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Manual

DCB-IT-1k-2k-W-001 CERN 1000V - 2kA

Features

> Fast breaking capability (<10µs)
> Pyrofuse for emergency breaking
> Modular system

Contents

1 Introduction

1.1 Abstract

A breaker has to interrupt the current within microseconds. With this response time requirement, local fault protection must be performed autonomously by the switch control system, without the need for external control or fault detection. The fast opening time of solid-state breakers limits the fault current and reduces the negative impact on the load to a minimum. The current does not reach damaging energy levels and can be interrupted without forming an arc. In addition to the fast over-current protection, the breaker opens according to a configurable time-current profile (I^2t) for overload protection.

1.2 Applicable Documents

Ref	Document Type	Document Number	Name	Rev.
1	Testplan	AD-11003-012	Testplan DC-Breaker CERN	1.0
2	Specification	DO-31798/TE/MPE	Software Design Report Comicon	October 2018

Table 1 Applicable Documents

1.3 Abbreviations and Terminology

Abbreviation	Description
POF	**P**lastic **O**ptical **F**iber
DC	**D**irect **C**urrent - unidirectional flow of current
MTBF	**M**ean **T**ime **B**etween **F**ailures
GDU	**G**ate **D**rive **U**nit
IGBT	**I**nsulated **G**ate **B**ipolar **T**ransistor
MPU	**M**odular **P**ower **U**nit
DCB	**DCB**reaker
Optical High	When talking about optical signal, high means light
Optical Low	When talking about optical signal, low means no light

Table 2 Abbreviations and Terminology

1.4 Notifications

This box is used to emphasize an important message.

This box indicates a general mandatory action.

This box prohibits a certain action.

This box indicates a situation of risk that requires special care and could cause injury or death.

This box indicates a situation where special care is required as a risk of electrocution is present.

2 System Description

2.1 System Block Diagram

Figure 1 shows a simplified block diagram of a DC network with a DC-Breaker.

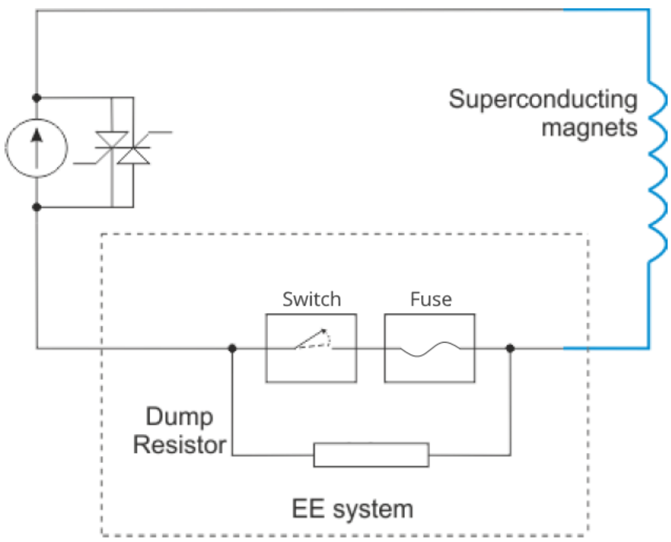


Figure 1 Block Diagram DC-Network

There are four main components:

1. Dump resistor (energy absorber)
2. Switching circuit breaker
3. Fuse (pyrofuses)
4. Auxiliary control electronics.

The dump resistors are permanently connected in parallel to the circuit breaker in order to dissipate the magnet energy in case of a breaking event. When the opening command appears, the power converter is switched off and bypassed with its crowbar circuit. The current continues flowing but is forced through the dump resistor and hence quickly decays with the time constant L/R (L is the circuit inductance and R is the circuit resistance).
The switch and the fuse are in general two series-connected circuit-breakers (forming a branch), independently controlled and operating simultaneously. This concept is established by purpose, in order to ensure the redundancy of the switch opening as this is a critical action requiring the highest reliability. Multiple switches can be installed in parallel, to cope with the high circuit currents.

2.2 DC-Breaker Block Diagram

Figure 2 illustrates the block diagram for the entire DC-Breaker. The system consists of one Power Module frame (AA-10785-002), a Control Module frame (AA-10785-101) and the Pyrofuse Module frame (AA-10769-101). The Power Module itself consists of two 1kA bi-directional Breaker Modules.

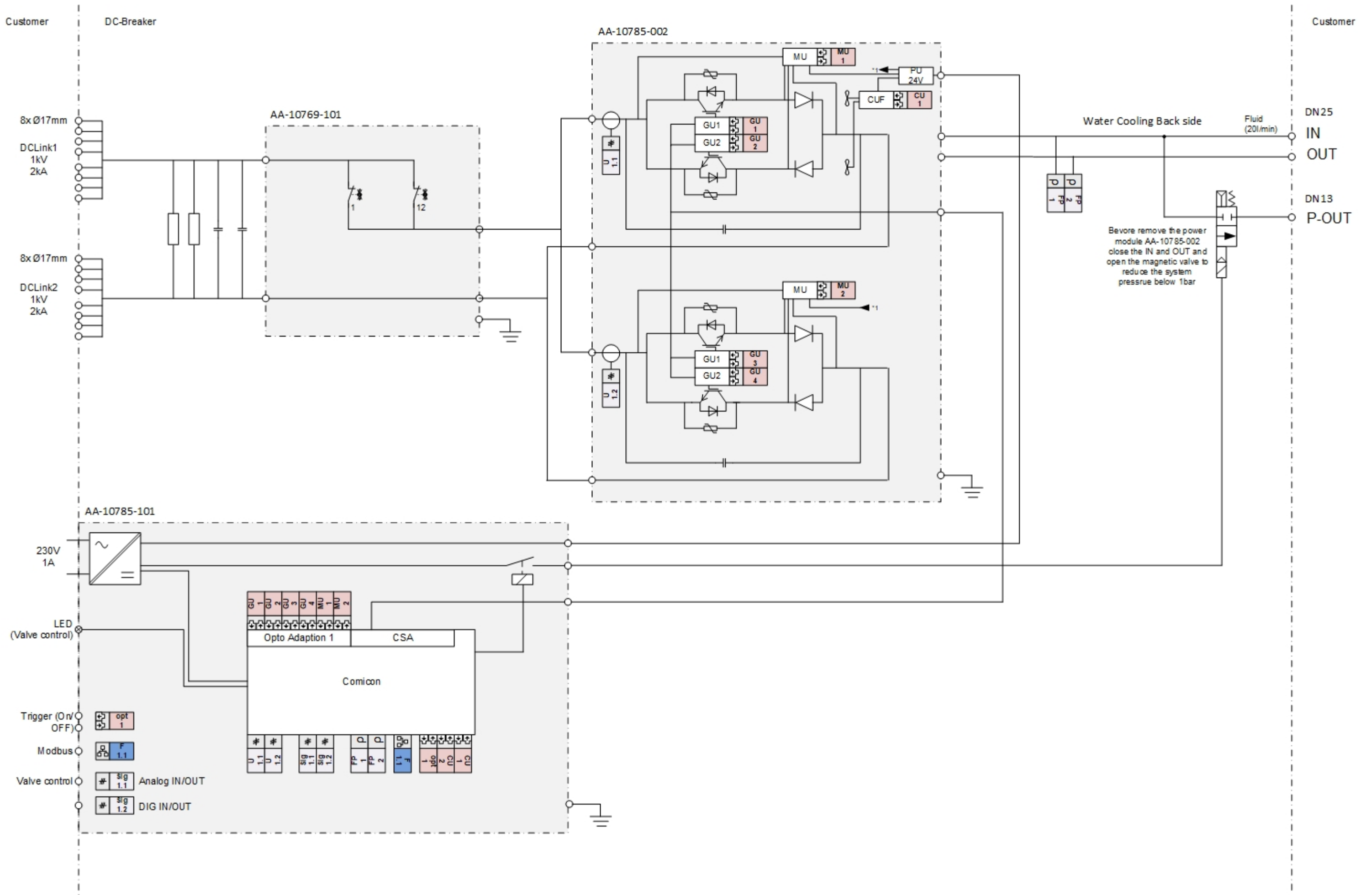


Figure 2 DC-Breaker Schematic Diagram

All the metallic parts in the cabinet are connected to the cabinet ground.

2.3 Cooling System

Due to the high level of losses, water cooling is used to actively cool the heatsink of each module.
The cooling system provides an inlet and outlet connection according to EN 14420 in DN25 dimension integrated. A maximum system pressure of **16bar** and a test pressure of **25bar** is allowed. The pressure sensors are mounted to these interfaces.
In addition there is a third connection DN13 integrated with a magnetic valve to reduce the system pressure when necessary (e.g. overpressure, maintenance).

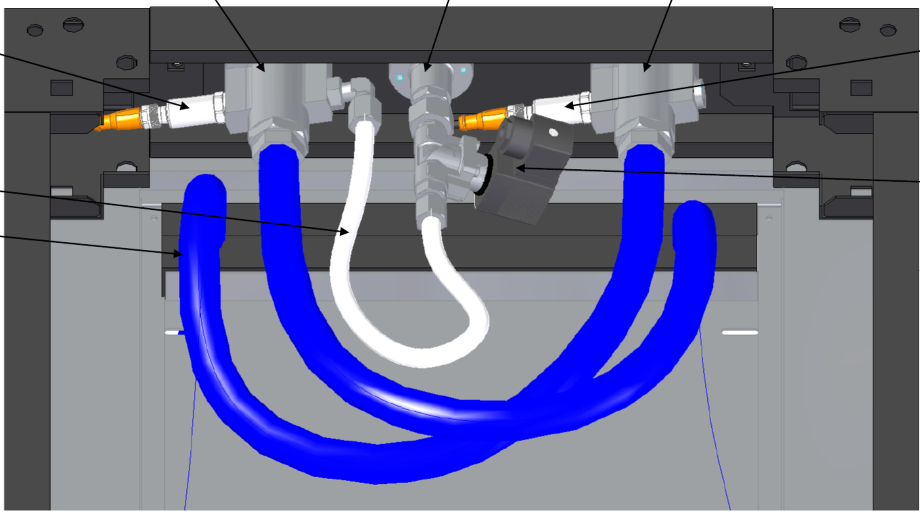


Figure 3 DC-Breaker Cooling Interface

These two DN19 hoses are connected to the backframe water manifold for the Power Module. For more details on cooling of the Power Module please refer to section 4.
The total pressure drop is around 1.5bar for the whole system (simplified calculation).

For filling up the system with deionized water, please note that there is no air bleed valve integrated.

To optimize the lifetime of the system and reduce the material friction in copper parts, we recommend to use an electrical Glycol (e.g. Glysofor ELM).

2.4 On-Board Diagnostics

Each module is equipped with a dedicated diagnostics module to measure the forward voltage V_F of the diodes and the V_{CE} voltage of the IGBT. Based on these measurements, a defect semiconductor can be detected whenever the DC-Breaker is switched on (current flow is needed for voltage measurement). In case of a detected failure, the Overall Controller will be notified so maintenance can be carried out in a timely manner.

2.5 Life Time

The life time is mainly given by the electronic components, especially optical components may suffer from aging. To reach 15 year life time, these components should be checked after 10 years of continued operation during a service interval. The fan requires maintenance every 5 and the gasket of the water point connectors every 10 years. All other components do not require service maintenance.

3 Technical Specification

3.1 Electrical Specifications

Parameter	Symbol	Condition	Min.	Typ.	Max.	Unit	Notes
DC Link voltage	$V_{dc\ link}$	-	-	10	1000	V	
DC Link Current	$I_{dc\ link}$	-	-	2	-	kA	
DC switch off time	t_{break}	-	-	-	10	µs	1
Voltage drop	V_{drop}	-	-	-	3.2	V	
Dump resistor	R_{dump}	-	-	0.3	-	Ω	
Dump resistor energy	E_{dump}	-	-	300	-	kJ	

[1] Time until maximum current is reached

Table 3 Electrical Specifications

3.2 Environmental Conditions

Parameter	Symbol	Condition	Min.	Typ.	Max.	Unit	Notes
Ambient temperature	T_{amb}	-	-5	-	+70	°C	1, 2
Storage temperature	T_{store}	-	-40	-	+85	°C	1, 2
Water temperature	T_{amb}	-	-	-	+27	°C	
Humidity	Hum	non condensing	-	-	95	% RH	1
IP grade electronic			-	-	IP20		3
IP grade switch			-	-	IP20		3
Operating altitude	Alt	-	-	-	2000	MSL	1

[1] Electronic and switch
[2] If the ambient temperature is below 0°C special care must be taken that cooling liquid will not freeze
[3] IP grade needed depends on the mounting place

Table 4 Environmental Conditions

3.3 Application Limitation

- The device is tested in accordance with relevant class rules.
- The device is used for fault current suppression and supports a second level of safety with a triggerable fuse.
- The system designer must provide:
  - means for manual, local, operation independent on higher level automation system, enabling necessary means for local operation, local remote change over, and interface for setting of parameters.
  - means for monitoring and indication of operating status and alarms.
  - means for isolation, enabling access for repair and electrical maintenance, in accordance with relevant rule requirements.
  - documentation of required system discrimination.

4 Mechanics

The DC-Breaker is a modular system with integrated Modular Power Unit (MPU), Controlling Unit and Pyrofuse Module. The modules are mounted in a 19" rack enclosure with a height of 1700mm and a depth of 800mm and directly interconnected with the Backside Connector Interface busbar. This allows an easy replacement of separate modules if necessary. The electrical power interface busbar is located on top while the fluid connections are located on the bottom rear side.

4.1 Overview

The complete DC-Breaker is built in a standard 19" rack enclosure.

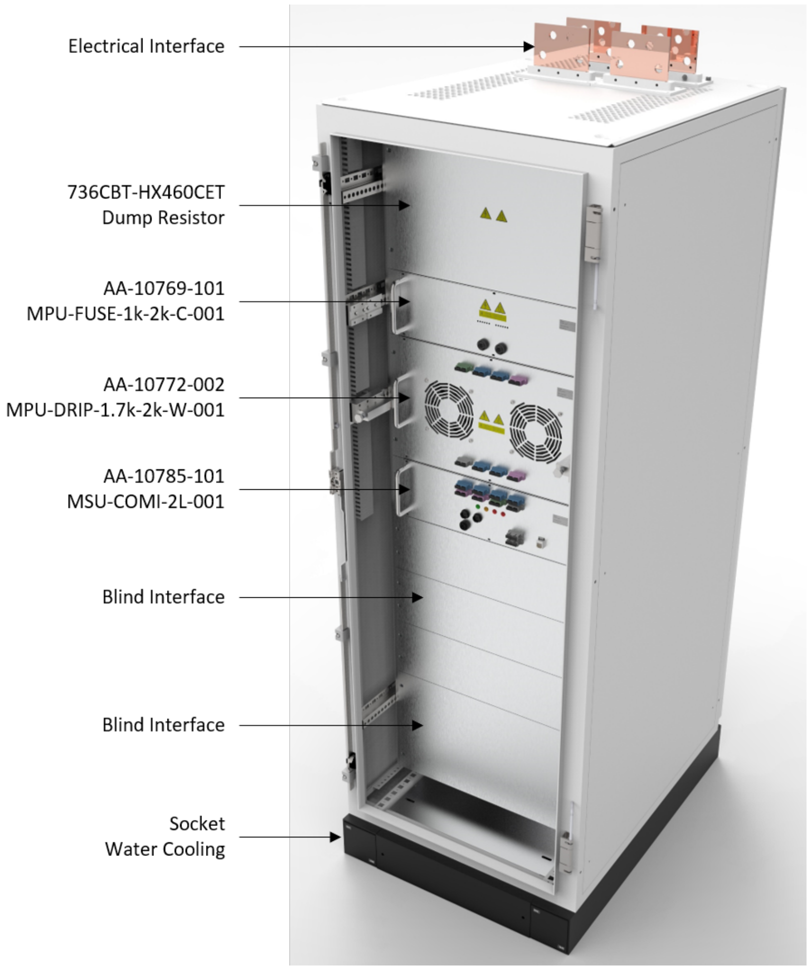


Figure 4 Rack System

The system consists of different replaceable rack modules.

Interface

- 1x MPU Power Module 1kV / 2kA
- 1x Controller Module
- 1x Pyrofuse Module
- Optional blind plates

All internal connectors of the DC-Breaker system (except optical interfaces) are located on the rear, while the customer interface (e.g. power input, control interface etc.) is located on the front.

4.2 MPU-DRIP Power Module

The Modular Power Module (MPU) is a very compact 2kA unit which is built up as a 6U 19" rack frame.
It consists of a copper heatsink with eight semiconductors placed at the top and bottom. The semiconductors are based on HiPack technology in configuration of 4 Diodes and 4 IGBTs for bidirectional usability. A dedicated voltage measurement unit on each side is used for semiconductor's health supervision and a fan controller for fan speed regulation directly in the module. Both busbars are equipped with a current sensor for accurate and fast current monitoring. MOV (Metal-Oxide Varistor) are directly mounted on the IGBTs for overvoltage protection, further there's a capacitor mounted on the back side between the input and output busbar connection.

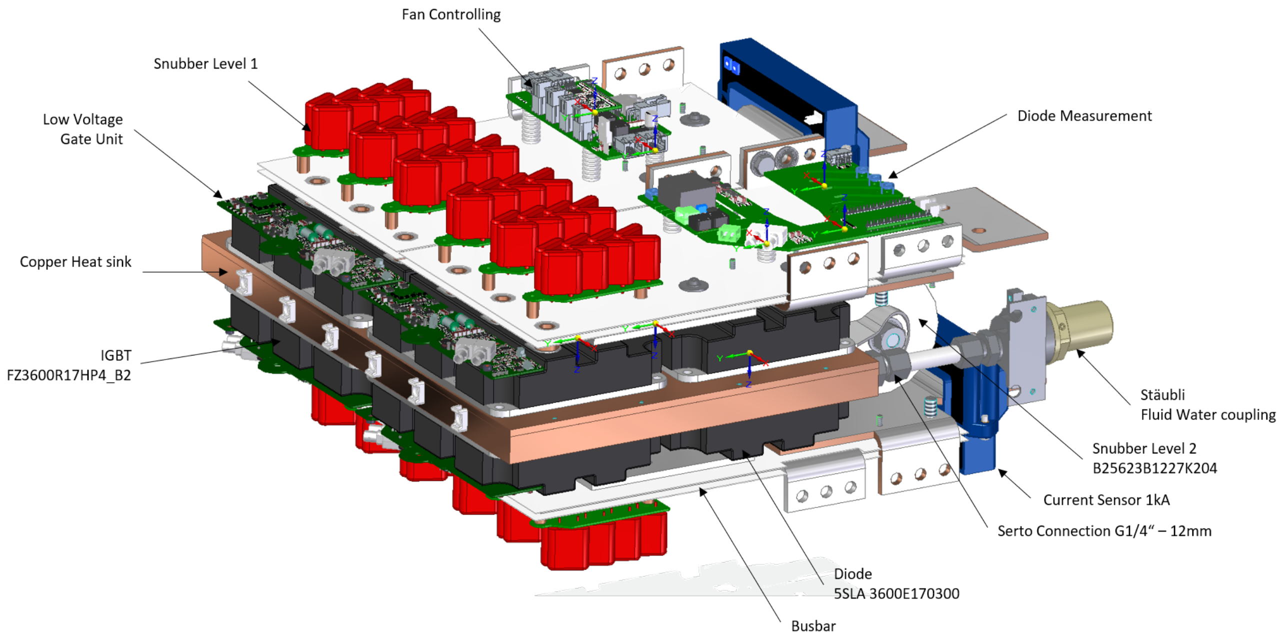


Figure 5 MPU-DRIP Module

The Power module is mounted in a Schroff 6U 19" rack cabinet for easy and safe handling.

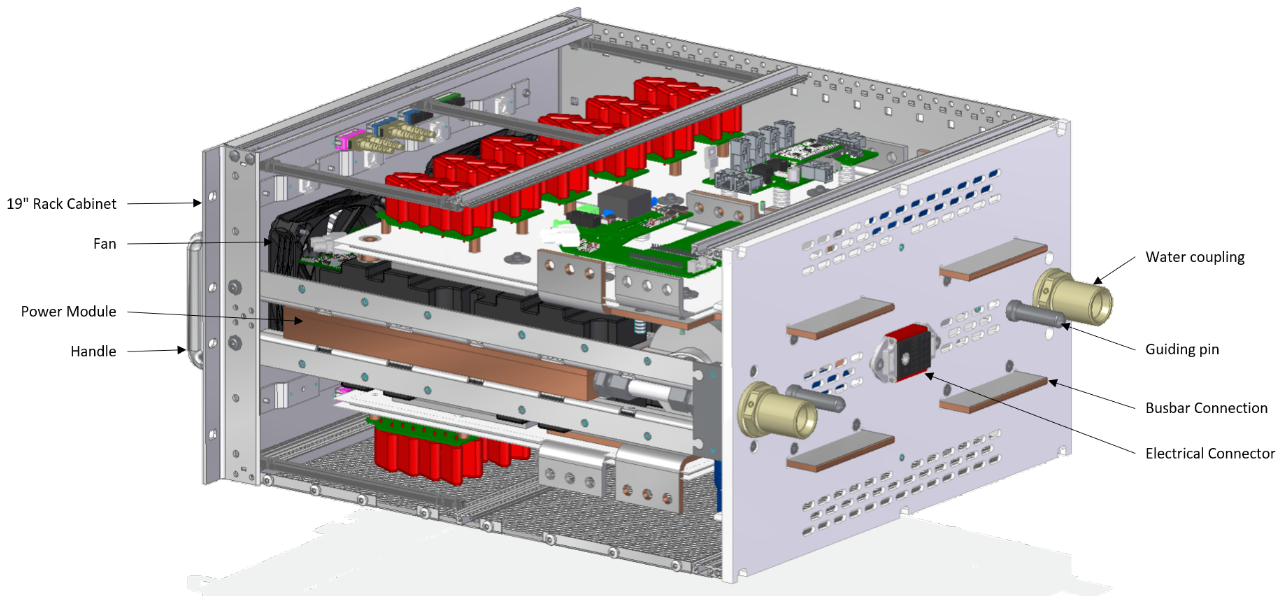


Figure 6 MPU-DRIP Power Module with Cabinet

4.2.1 Power Module Interface

The interface of the Power Module is designed for a simple replacement using self coupling connectors for electrical and fluid connections.
To connect the Power Module, a force of approximately 1kN is needed, the disconnecting force is around 180N. The exact required force depends on the fluid system pressure. Refer to fig. 7 to find the theoretical mounting and dismounting force.
The optical connectors are located on the front (refer to section 5.6 for more details).

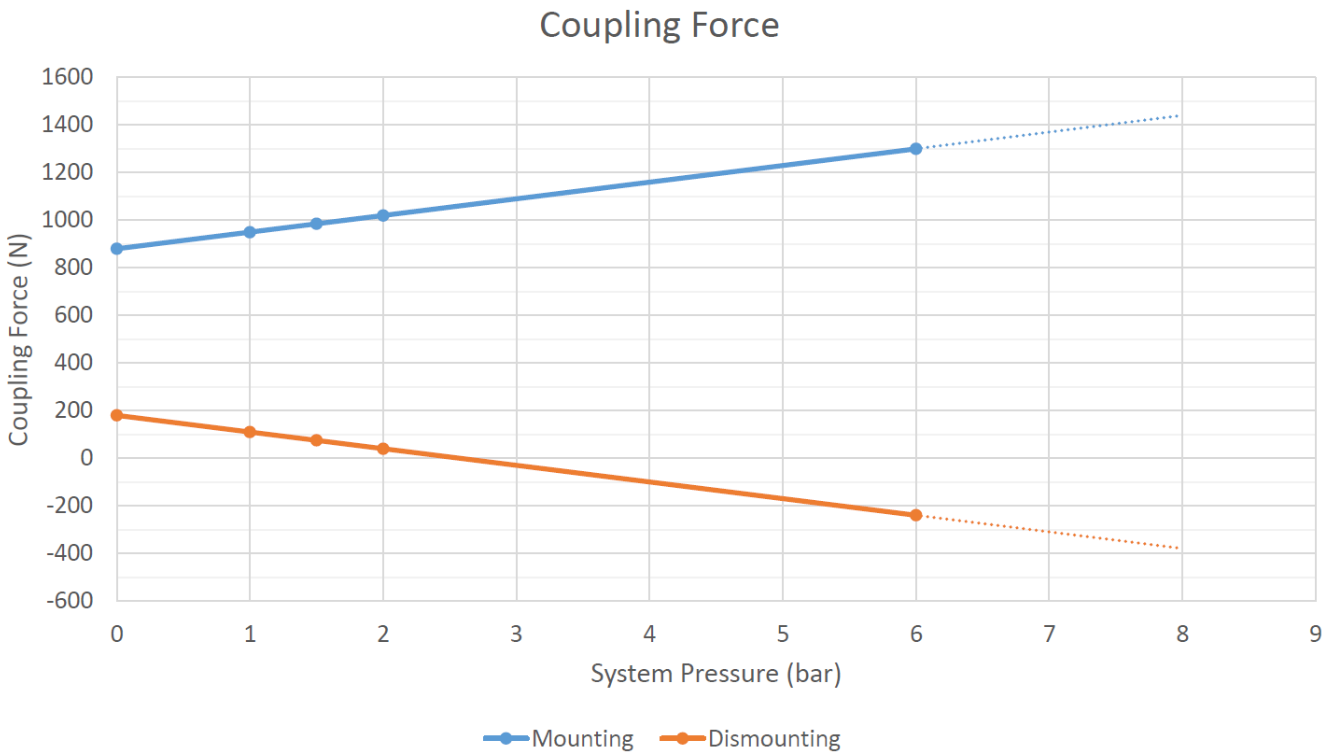


Figure 7 MPU DRIP Coupling force

Do not remove the power module with a system pressure >3bar.

Do not mount a Power Module with a system pressure >1.5bar as this may damage the cooling system.

To support maintenance there's a replacement tool mounting plate on both sides of the rack.

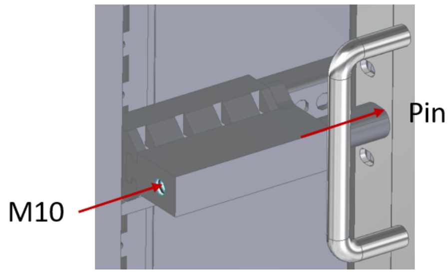


Figure 8 MPU Mounting Tool

The MPU Power Module needs to be screwed in on both sides symmetrically using the MPU mounting tool.

4.3 Control Module

The Control Module is built up as a 3U rack frame. It serves as a $24V_{DC}$ power distributor for the other rack modules. The system's control interface is located on the Control Module front (refer to section 5.5), it provides optical signals for state control and feedback as well as a RJ45 connector to access the controller's web- or Modbus/TCP interface respectively. Four signal LEDs provide the important status information at first glance.

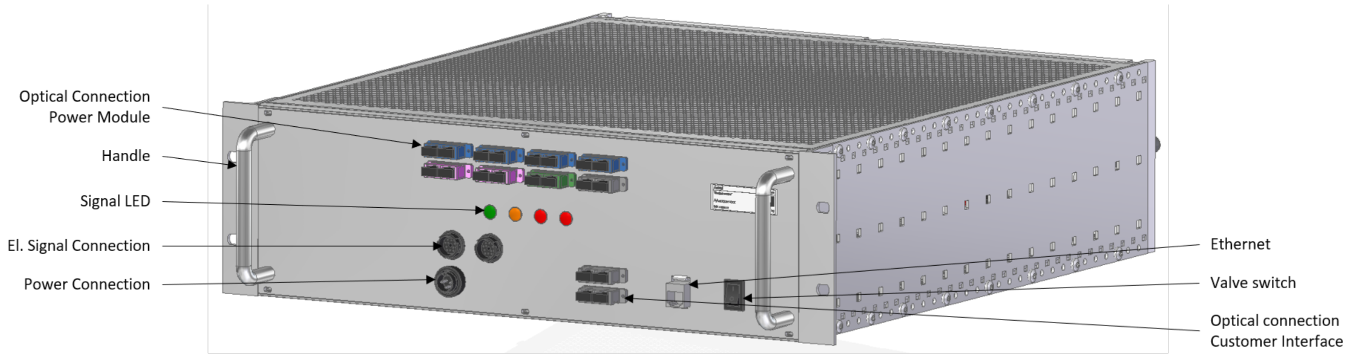


Figure 9 MCU Control Module Front

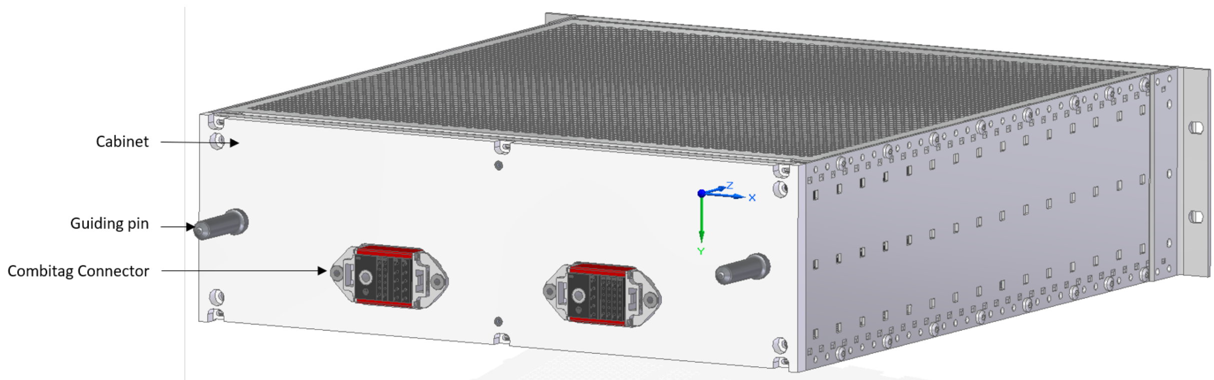


Figure 10 MCU Control Module Rear

The mounting and dismounting force is approximately 100N.

4.4 Pyrofuse Module

An electrical connector to communicate with the Control Module, 12 LEDs which represent the status of each pyrofuse as well as a switch to enable/disable the fuses are located on the module front.

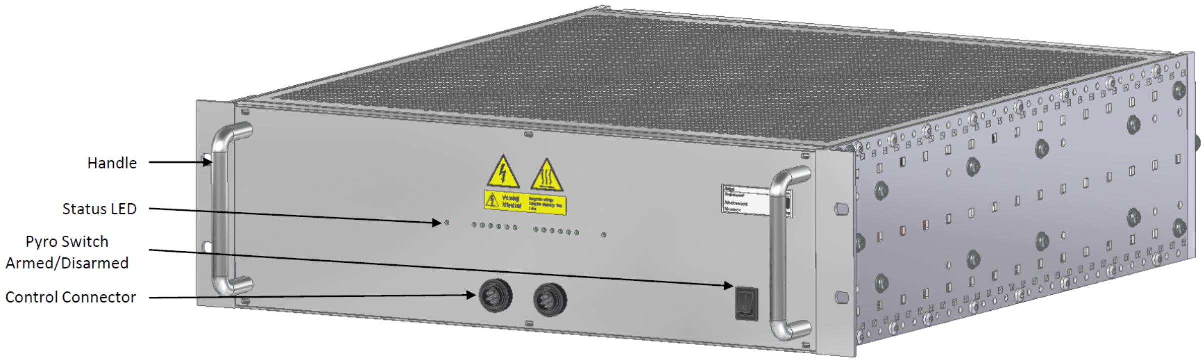


Figure 11 Fuse Module

The module has 12 slots for pyrofuses available and is connected in series to the MPU-DRIP module.
The fuses are mounted on fiber plastic GPO3 to ensure fire protection and electrical isolation.

Empty slots have to be bridged with a 100Ω resistor. Indicators for bridged fuses will not turn red when triggered.

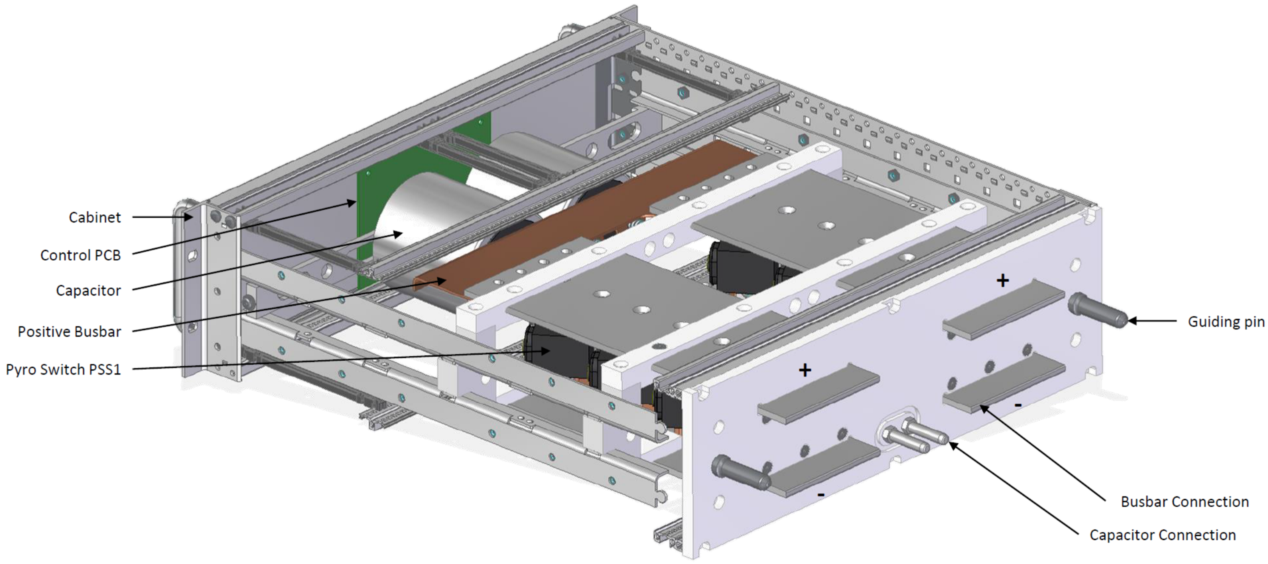


Figure 12 Fuse Module

The mounting force is around 650N, the removing force is approximately 320N.

The Pyrofuse Module needs to be screwed in on both sides symmetrically using the MPU mounting tool.

5 Connectors and Interfaces

5.1 Mechanical Interface

The DC-Breaker modules are integrated in a rack enclosure with a total height of 1700mm. At the top there is a cable panel on each side for all signal and power cables. The busbar power interface is also located on top. On the bottom there's a 100mm base plinth panel which includes the water connections.

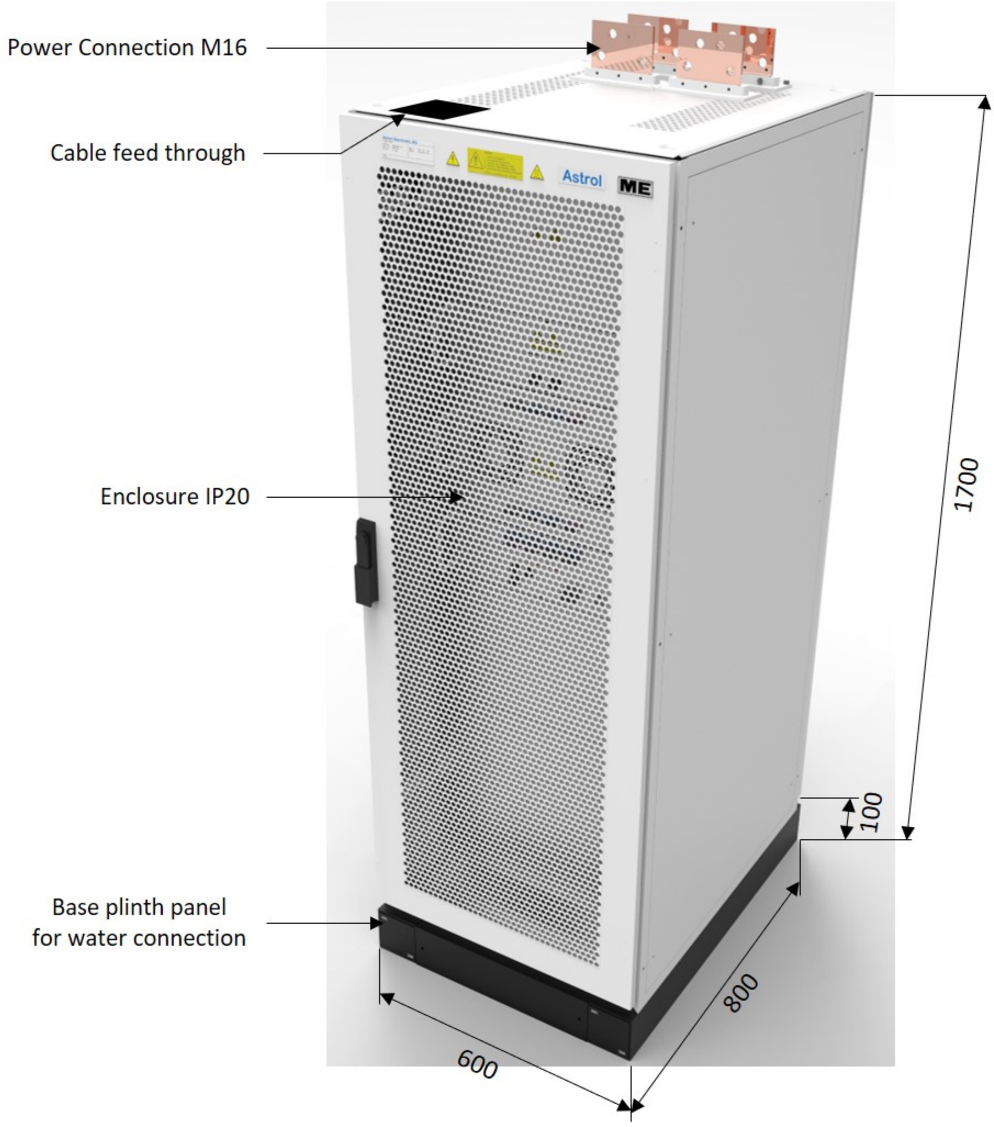


Figure 13 Mechanical Interface

5.2 Power Interface

The power interface on top of the enclosure provides four busbar power connections (two for both potentials) with 4x 17mm diameter holes on each connection bar (see fig. 14). The busbars at the back side (marked green) are on the same potential as well as the two busbars in the front (marked blue) are on the same potential.

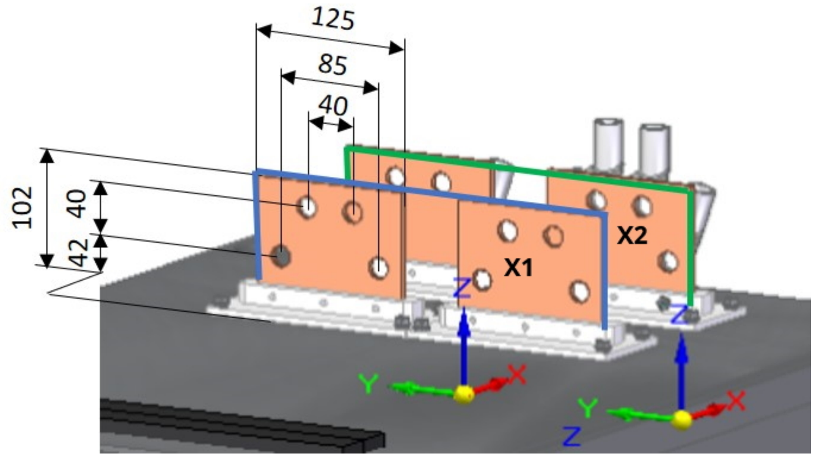


Figure 14 High Power Interface Connection

5.3 Cooling Water Hoses

The connectors for the cooling water in- and outlets are located on the bottom of the DC-Breaker. At the back side there are two G1" threads for DN25 according to EN 14420. In the middle is a third thread with G1/2" on which the EN 14420 male hose fitting for DN13 is mounted. This connection is used for the emergency pressure valve to reduce the system water pressure in case of overpressure or in order to replace the power module.

Water hose size

- G1/2" Inner diameter 13mm Outer diameter 22-24mm
- G1" Inner diameter 25mm Outer diameter 36-39mm

The material of the screwing parts is according to EN-14420-2 is 1.4401 (stainless steel). The clamping jaw, which is not in contact with any liquid, is made of aluminum.

> The clamping jaw is not compatible with steam hose armature.

Figure 16 shows the water hose connectors on the rear of the cabinet.

Figure 15 Male Hose Fitting

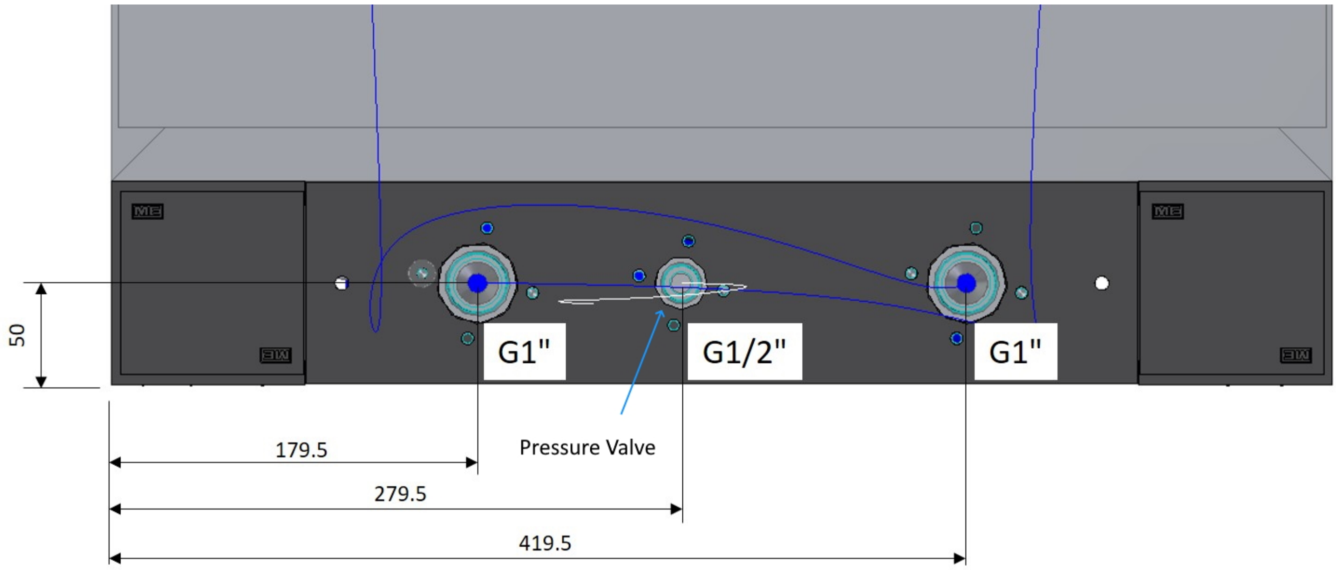


Figure 16 Water Hose Position

The two G1" connections are the main in- and outlet of the cooling circuit, the G1/2" is the outlet of the pressure valve.

5.4 External Connections

On top of the cabinet there is a cable bushing system for all external cable connections.

5.5 Interface Control Module

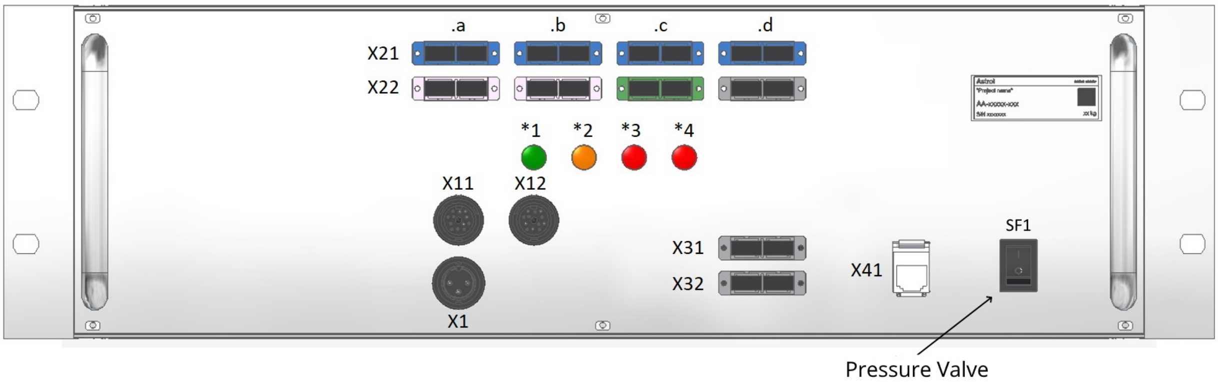


Figure 17 MCU Controlling Unit

The DC-Breaker system is powered through *X1* with 230V_{AC}. The optical connectors *X21a..d* and *X22a..d* are the interface to the Power Module. The connector *X12* is used to interact with the Pyrofuse Module. The other connectors *X11*, *X31*, *X32* and *X41* are the customer interface. For these check the following signal definitions at the follow tables. The switch (SF1) next to the RJ45 port activates the pressure valve.

5.5.1 Optical Indicators

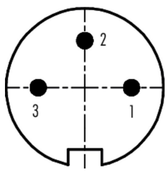
In the front of the Control Module there are four signal LEDs for status indication according to table 5.

LED	Color	Signal	Reference	Comment
*1	Green	Power ON	-	The controller is powered.
*2	Orange	Switch ON	-	The switch is closed
*3	Red	Error	-	The switch has an error.
*4	Red	System under pressure	-	The system pressure is >1.5bar

Table 5 Optical Indicators

5.5.2 -X1 Power Supply

Type: 99 0607 00 03 Binder 3P Miniature Bajonett Male Flange Connector IP40 Series 678

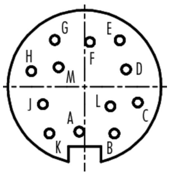


Pin	Used Square	Signal	Reference	Comment
1	$0.5mm^2$	$230V_{AC}$ L	-	-
2	$0.5mm^2$	$230V_{AC}$ PE	-	-
3	$0.5mm^2$	$230V_{AC}$ N	-	-

Table 7 Pin Definition X1

5.5.3 -X11 and -X12 Signal Interface

Type: 99 0652 00 12 Binder 12P Miniature Bajonett Female Flange Connector IP40 Series 678



-X11

Pin	Used Square	Signal	Reference	Comment
A	$0.25mm^2$	Valve Switch	-	-
B	$0.25mm^2$	GND	-	-

Table 9 Pin Definition X11

-X12

Pin	Used Square	Signal	Reference	Comment
A	0.25mm^2	TrigSig1+	-	-
B	0.25mm^2	TrigSig1-	-	-
C	0.25mm^2	+24V	-	-
D	0.25mm^2	Fuses_OK	-	-
E	0.25mm^2	Fuses_Ready	-	-
F	0.25mm^2	GND	-	-

Table 10 Pin Definition X12

5.5.4 -X31 and -X32 Optical Connectors

The designators -X21 and -X22 include multiple optical connectors used as communication interfaces between the Power Module and the Control Module and are therefore not described in further details.

Type: 11895 FS SC/SC 10G Duplex Multimode Connector green
Type: 48495 FS SC/SC 10G Duplex Multimode Connector Blue
Type: 68521 FS SC/SC 10G Duplex Multimode Connector Pink
Type: 48494 FS SC/SC 10G Duplex Multimode Connector Grey
Type: 20 10 001 5211 FS SC Crimp Connector for 1mm POF cable 2.2mm





-X21 and -X22
This connectors are internally used for communication between Power Module and Controlling Module. Connector target is marked on each cable.

-X31

Pin	Used Square	Signal	Reference	Comment
1	1mm POF	Switch Status	-	-
2	1mm POF	Control Signal	-	-

Table 12 Pin Definition X31

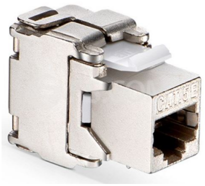
-X32

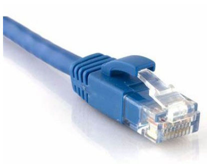
Pin	Used Square	Signal	Reference	Comment
1	1mm POF	Warning	-	Active Low
2	1mm POF	Fault	-	Active Low

Table 13 Pin Definition X32

5.5.5 -X41 Ethernet

Type: 13657 FS Cat5e RJ45 shielded female connector





Pin	Used Square	Signal	Reference	Comment
1	0.16mm^2	TX+	-	-
2	0.16mm^2	TX-	-	-
3	0.16mm^2	RX+	-	-
4	0.16mm^2	-	-	-
5	0.16mm^2	-	-	-
6	0.16mm^2	RX-	-	-
7	0.16mm^2	-	-	-
8	0.16mm^2	-	-	-

Table 15 Pin Definition X41

5.6 Interface MPU Power Unit

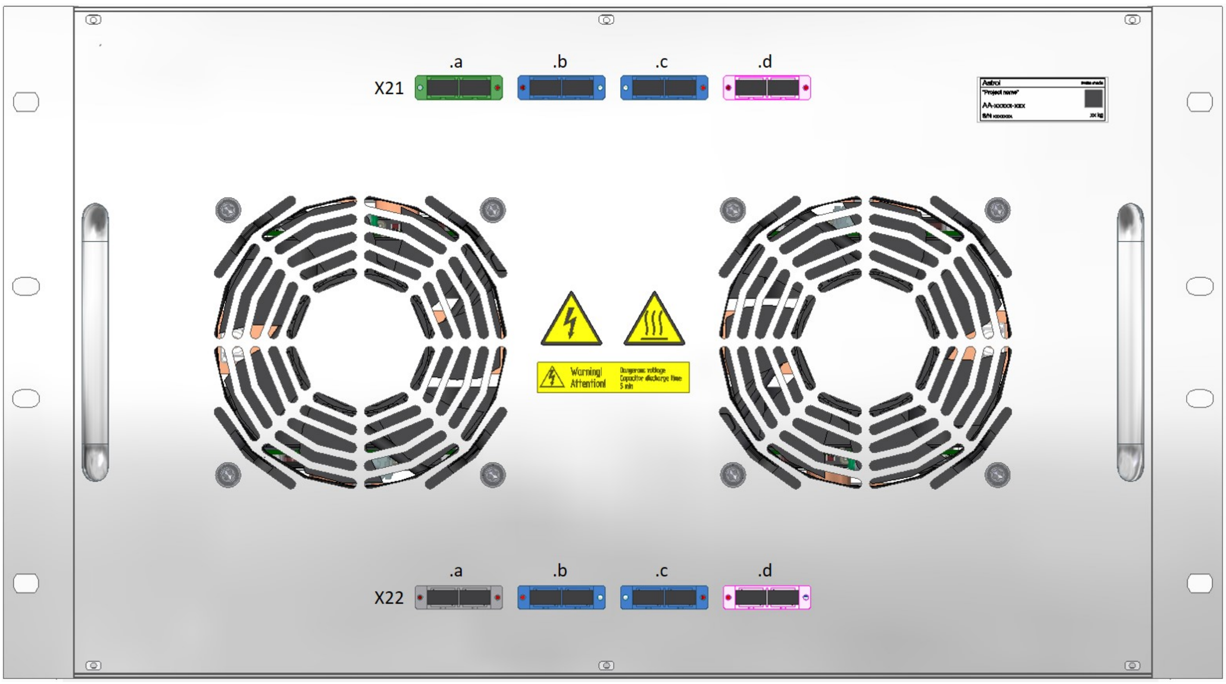
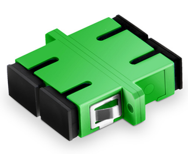


Figure 18 MPU Power Unit

5.6.1 -X21 and -X22 Optical Connectors

The designators -X21 and -X22 include multiple optical connectors used as communication interfaces between the Power Module and the Control Module and are therefore not described in further details.

Type: 11895	FS	SC/SC 10G Duplex Multimode Connector green
Type: 48495	FS	SC/SC 10G Duplex Multimode Connector Blue
Type: 68521	FS	SC/SC 10G Duplex Multimode Connector Pink
Type: 48494	FS	SC/SC 10G Duplex Multimode Connector Grey
Type: 20 10 001 5211	FS	SC Crimp Connector for 1mm POF cable 2.2mm





5.7 Interface Pyrofuse Module

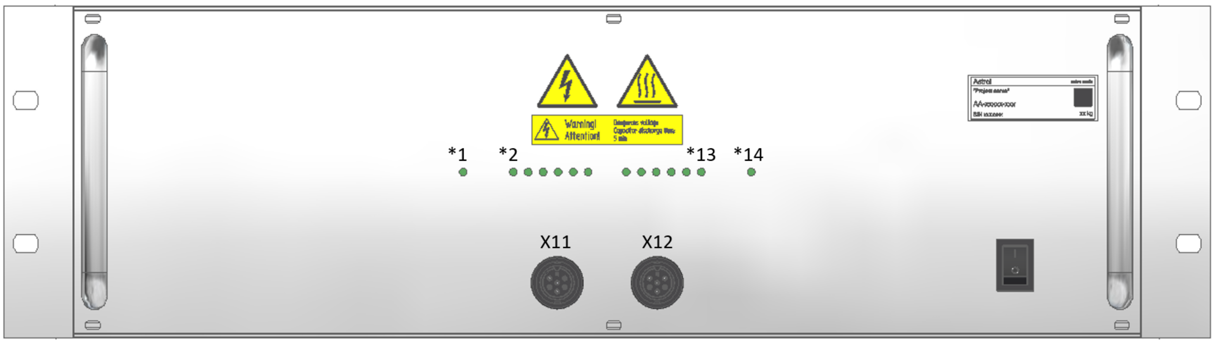
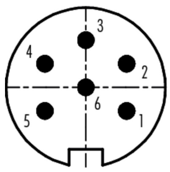


Figure 19 Pyrofuse Module

5.7.1 -X11, -X12 Fuse Trigger and Status

Type: 99 0619 00 06 Binder 6P Miniature Bajonett Male Flange Connector IP40 Series 678



-X11

Pin	Used Square	Signal	Reference	Comment
1	0.25mm^2	TrigSig1+	-	-
2	0.25mm^2	GND	-	-
3	0.25mm^2	+24V	-	-
4	0.25mm^2	Fuses_OK	-	-
5	0.25mm^2	Fuse_Ready	-	-
6	0.25mm^2	GND	-	-

Table 18 Pin Definition X11

-X12

Not used

5.7.2 Fuse Status

With this switch the pyrofuses can be armed/disarmed. Note that the breaker cannot be closed without armed pyro-fuses.

6 Functions

6.1 Control Functions

Function	Description
Close / Open	The state of the DC-Breaker is controlled with the optical control signal on *-X31.3* where an applied *HIGH* initiates a close while *LOW* open the DC-Breaker. Closing is only allowed if the device is *ready* and no faults apply. When closed, this is indicated with the *Status Feedback* being active.
Fault Reset	If the DC-Breaker is in fault state, it can be reset by applying a signal pulse on the control signal input on *-X31.3*. The DC-Breaker will not be closed under this condition.
Valve Control (*SF1*)	Used to release water pressure for maintenance as module replacement should take place with a system pressure <1.5bar.
Feedback	The switch status on *-X31.1* represents whether the switch is conducting or not (light=conducting/no light=not conducting).
Warning	The warning feedback line is active low (light=ok/no light=warning).
Fault	The fault feedback line is active low (light=ok/no light=warning).

Table 19 Control Functions

6.2 Protection Functions

6.2.1 Overload/Overcurrent Detection

One of the main functions of a DC-Breaker is the overcurrent detection.

A parameter set is implemented with adjustments relative to the maximum continuous current I_{cmax}.

Parameter	Symbol	Description	Min	Max	Unit	Remark
Maximum Continuous Current	I_{cmax}	This current can be conducted continuously without causing an overload error.	50	$I_{dc\ link}$	A	-
Overload Factor	K_{OL}	If this current is applied continuously it will cause an error after the time T_{OL} has reached.	1	1.25	-	-
Overload Time	T_{OL}	The overload current can be applied continuously for this time without causing an overload error.	1	100	s	-
Peak Current	I_P	Exceeding this current level causes an immediate trip.	I_{cmax}	$I_{dc\ link} \cdot 1.25$	-	-

Table 20 Tripping Characteristic Parameter Set

With these parameters the tripping characteristic is divided into an overload range with a thermal tripping characteristic and the overcurrent range with immediate tripping. The following figure shows this characteristic with two different examples.

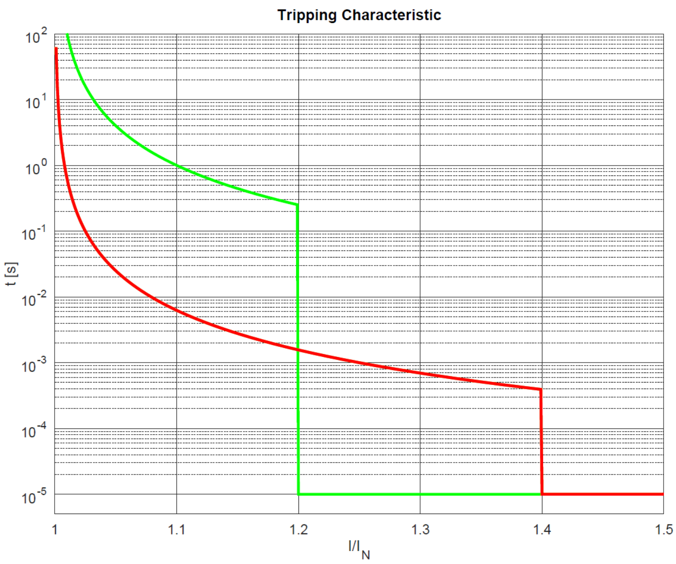


Figure 20 Tripping Characteristic

Green: K_{OL}=1.1, T_{OL}=1s, I_P=1.2·I_N Red: K_{OL}=1.25, T_{OL}=1e-3s, I_P=1.4·I_N

In order to avoid absolute parameters there is no setting for the load integral i^2t foreseen, which is more common for melting fuses. However the load integral can be calculated as follows:

$$i^2t = ((K_{OL} - 1) \cdot I_{cmax})^2 \cdot t_{OL} \tag{1}$$

In case of an overcurrent trip event, the breaker's global status would look like illustrated in fig. 21.

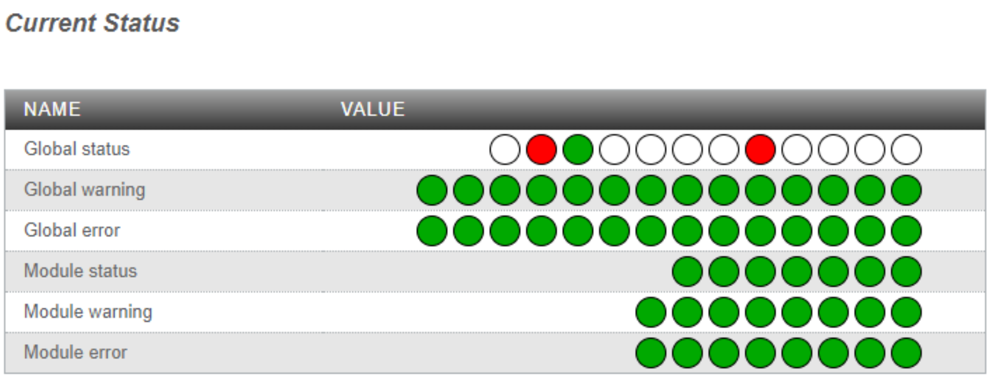


Figure 21 Global Status Overcurrent Trip

6.2.2 Pressure and Temperature Supervision

System Temperature

The controller constantly measures the temperature of the cooling plates in order to protect the system from being damaged due to overtemperature.
In case the temperature exceeds the allowed threshold, the DC-Breaker opens autonomously and cannot be closed until the temperature is normalized.

Dumping Resistor Temperature

In case of a breaking event, the system's dumping resistors (see fig. 1) have to absorb the residual energy in the system. After such an event, the DC-Breaker cannot be closed until the temperature of the dumping resistors return to a normal level.

System Pressure

The controller constantly measures the system pressure of the cooling circuit on the in- and outlet. The system allows a maximum pressure of 16bar, if the pressure exceeds 16bar this causes a warning *overpressure*. When the pressure increases between 23bar and 25bar for more than 1 minute, the controller opens the emergency pressure valve to release the system pressure until it falls below 16bar again. Above 25bar the emergency pressure valve opens immediatly.

6.2.3 Pyrofuse

The Pyrofuse Module provides an additional level of safety in case the DC-Breaker is conductive while technically in *open* state.

The fuses are triggered if the control signal (-*X31.3*) is not applied but the controller still measures a current in one of the two current-paths. The trigger level I_{th_pyro} is 150A.
As a second parameter there's a 800µs blanking time $t_{blanking}$ which ensures that the current has enough time to decrease below the threshold after an opening event to prevent false positive triggering of the pyrofuses.

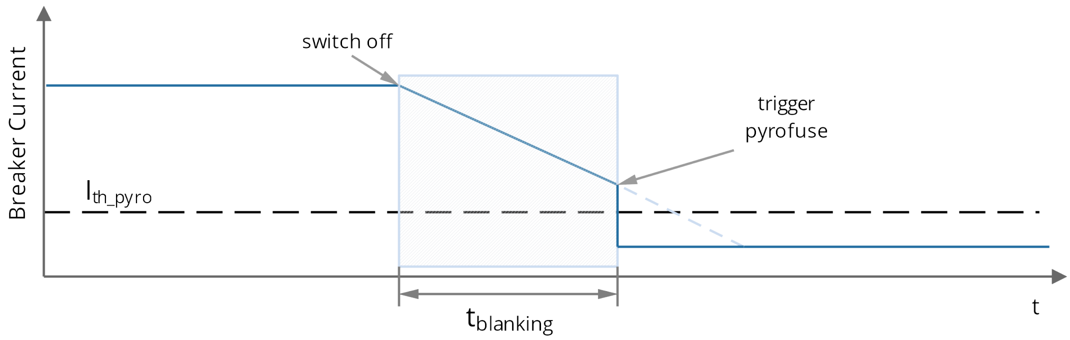


Figure 22 Pyrofuse Trigger Behavior

The status of the pyrofuses is supervised, if one of them is broken the DC-Breaker cannot be closed and the fault line (-*X32.3*) is set active.

6.2.4 Pole-to-Pole Voltage

The DC-Breaker measures the voltage between the two poles during operation. The controller doesn't accept incoming close requests if the Pole-to-Pole voltage is above 5.0V as this indicates that there's still current flowing through the dumping resistor.

6.2.5 Semiconductor Health State

The controller supervises the diodes' forward voltage and the IGBTs' V_{CE} voltage in order to draw conclusions about the semiconductor's health state.
While in open state, the Gate Driver apply a V_{CE} voltage of $\approx$27V. In case the measured voltage is <15V, the system raises a fault as one of the semiconductors might has a short. While conducting (I>10A), the measured V_{CE} and V_F have to be in the range of 0.2V to 2.0V, otherwise the warning line is set.

6.2.6 Current Asymmetry

The maximum tolerated current asymmetry between the two current paths is limited to 5% of the configured nominal current for a warning and 7% for a fault respectively. These threshold refer to the configured maximum continuous current.

7 Operation

7.1 Parameter

The DC-Breaker offers certain configuration parameter to customize the protection behavior.
In order to change the parameters, the DC-Breaker has to be connected to a computer within the same subnet.

> The DC-Breaker's default IP address is 192.168.2.10
> The web-interface can be reached with a normal browser (e.g. Firefox, Chrome).

Enable the configuration by pressing *Advanced Access* on the *Home* tab, the password is **service**, then navigate to the *Parameter*.

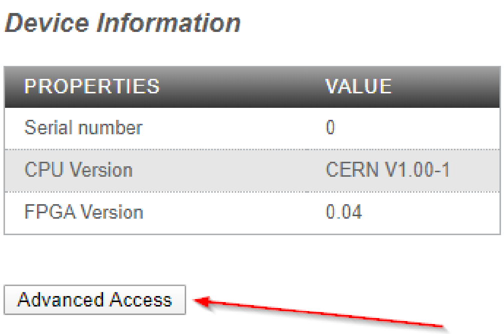


Figure 23 Advanced Access

Parameter	Description	Remark
Continuous total current	Defines the nominal current of the breaker.	
Overload factor	Overload factor K_{OL} as defined in section 6.2.1 as a ratio of the continuous total current.	
Overload time	Overload time t_{OL} as defined in section 6.2.1.	
Peak current	The maximum allowed peak current for the breaker. Exceeding this level causes an overcurrent trip and the breaker opens automatically.	

Table 21 Parameter Overview

> If the Continuous Total Current is set too low, this can cause issues due to resolution limitations.

7.2 Breaker Status

7.2.1 Global Status Register

The breaker's current status is available on the web-interface and provides thorough information on the breaker's health state. An open and ready breaker might has a current status as shown in fig. 24.

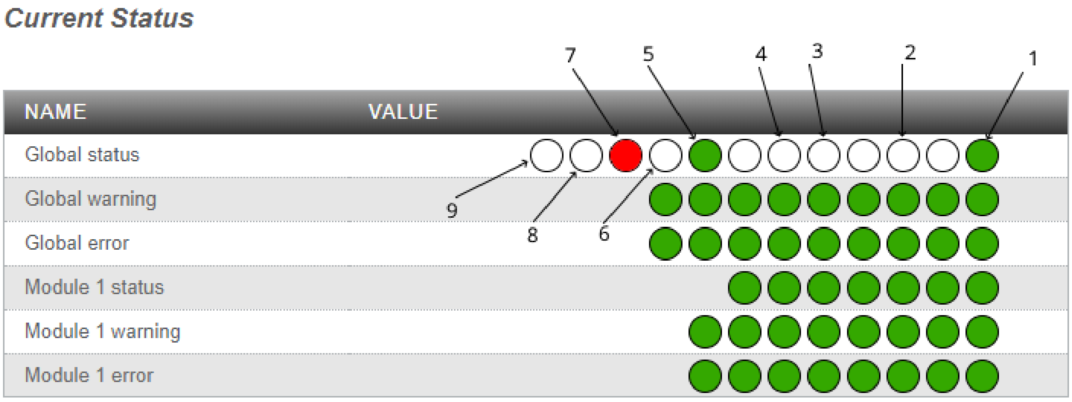


Figure 24 Current Status

1. Breaker is ready
2. Breaker is closed and conducting
3. An active fault is present, refer to *Global error*
4. An active warning is present, refer to *Global warning*
5. The system pressure is >1.5bar
6. The breaker was opened due to overload
7. The pyrofuses are armed and ready
8. The breaker was opened due to an overcurrent event
9. The pyrofuses have been triggered

Tooltip information is available for all the individual status flags.

7.2.2 Measurements

The breaker's measurement values are available on the web-interface as *current readings* and list a variety of measured and/or calculated values.

7.3 Breaker Control

1. The breaker has to be ready for operation in order to be closed. This includes the breaker itself as well as the pyrofuses.

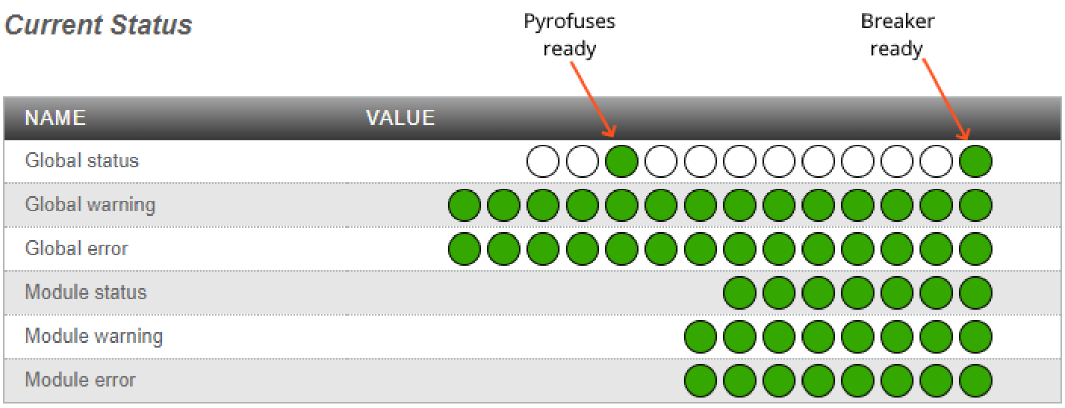


Figure 25 Breaker Ready

2. The breaker is closed by applying a signal (light) on the control input *-X31/TX* and opened by removing it. Whether the breaker is closed or not is also resembled on the optical status feedback, the light indicator (refer to section 5.5.1) and the global status information.

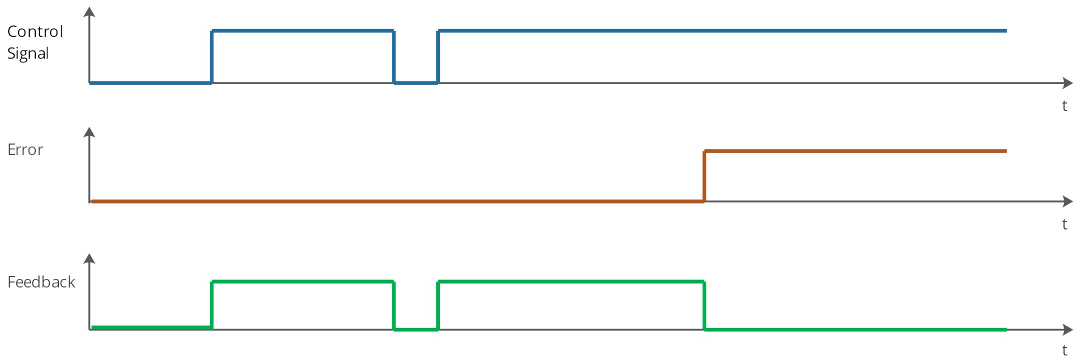


Figure 26 Control Signals

The control signal has a 2ms blanking time on the rising edge as noise protection and a minimal off time of 10ms.

3. If the closed switch is conducting current, the measurement can be observed on the web-interface under *Current Reading*.

7.4 Warnings and Errors

7.4.1 Warnings

Warnings are conditions which are abnormal but still allow operation.
Warnings are self-clearing once the causing condition is resolved. An active warning is indicated by the optical warning feedback beeing low.

Name	Description	Action
Pressure	The pressure in the cooling system is above the warning threshold.	The *warning* line is set active and the corresponding bit in the warning register is set.
Temperature	The temperature of the heatsink is above the warning threshold.	The *warning* line is set active and the corresponding bit in the warning register is set.
Overload	The overload (I^2t) is above 80%.	The *warning* line is set active and the corresponding bit in the warning register is set.
Fan	One of the fans is defective (no tacho feed-back detected).	The *warning* line is set active and the corresponding bit in the warning register is set. Fan should be re-placed in a timely manner.
Current Asymmetry[1]	The relative difference of the current in both paths is above threshold (5%).	The *warning* line is set active and the corresponding bit in the warning register is set.
Semiconductor Voltage	The forward voltage of either a diode or an IGBT is out of range while the breaker is closed (health supervision).	The *warning* line is set active and the corresponding bit in the warning register is set.

[1] The current asymmetry is defined in regards of the configured maximum continuous current ($\Delta I_{max} = 100A$ @2000A).

Table 22 Warnings

7.4.2 Error

Errors are conditions which are abnormal and do not allow further operation of the DC-Breaker.
Errors have to be actively cleared by applying a reset pulse on the control input (except for pressure fault).
An active error is indicated by the optical error feedback beeing low, additionally there's a light indicator in the front of the Control Module (refer to section 5.5.1).

Name	Description	Action
Pressure	The pressure in the cooling system is above the error threshold.	The *fault* line is set active and the corresponding bit in the fault register is set. The pressure level is lowered by opening the emergency valve. The DC-Breaker doesn't open if closed but cannot be closed if open. [1]
Temperature	The temperature of the heatsink is above the error threshold.	The *fault* line is set active and the corresponding bit in the fault register is set. The DC-Breaker opens au-tomatically. [1]
Overload	The overload (I^2t) has reached 100%.	The *fault* line is set active and the corresponding bit in the fault register is set. The DC-Breaker opens au-tomatically.
P2P voltage	The voltage between the two poles is above the threshold when the breaker is open.	The *fault* line is set active and the corresponding bit in the fault register is set.
Resistor Temperature	Dump resistor is too hot (150°C).	The *fault* line is set active and the corresponding bit in the fault register is set.
Current Asymmetry[2]	The relative difference of the current in both paths is above threshold (7%).	The *fault* line is set active and the corresponding bit in the fault register is set. The DC-Breaker opens au-tomatically.

Overcurrent	The total current exceeded the configured overcurrent threshold.	The *fault* line is set active and the corresponding bit in the fault register is set. The DC-Breaker opens automatically.
Pyrofuse	The pyrofuses have been triggered.	The *fault* line is set active and the corresponding bit in the fault register is set.
Gate Driver	A gate driver of the Power Module has a fault.	The *fault* line is set active and the corresponding bit in the module status register is set.
Semiconductor Voltage	The V_{CE} Voltage an IGBT is out of range while the breaker is open (health supervision).	The *fault* line is set active and the corresponding bit in the fault register is set.

[1] This fault is not latched and has not be cleared
[2] The current asymmetry is defined in regards of the configured maximum continuous current ($\Delta I_{max} = 140A$ @2000A).

Table 23 Errors

7.4.3 Clear Error

As errors are latched, they need to be cleared before the breaker is operational again. Faults are cleared on the next positive edge of the control input (refer to fig. 27). Note that the breaker does not automatically close on fault reset but needs another rising edge on the control signal to be closed.

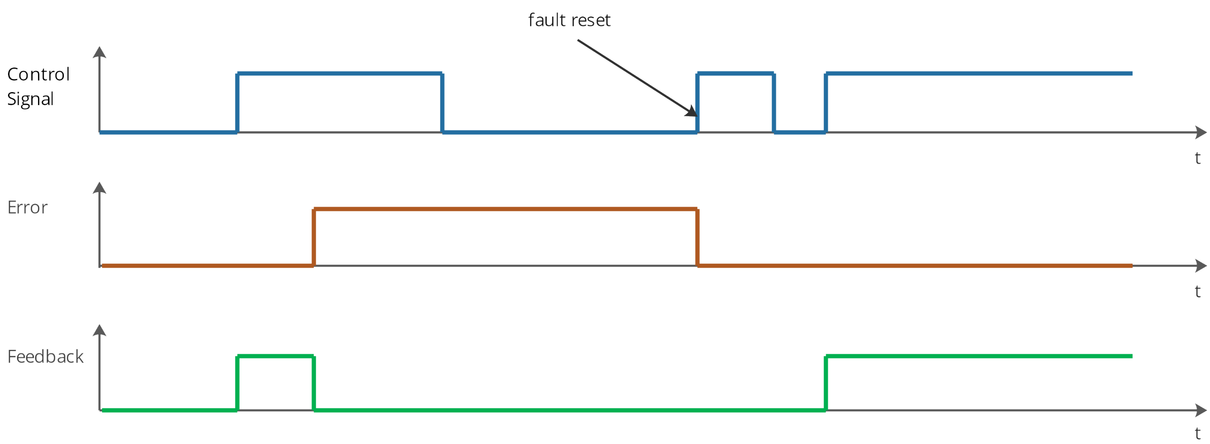


Figure 27 Fault Reset

7.5 Troubleshooting

Problem	Solution
Breaker is not ready after startup but doesn't have any fault.	Make sure no trigger is applied on startup, this would block the breaker from becoming ready and is intended design.

Table 24 Troubleshooting

8 Quick Start

1. Connect the water cooling system to the DC-Breaker. To do this, the appropriate connectors must first be attached to the DC-Breaker and then the connection can be made with a hose. The connection is described in section 5.3.
2. Connect the main terminals X1, X2 to the DC grid (refer to section 5.2)
3. Connect the electrical and optical wires to the corresponding connectors on the Control Module as outlined in section 5.5.
4. The DC-Breaker can now be configured, follow the instructions given in section 7.1.
5. The DC-Breaker is ready for operation. Detailed operation instructions can be found in section 7.

9 Modbus Definition

9.1 Data Types

Format	Description	Type	# Register	Acceptable Range
UINT16	16-bit unsigned	Integer	1	0 to 65535
INT16	16-bit signed	Integer	1	-32768 to 32767
UINT32	32-bit unsigned	Integer	2	0 to 4294967295
INT32	32-bit signed	Integer	2	-2147483648 to 2147483647
BoolArray	Boolean array	Integer	1	0 to 0xFFFF (BITx)
Float	IEEE float	Float	2	-3.402823466 x 10^{38} to 3.402823466 x 10^{38}

Table 25 Modbus Data Types

9.2 Register Groups

Type Access	Address	# Register	Description
Input registers	0	16	System information
Input registers	16	32	Status
Input registers	48	64	Measurement
Holding registers	16	16	Parameter

Table 26 Modbus Register Groups

9.3 Input Register

9.3.1 System information

Address	Type	# Register	Unit	Description
0	UINT32	2		Serial number
2	UINT16	1		Software version (2 bytes major, 2 bytes minor)
3	UINT16	1		FPGA version (2 bytes major, 2 bytes minor)
4	UINT16	1		Device type (1=DC Breaker)

Table 27 Modbus System Information

9.3.2 Status

Address	Type	# Register	Unit	Description
16	BoolArray	1	-	Global status
17	BoolArray	1	-	Global warning
18	BoolArray	1	-	Global error
19	BoolArray	1	-	Module status
20	BoolArray	1	-	Module warning
21	BoolArray	1	-	Module error

Table 28 Modbus Status

9.3.3 Measurements

Address	Type	# Register	Unit	Description
48	INT16	1	[A]	Load current line 1
49	INT16	1	[A]	Load current line 2
50	INT16	1	[A]	Total current
51	INT16	1	[°C]	Overload
52	INT16	1	[mBar]	Pressure 1
53	INT16	1	[mBar]	Pressure 2
54	INT16	1	[mBar]	Pressure delta
55	INT16	1	[%]	Overpressure
56	INT16	1	[°C]	Tsense 1
57	INT16	1	[°C]	Tsense 2
58	INT16	1	[°C]	Tsense delta
59	INT16	1	[mV]	Pyrofuses ready (8V)
60	INT16	1	[mV]	Pyrofuses ok (8V)
61	INT16	1	[°C]	Rtemp 1
62	INT16	1	[°C]	Rtemp 2
63	INT16	1	[°C]	Rtemp delta
64	INT16	1	[°C]	Controller temperature
65	INT32	2	[mV]	Module 1 voltage VCE path 1
67	INT32	2	[mV]	Module 1 voltage VF path 1
69	INT32	2	[mV]	Module 1 voltage VCE path 2
71	INT32	2	[mV]	Module 1 voltage VF path 2
73	INT32	2	[mV]	Module 1 voltage breaker
75	INT32	2	[mV]	Module 2 voltage VCE path 1
77	INT32	2	[mV]	Module 2 voltage VF path 1
79	INT32	2	[mV]	Module 2 voltage VCE path 2
81	INT32	2	[mV]	Module 2 voltage VF path 2
83	INT32	2	[mV]	Module 2 voltage breaker

Table 29 Modbus Measurements

9.3.4 Parameter

Address	Type	# Register	Unit	Description
16	INT16	1	[A]	Continuous total current
17	UINT16	1	[%]	Overload factor
18	UINT16	1	[s]	Overload time
19	UINT16	1	[A]	Peak current

Table 30 Modbus Parameter

10 Document History

Rev.	Changes	Visum	Date
1.0	Initial Release	Adrian Jaeggi Gianluca Picciola	22.07.2020

Figure 28 Checked

Figure 29 Approved

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