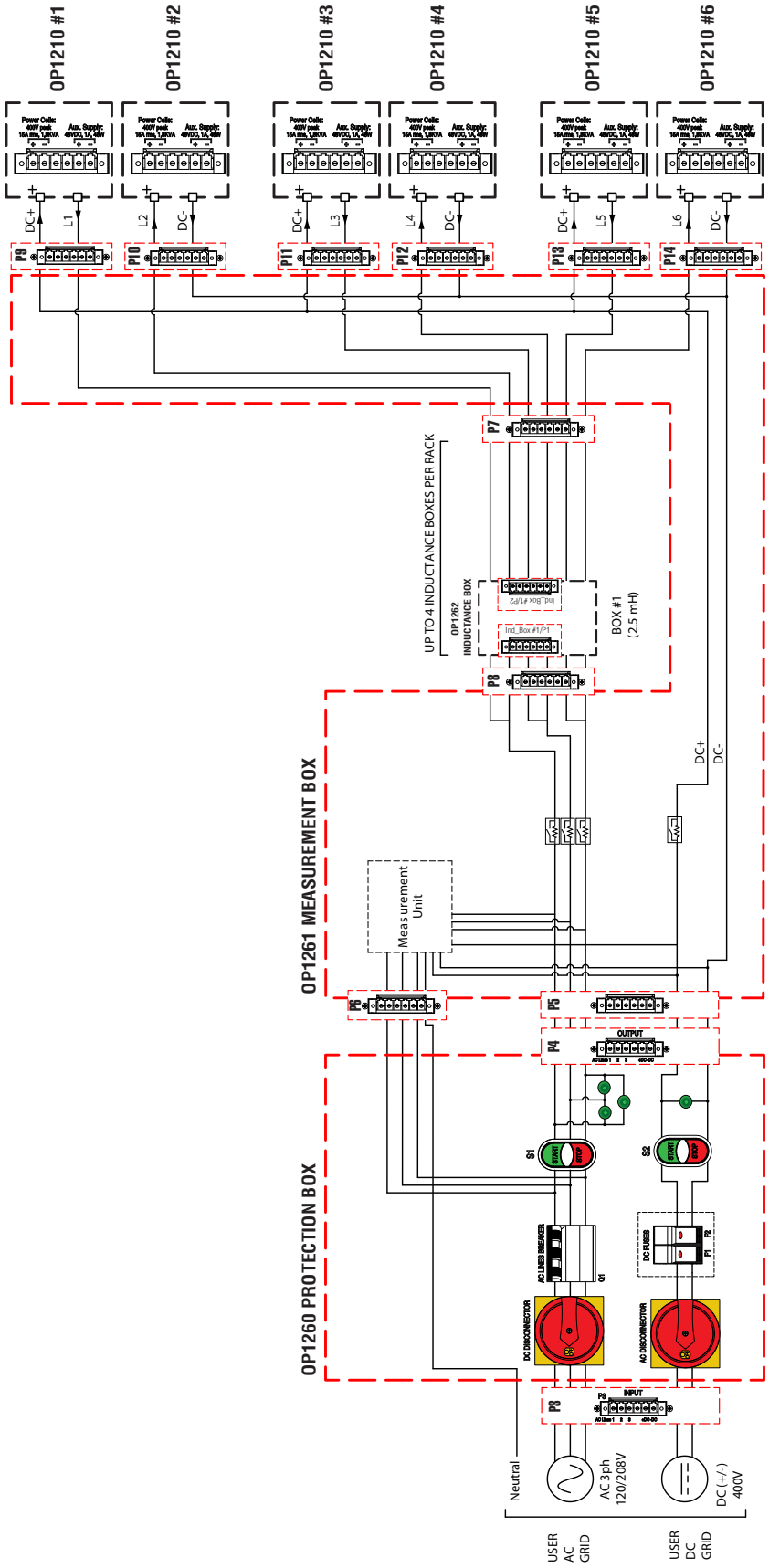


Figure 3: MMC Test Bench System Wiring Diagram

INSTALLATION

CONNECTING CABLES

The MMC Test Bench is shipped with units already mounted in the rack and cable assemblies completed. However, there are certain cables that must be connected:

1. Connect the auxiliary power bar
   The auxiliary power bar is affixed to the bottom of the rack and all units are connected. You need only plug the power bar into an approved power outlet as shown in Figure 4.

Make sure that the rack is configured for the appropriate local voltage (120V or 240V).

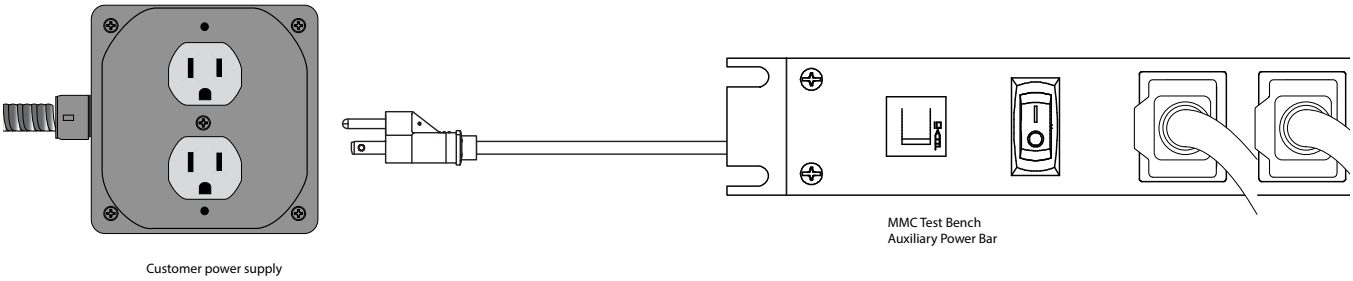


Figure 4: Connecting the auxiliary power bar

2. Connect the Ethernet cable from the OP4510 to the nearest network jack, as shown in Figure 5

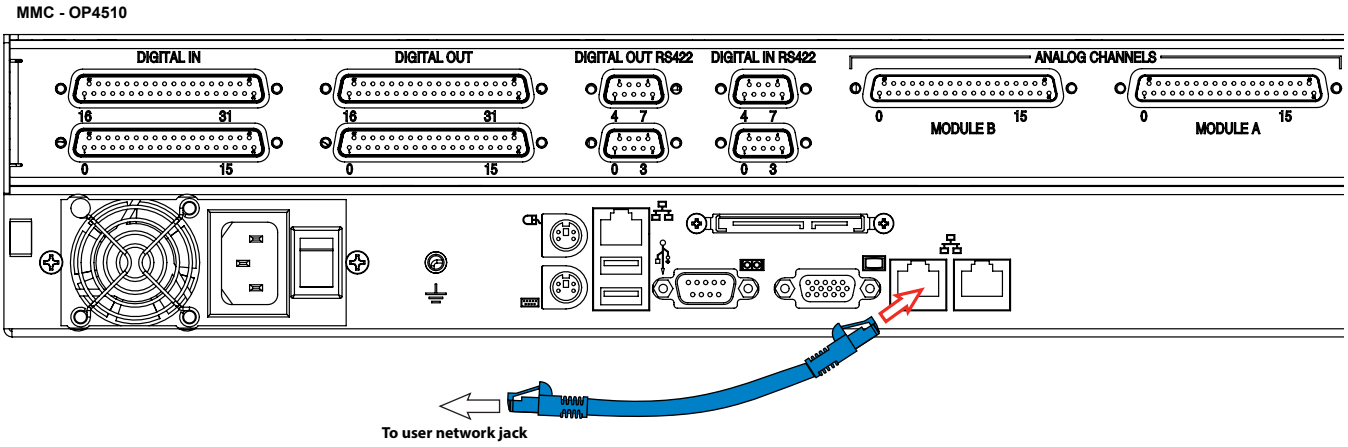


Figure 5: Connecting the MMC/OP4510 to the network

3. Connect grounding wire for the entire rack (optional: if high voltage cables are not already grounded) See Figure 6.
4. Connect high voltage cables to the protection box (refer to the diagram shown in Figure 14).

You are now ready to power up your MMC Test Bench.

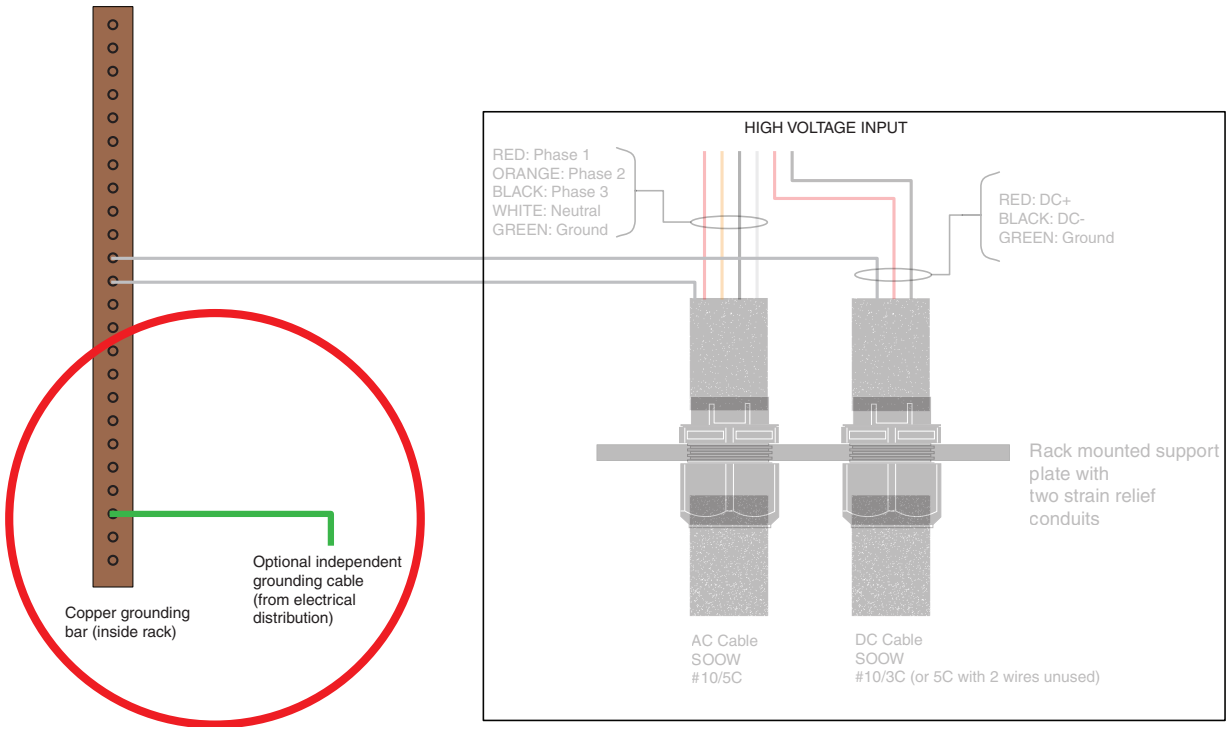


Figure 6: Connecting the optional, independent ground wire to the rack

Because it is connected to hazardous voltages, the OP1200 MMC Test Bench must be properly grounded at all times.

OP1210 MMC 10 CELLS FB/HB

The OP1210 is a sub-module unit that houses 10 sub-modules to create an MMC arm. It can be configured in the standard half-bridge or the optional full bridge topology.

The user has 3 options when using the sub-modules in the OP1210 (see “OP1210 Submodule Options”). The first two options are software controlled, using the model, and the third option is hardware controlled and must be specified at time of purchase:

1. Use the sub-modules as full-bridge cells (FB), which means there are 4 active switches (2 half bridge). See Figure 9.
2. Use the sub-modules as “emulated” half-bridge cells (HB), which means 2 switches are active and the 2 others are disabled in the software (switch state is forced to make a half-bridge cell topology). See Figure 10.
3. Use the sub-modules as “hardware” half-bridge cells (HB) which means that a jumper is used to make to bypass the second half bridge (must be factory configured). See Figure 11.

FEATURES

- Hardware instantaneous overcurrent and overvoltage detection
- Arm bypass electronic switch (thyristor)
- Fiber optic communication with OP4510
- Arm current measurement
- Sub-module capacitor voltage measurement
- 500 ns switch state refresh rate
- 20 us measurement sample rate
- Optional AAC directional switch

USER INTERFACE

Front Interface

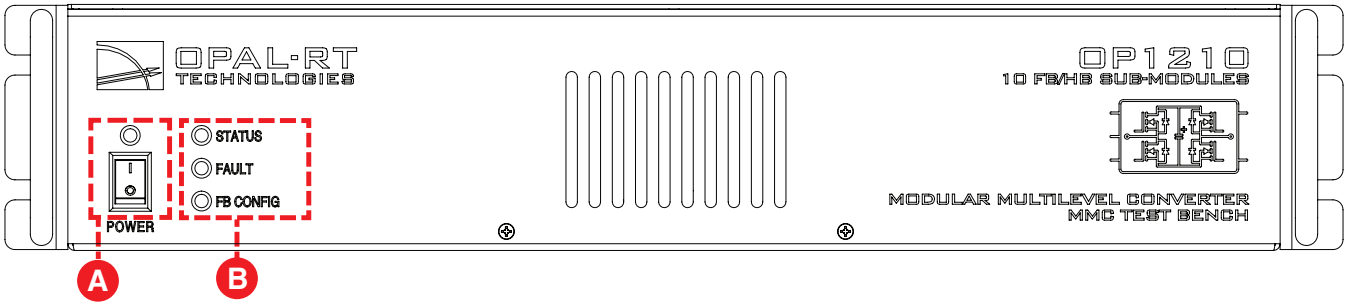


Figure 7: OP1210 front interface

A. Power switch. When powered up, the green LED is on
B. Status LEDs:

LED Label	Description
STATUS	On: converter is running (transmitting pulses to transistors) Off : converter blocked (sub-module in high impedance (Hi-Z))
FAULT	On : fault detected by internal controller Off : normal operation
FB CONFIG	On : sub-module in full bridge operating mode (FB) Off : sub-module in half bridge operating mode (HB)

Note: when the converter is in half-bridge mode, all LEDs should be off when the converter is operating.

Rear Interface

OP1210 Standard Configuration

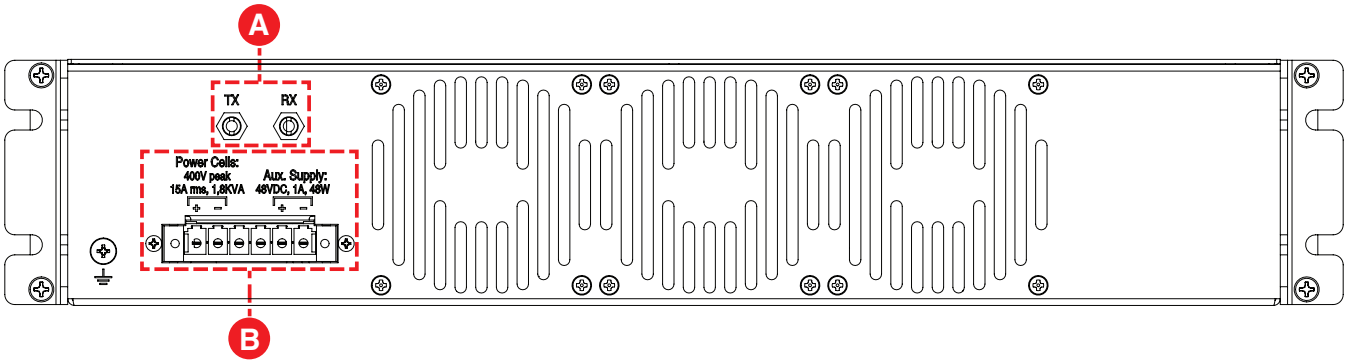
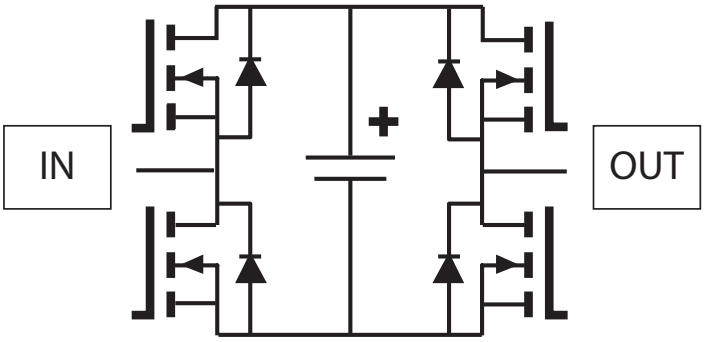


Figure 8: OP1210 rear interface

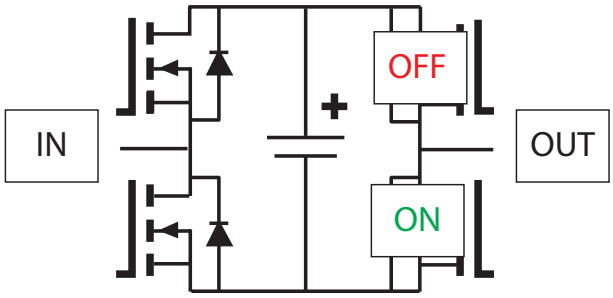
A. Fiber optic TX/RX connectors for communication with OP4510.
B. Power Cells screw terminal connectors
   The first two connect the + and - for the power cells 400V peak, 15Arms, 1.8Kva
   The last two connect the + and - for the Auxiliary supply, 48 Vdc, 1A, 48W

OP1210 SUBMODULE OPTIONS



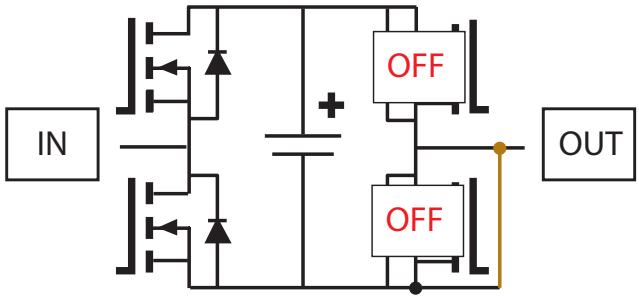
Full-Bridge Submodules

Figure 9: Option 1, full-bridge submodules



Emulated Half-Bridge Submodules
(software controlled switch state)

Figure 10: Option 2, emulated half-bridge submodules



Hardware Half-Bridge Submodules
(second half-bridge is bypassed via a jumper)

Figure 11: Option 3, hardware half-bridge submodules

OP1260 PROTECTION BOX

The OP1260 is a protection box designed to provide protection, control and isolation of AC and DC lines. In the event of an emergency, the emergency stop button cuts the main MMC power circuit. Rotary switches on the OP1260 allow operators to isolate incoming high voltage to the MMC circuit (the auxiliary power bar should also be disconnected to completely remove any voltage from the equipment).

Features

- Client line connection terminal
- Hardware DC and AC overvoltage and overcurrent line protection
- Emergecy stop button
- Contactor control
- Safety padlock disconnect switches

USER INTERFACE

Front Interface

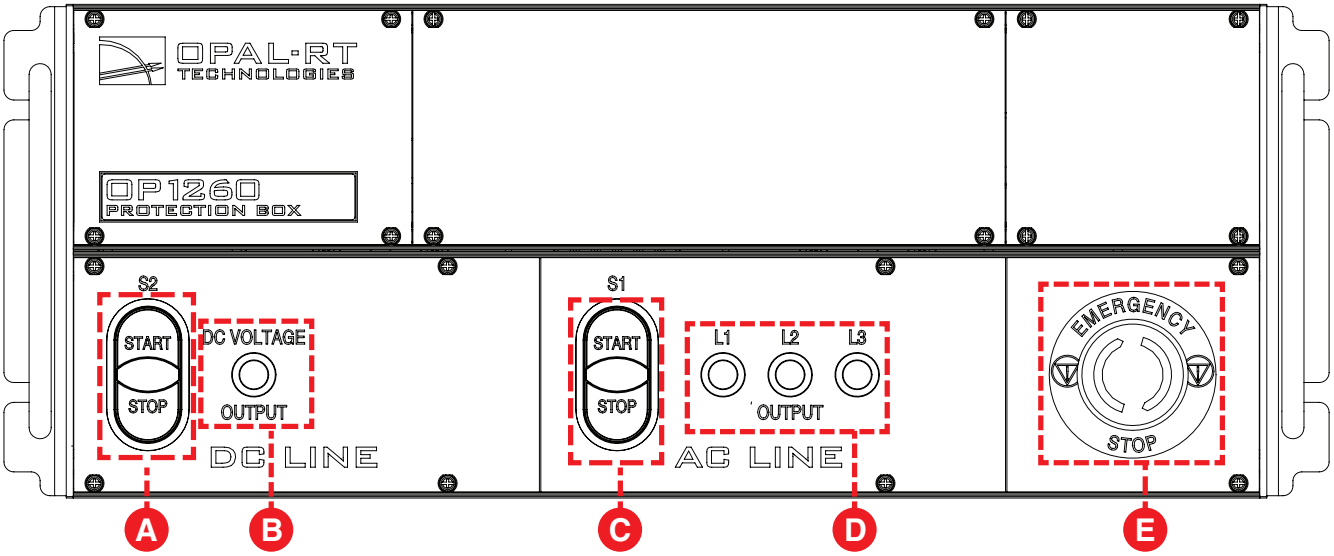


Figure 12: OP1260 front interface

A. **Start/Stop** switch*: pressing start closes the DC contactor and allows user to connect the DC grid to the converter. Pressing stop opens the contactor and disconnects DC grid*.

B. **DC Voltage Output** LED: when this light is on, it indicates that a DC voltage is present/active on the converter side of the DC contactor.

C. **Start/Stop** switch*: pressing start closes the AC contactor and allows user to connect the AC grid to the converter. Pressing stop opens the contactor and disconnects AC grid.

D. **L1 L2 L3** LEDs: when this light is on, it indicates that a voltage is present/active on the converter side of the AC controller.

E. **Emergency Stop***: shuts all contactors and cuts both AC and DC lines to the MMC.
Note: when restarting, make sure that switches and breakers (rear interface) are not tripped. If tripped, they need to be reset (make sure to test fuses in the event of a reset and replace as needed).

* These switch are only operational when a a permission is given by the model running in the OP4510. If no permission is given, the switches perform no action.

Rear Interface

OP1260 Standard Configuration

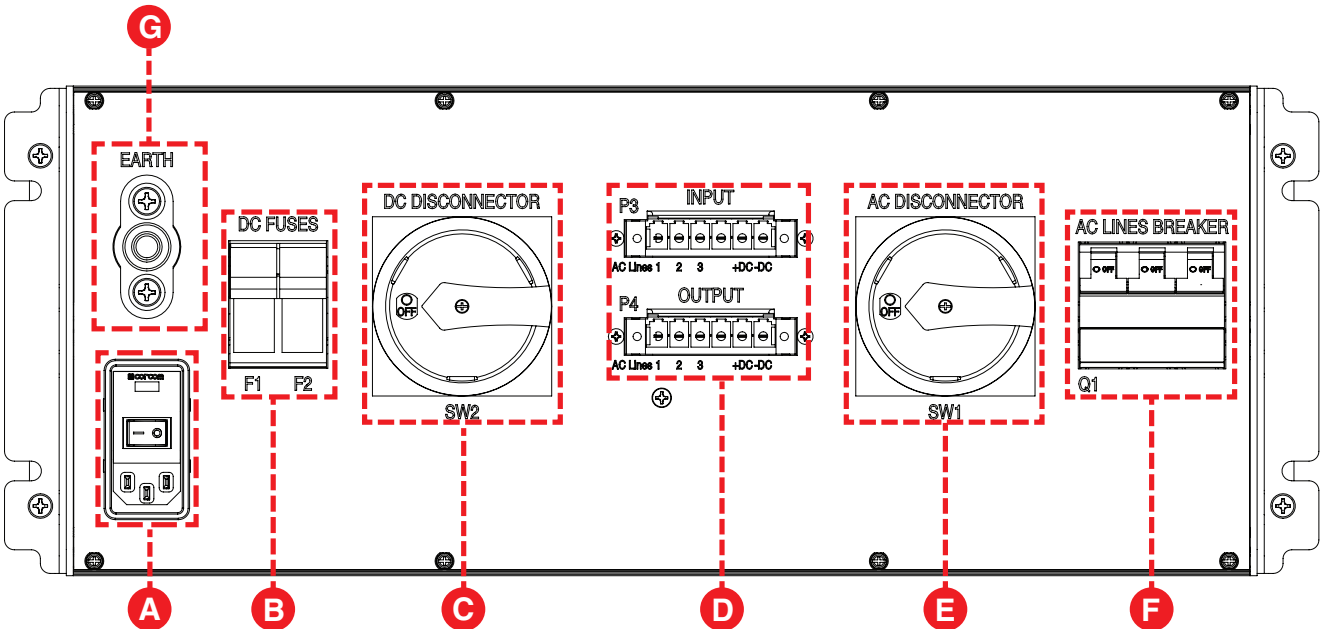


Figure 13: Rear interface

A. Power Switch. Power input from rack power bar that will provide auxiliary power to OP1260.
B. DC FUSES: overcurrent protection shuts down DC current in the event of an overage.
C. DC DISCONNECTOR: provides safety voltage shutdown/isolation on DC lines, with a safety lockout feature for padlocking the disconnector during service.
D. P3 INPUT, P4 OUTPUT: P3 connects to the AC and DC power input cables and P4 connects the protection box's outputs to the OP1261 Measurement Box
E. AC DISCONNECTOR: provides safety voltage shutdown/isolation on AC lines, with a safety lockout feature for padlocking the disconnector during service.
F. AC LINES BREAKER: overcurrent protection shuts down AC current in the event of an overage.
G. EARTH: (ground) connector

CAUTION	**Even if breakers are triggered or fuses are blown, there is still voltage present on the lines. Always use disconnectors to shut off power completely.**
DANGER HIGH VOLTAGE	**High voltage wiring operations should always be carried out by qualified personnel.**
WARNING	**Lockout switches before working on equipment**

Wiring Diagram

This is the basic cabling diagram to connect the AC and DC power cables to your OP1260.

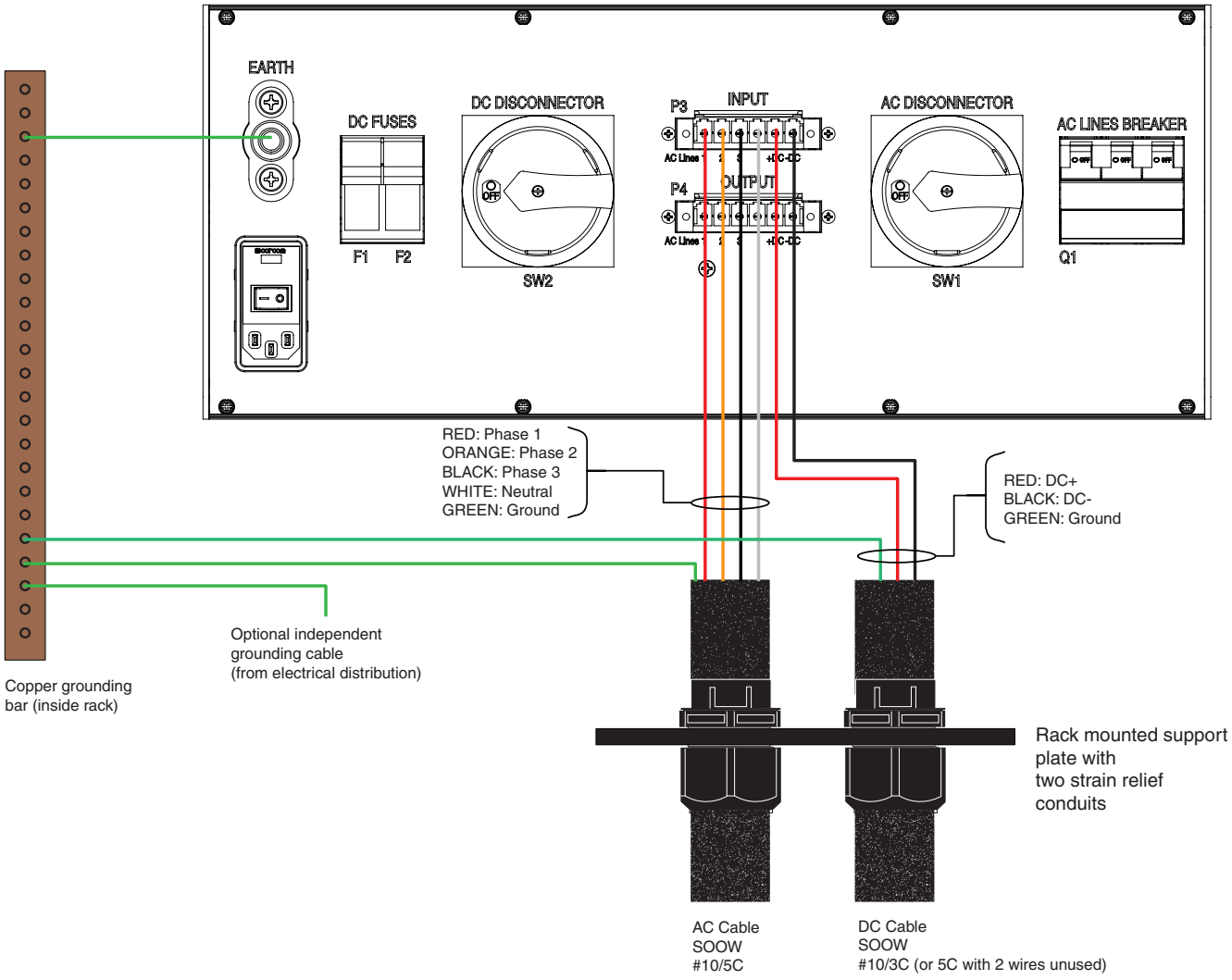


Figure 14: Connecting AC and DC high voltage power input cables

High voltage wiring operations should always be carried out by qualified personnel.

OP1261 MEASUREMENT BOX

The OP1261 is a connection hub for all OP1210 and the OP1260 protection, therefore it is the ideal place to centralize AC and DC control measurements. It allows users to implement these variables in their control schemes to regulates power flow between the MMC and the AC or DC grid. It also allows the user control to synchronize on the AC grid.

The following signals can be measured through this unit:

- AC 3-phase voltages (L1 to neutral, L2 to neutral and L3 to neutral)
- DC voltage
- AC 3-phase current
- DC current

The OP1261 measurement box also provides the auxiliary 48V power supply to the OP1210 units. The MMC topology interconnections (grid, sub-modules, inductors) are made through the OP1261.

USER INTERFACE

Front Interface

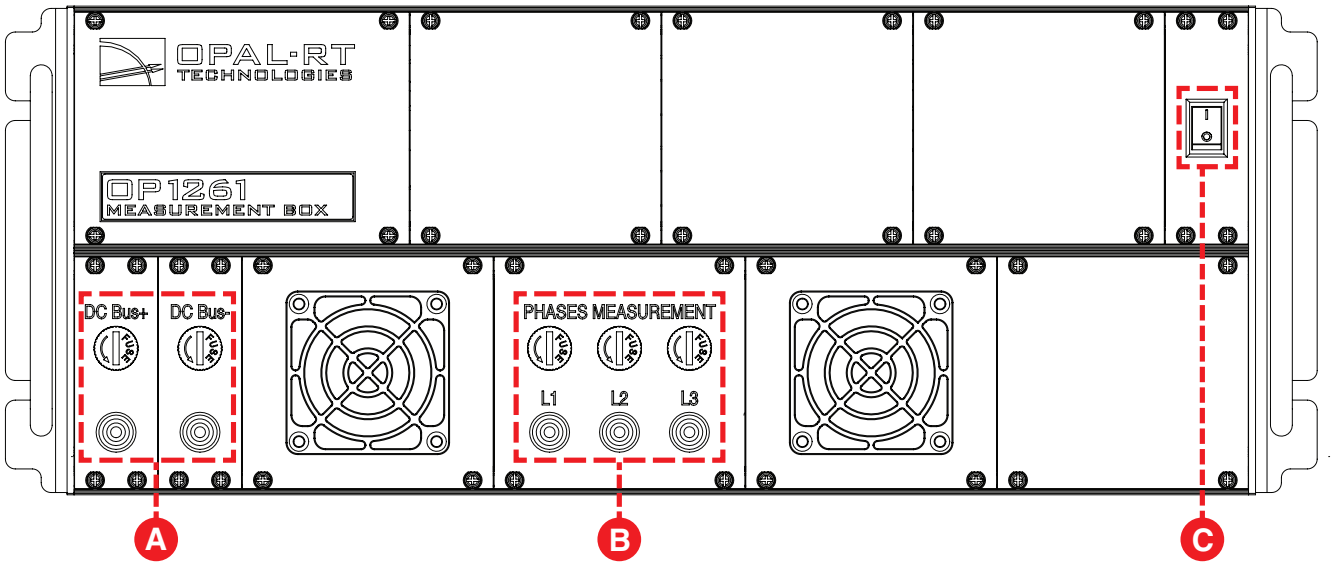


Figure 15: OP1261 front interface

A. DC measurement connector (banana jack): allows users to monitor DC voltage on external equipment (oscilloscope or multimeter). **Use only high voltage differential probes.**
B. AC measurement connector (banana jack): allows users to monitor AC voltage on external equipment (oscilloscope or multimeter). **Use only high voltage differential probes.**
C. Power switch: provides power to measurement circuits on internal board (5511) and controls auxilliary power to OP1210 units

* Rear Interface

OP1261 Standard Configuration

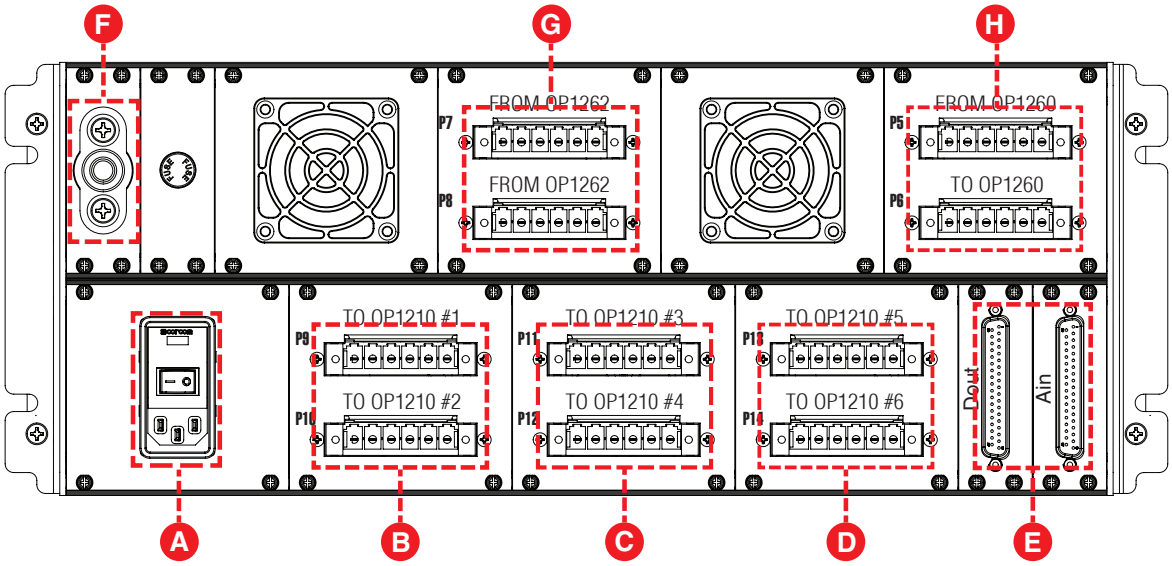


Figure 16: OP1261 rear interface

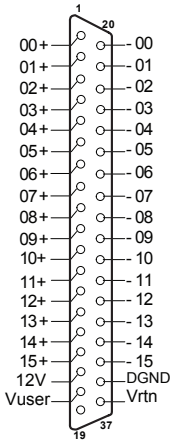
A. Auxiliary power connector and switch.
B. Phoenix terminal connectors: cables connecting output to OP1210 #1 and #2
C. Phoenix terminal connectors: cables connecting output to OP1210 #3 and #4
D. Phoenix terminal connectors: cables connecting output to OP1210 #5 and #6
E. DB37 connectors: Dout carries digital signals from the OP4510 (which controls relays), Ain carries measurement signals to the OP4510 (see “Pin Assignments” for details).
F. Grounding connection: connects ground cable from OP1261 to rack grounding bar
G. Phoenix terminal connectors: cable interconnection with OP1262 Inductance Box
H. Phoenix terminal connectors: P5 connects cable from P4 on OP1260 power output (see Figure 13)

PIN ASSIGNMENTS

The following tables provide the generic pin assignments for the OP1261's DB37 and DB9 connectors. More detailed information, tailored to specific firmware, can be found in the Integration documents provided with your order.

DB37 Pin Assignments

DB37 pin	Channel pin assignment	DB37	Channel pin assignment
1	+00	20	-00
2	+01	21	-01
3	+02	22	-02
4	+03	23	-03
5	+04	24	-04
6	+05	25	-05
7	+06	26	-06
7	+07	27	-07
9	+08	28	-08
10	+09	29	-09
11	+10	30	-10
12	+11	31	-11
13	+12	32	-12
14	+13	33	-13
15	+14	34	-14
16	+15	35	-15
17	+12V*	36	DGND
18	Vuser	37	Vrtn
19			



* Non-isolated, limited to 400mA

OP1262 INDUCTANCE BOX

The OP1262 provides arm inductors between the MMC arm and the AC grid, which are part of standard MMC topology. It can be connected in series with other inductance boxes (if more than one is present in rack) to provide greater inductance values. Each OP1262 adds 2.5 mH of inductance, therefore 2 units provide 5mH inductance, 3 would provide 7.5 mH and the maximum four would total 10 mH.

USER INTERFACE

The front of the OP1262 provides no user interface, only ventilation,

Rear Interface

The rear interface provides Phoenix terminal connectors that connect the OP1261 to the OP1262 and from the OP1262 to the OP1210. These connections will be made by an OPAL-RT technician during commissioning.

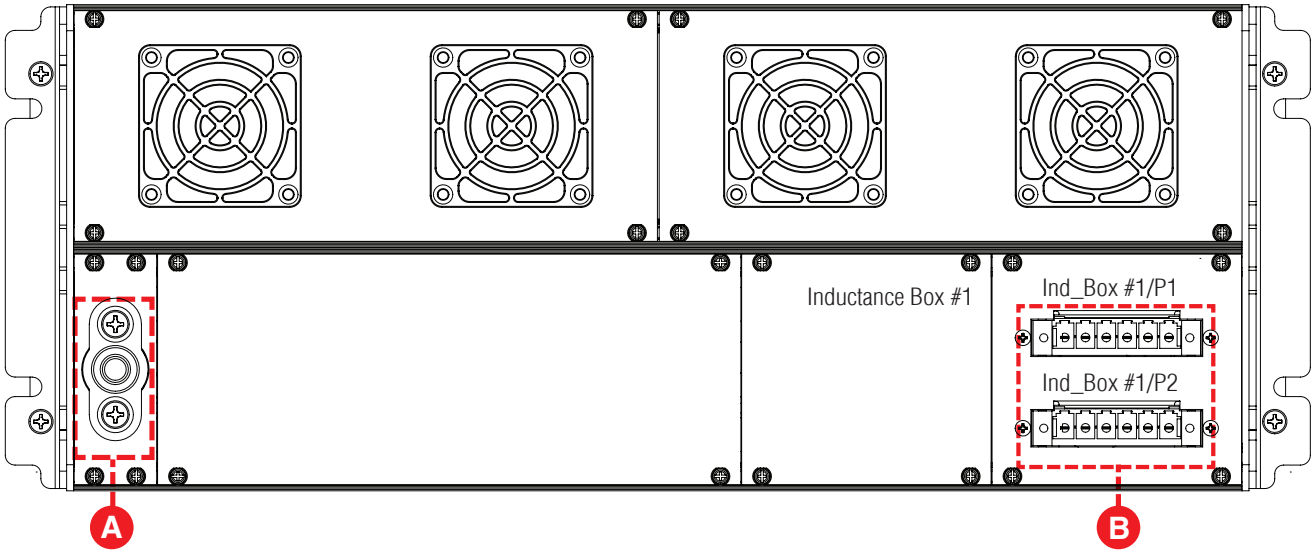


Figure 17: OP1262 rear interface

A. Ground connector. The ground cable is connected from the OP1262 to the grounding bar in the rack.
B. Phoenix terminal connectors. Connector P1 connects one side of the inductors while P2 connects the other (see Figure 18). Terminal 1 on both P1 and P2 connect to the OP1261 Measurement Box connector P7 and P8.

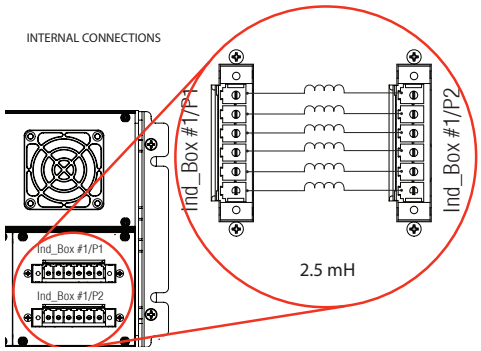


Figure 18: Inductor connection diagram

SPECIFICATIONS

MMC TEST BENCH GENERAL SPECIFICATIONS

OPAL-RT Lab-Scale MMC Test Bench specifications for a MMC Full Bridge, 11 levels, 400V, 6kW.

Product name	MMC Test Bench
Part number	429-0500-0068
Included products	OP4510 RT-LAB RCP/HIL System OP1210 10 FB/HB Sub Modules OP1260 Protection Box OP1261 Measurement Box OP1262 Inductance Box
Nominal DC voltage	400 Vdc
Nominal DC Current	15 A DC
Nominal AC Voltage	120/208 V rms (3ph)
Nominal AC current	16.7 A rms
Nominal Output Power	6 kW
Total number of submodule	60
Submodule capacitor (typical)	5 mF
Nominal submodule voltage	40 V
Arm inductor (1 inductor box)	2.5 mH
Auxiliary control voltage (power bar)	North America:100-120V ac, 60 Hz Europe: 200-240 Vac, 50 Hz
Rack dimensions (HxWxD)	196.37 x 58.42 x 91.44cm (77.31” x 23” x 36”)
Rack weight	427.28 Kg (942 lbs)
Operating temperature	10 to 40 ºC (50 to 104ºF)
Storage temperature	-55 to 85ºC (-67 to 185ºF)
Relative humidity	10 to 90% non-condensing
Maximum altitude	2000 m (6562 ft.)

OP1210 SPECIFICATIONS

Product name	OP1210 MMC 10 Cells FB/HB
Part number	429-0500-0048
Number of submodules	10
Submodule topology	Full-bridge or emulated or hard wired half-bridge
Switch technology	MOSFET
Nominal voltage	40 V
Maximum continuous current	15 A rms
Maximum submodule switching frequency	10 kHz
Factory dielectric test	2000 Vac, 2 sec (power circuit to case and control voltage)
Submodule capacitor (typical)	5 mF
Serial communication data rate	10/50 Mbps (Tx/Rx)
Switch state refresh rate	500 ns
Measurement refresh rate	20 us
Submodule Voltage measurement range	0 to 80 V
Voltage resolution	12 bit
Arm current measurement range	-29.9 to 29.9 A
Arm current resolution	12 bit
Hardware overcurrent protection level	45 A
Hardware overvoltage protection level	60 V
Auxiliary supply voltage	48 Vdc
Dimensions (WxDxH)	43.2 x 54.6 x 8.9cm (17” x 21.5” x 3.5”)
Weight	Approx. 12.7 Kg (28 lbs)
Operating temperature	10 to 40 ºC (50 to 104ºF)
Storage temperature	-55 to 85ºC (-67 to 185ºF)
Relative humidity	10 to 90% non-condensing
Maximum altitude	2000 m (6562 ft.)

OP1260 SPECIFICATIONS

Product name	OP1260 Protection Box
Part number	429-0500-0050
Nominal AC voltage rating	120/208 Vac
Nominal DC voltage rating	400 V dc
DC overvoltage protection	540 V dc
AC overvoltage protection	270 V rms phase to phase
DC fuse rating	30 A dc (greater than the converter nominal current)
DC fuse type	KLK030
AC breaker rating	32 A rms (greater than the converter nominal current)
Auxiliary supply voltage range	90 to 265 Vrms, 50-60 Hz
Auxiliary supply fuse	3 A
Power connector mating	Phoenix P/N 1777875
Dimensions (WxDxH)	43.2 x 53.34 x 17.8 cm (17” x 21” x 7”)
Weight	Approx. 14.5 Kg (32 lbs)
Operating temperature	10 to 40 ºC (50 to 104ºF)
Storage temperature	-55 to 85ºC (-67 to 185ºF)
Relative humidity	10 to 90% non-condensing
Maximum altitude	2000 m (6562 ft.)

OP1261SPECIFICATIONS

Product name	OP1261 Measurement Box
Part number	429-0300-0051
AC circuit current rating	32 A (greater than the converter nominal current)
DC circuit current rating	30 A (greater than the converter nominal current)
AC/DC precharge resistor value	47 ohm
Precharge resistor overtemperature protection	65 °C
DC line voltage measurement range	- 600V to 600V
AC line voltage measurement range	Phases AN, BN, CN: - 600V to 600V
DC line current measurement	-50 to 50 A
AC line current measurement	Phases A, B and C: - 50 to 50 A
48 V supply maximum power	480W
Auxiliary supply voltage range	North America:100-120V ac, 60 Hz Europe: 200-240 Vac, 50 Hz (Warning, must be adapted manually)
Auxiliary supply fuse	3 A
Power connector mating	Phoenix P/N 1777875
Dimensions (WxDxH)	43.2 x 53.34 x 17.8 cm (17” x 21” x 7”)
Weight	Approx. 17.23 Kg (38 lbs)
Operating temperature	10 to 40 ºC (50 to 104ºF)
Storage temperature	-55 to 85ºC (-67 to 185ºF)
Relative humidity	10 to 90% non-condensing
Maximum altitude	2000 m (6562 ft.)

OP1262 SPECIFICATIONS

Product name	OP1262 Inductance Box
Part number	429-0300-0052
Maximum voltage	600 Vac (Power circuit to case)
Dielectric test (by supplier)	2500 Vac
Typical inductance	2.5 mH
Maximum RMS current (with typical)	30 A
Saturation current	Approx. 60 A (with typical)
Power connector mating	Phoenix P/N 1777875
Dimensions (WxDxH)	43.2 x 53.34 x 17.8 cm (17” x 21” x 7”)
Weight	Approx. 42.64 Kg (94 lbs)
Operating temperature	10 to 40 ºC (50 to 104ºF)
Storage temperature	-55 to 85ºC (-67 to 185ºF)
Relative humidity	10 to 90% non-condensing
Maximum altitude	2000 m (6562 ft.)

CONTACT

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Note:

While every effort has been made to ensure accuracy in this publication, no responsibility can be accepted for errors or omissions. Data may change, as well as legislation, and you are strongly advised to obtain copies of the most recently issued regulations, standards, and guidelines.
This publication is not intended to form the basis of a contract.

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