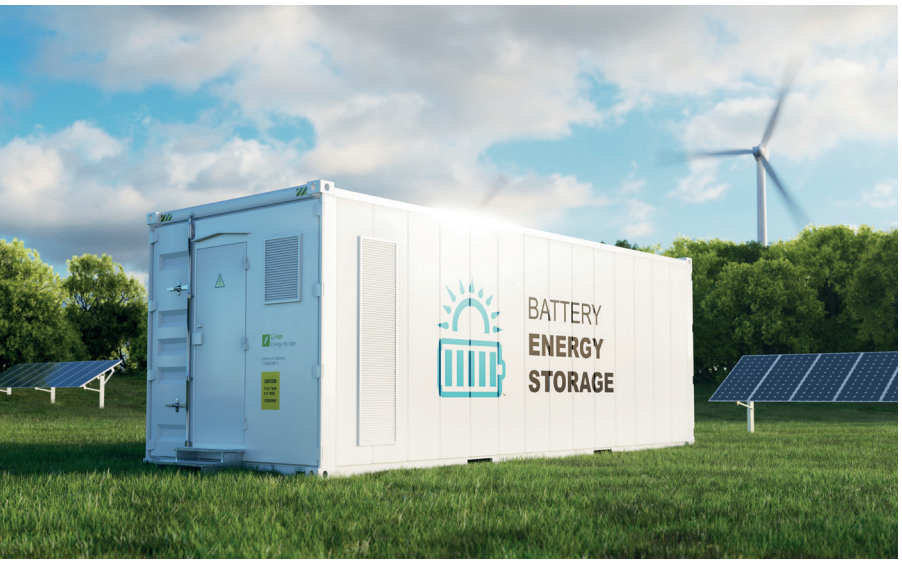
APPLICATION NOTE

Switching & Protection of 1500V DC Bus in Power Conversion Systems



To ensure optimal energy efficiency and uninterrupted service, power conversion systems require effective fault protection, load switching, and galvanic isolation. Explore our pre-configured solution packages tailored for designing 1500V DC bus protection and switching of power conversion systems used in photovoltaic (PV), battery energy storage (BESS), and hydrogen (H^2) applications.

What is a Power Conversion System (PCS)?
A Power Conversion System (PCS) is a critical component for integrating renewable energy sources such as photovoltaic (PV) systems, battery energy storage systems (BESS), and hydrogen (H^2) systems connected to the AC utility grid. The primary function of the PCS is to convert the direct current (DC) output from these sources into alternate current (AC) and to ensure compatibility with the grid requirements. In storage applications, the PCS is typically a bi-directional inverter, enabling energy flow between the storage system and the grid, while for PV applications, it is a uni-directional inverter. Depending on the application the PCS regulates voltages, currents, frequency, phase angle, and phase sequence.

Why PCS needs a Switching & Protection solution
The PCS requires a robust Switching & Protection solution to ensure operational safety and reliability. Adequate protection and switching capabilities are essential for both AC and DC operations. Switching is vital for enabling safe maintenance, grid connection, and load or supply disconnect. Furthermore, the PCS must be safeguarded against short-circuit currents, overvoltages, and excessive overload currents. Given the high prospective short circuit current of batteries and DC-link capacitors, a coordinated approach between protection and switching devices is crucial, as detailed in this application note.

Main benefits

Ease of Use
Tested and verified product bundle of ABB switches and contactors together with the fast ABAT fuses for 1500V DC applications.

Reliability
Reduce the short-circuit stress on the down-stream installation for 1500V DC applications.

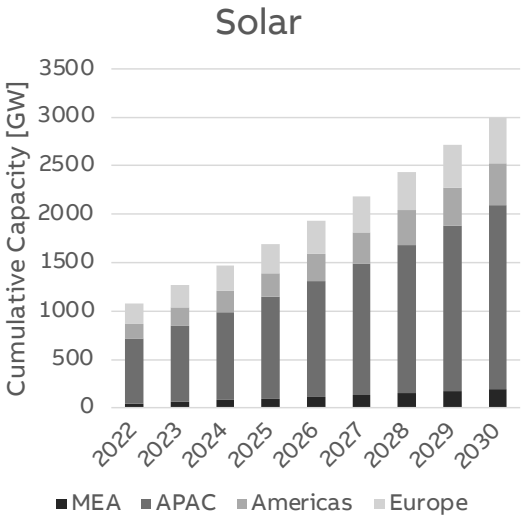
Design efficiency
Reduce the overdesign needed for anti-parallel diodes used in the power conversion system by limiting the peak let-through current during short-circuit.

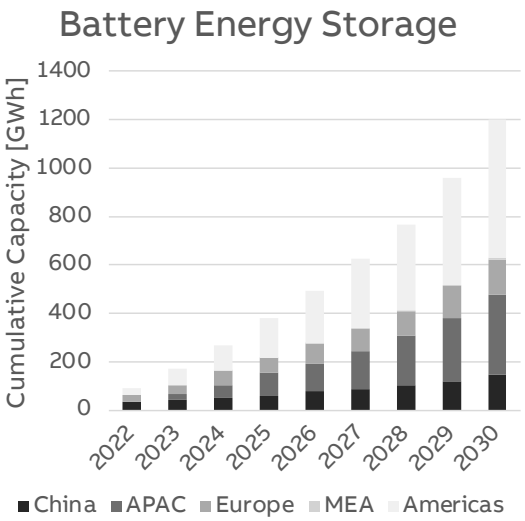
Validated solution
Tested and validated solution with measurement data available for peace of mind and the certificaiton needs.

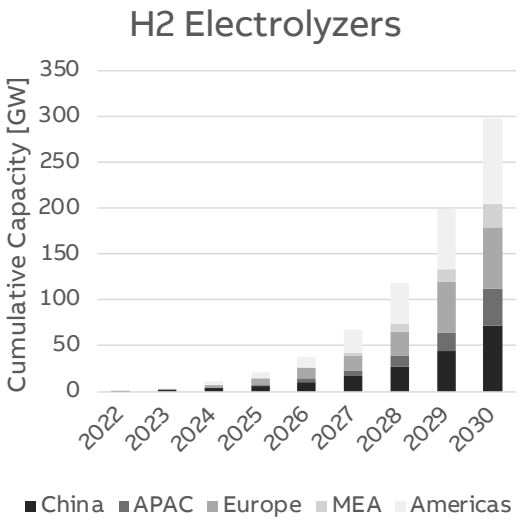
Reference Markets Outlook

Increasing energy demand and energy transition powering the market growth

The Power Conversion Systems (PCS) market is set for substantial growth, fueled by two main trends. Firstly, there is an expected increase in demand for installed capacity in the three key segments-solar, battery energy storage systems (BESS), and H^2 electrolyzers-by the year 2030. The following charts offer a comprehensive overview of the projected increase in installed capacity across the three segments.







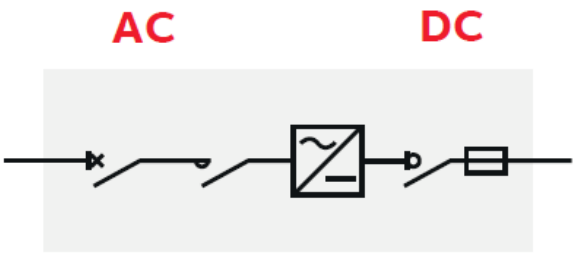
—

Moreover, the growing demand for power, fueled by increasing energy needs and the ongoing transition to sustainable energy sources, is anticipated to drive the need for PCS solutions.

As the requirement for dependable and efficient power conversion continues to rise alongside the expanding capacity of solar, BESS, and H^2 electrolyzer installations, the demand for PCS is expected to increase to meet these evolving market needs.

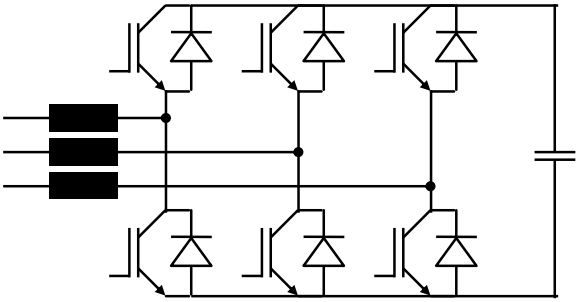
IEC TS 62578: Power Conversion System

Common PCS Topologies



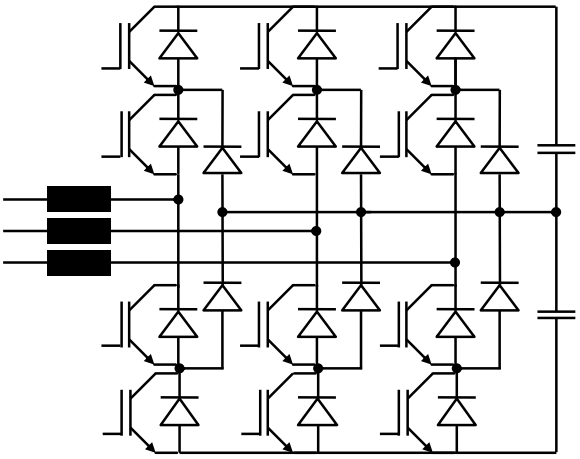
Active Infeed Converters (AIC) according to IEC TS 62578 are a self-commutated electronic power converters of all technologies, topologies, voltages and sizes which are connected between the AC power supply network (lines) and usually a stiff DC side (current source or voltage source) and which can convert electric power in both directions (generative or regenerative) and which can control the reactive power or the power factor.

2-level Active Infeed Converter



- Two level pulse width modulation (PWM) voltage source AICs are state of the art in the field of LV applications and are used for battery, wind-power and solar energy applications and active filters.
- The dynamic performance is limited by the supply side reactance, for applications with current control low reactance is preferred.
- The supply side reactance can be reduced by increasing the switching frequency which reduces the current ripple.

3-level Active Infeed Converter



- 3-level converters are typically used when DC link voltage requirement is higher than standard semiconductor switch rating. Typical applications include process-oriented drives where additionally high dynamic behaviour is required.
- The resultant pulse frequency at neutral point is two times the valves switching frequency thus minimizing the size of the filter.
- Power ranges up to around 10 MVA with an output voltage of approximately 3.3 kV. With parallel connection it is possible to handle around 20 MVA and higher ratings.

Short-circuit Protection Analysis

Recommended practices by IEC 62477

The damage in a circuit exposed to high prospective short-circuit current is primarily caused by the significant mechanical stress resulting from the magnetic field and extreme thermal rise in the circuit and its components. The analysis of single fault conditions and abnormal operating conditions begins with identifying all energy sources in the circuit. For the mains supply, it is essential to define the power circuit configuration and grounding, as well as the maximum variation in mains supply impedance, frequency, and voltage relevant to the specified product application. It is crucial to identify the nature of failure concerning the physical location and the potential for cascading failures.

Once the fault current paths and impedance of the Power Conversion System (PCS) are identified, it is vital to analyze the I^2t breakdown ratings of conductors and components, the impact of multiple ratings of the PCS, and the variation in PCS components. In the final stages, the types and ratings of the short-circuit protective devices to be used with the PCS, as well as the linearity of the current limiting components, should be specified. It is also important to ensure that the enclosure size, material, structure, openings, and other aspects adhere to safety standards.

While the manufacturer has full control over the internal design, the external parameters depend on the circuit characteristics of the installation. The prospective short-circuit current of the installation is especially important and should be considered for each installation.

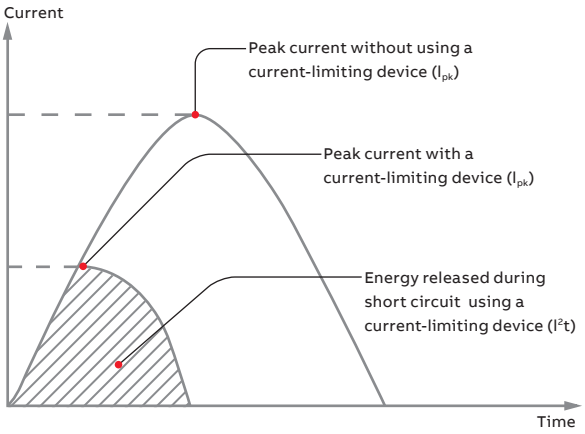
The prospective short-circuit current of the installation indicates the amount of energy available from the installation during a product failure. Without any limiting device, the available energy increases with higher prospective short-circuit current, elevating the risk of fire, mechanical hazard, electric shock, or other hazards during a failure.

The characteristics of the short-circuit protective device determine the minimum current required during a failure to ensure proper operation. The maximum prospective short-circuit current results in the highest fault current but ensures the shortest operating time of the short-circuit protective device. In contrast, the minimum prospective short-circuit current results in a lower fault current, considerably longer operation time, and consequently, an increasing I^2t during the fault.

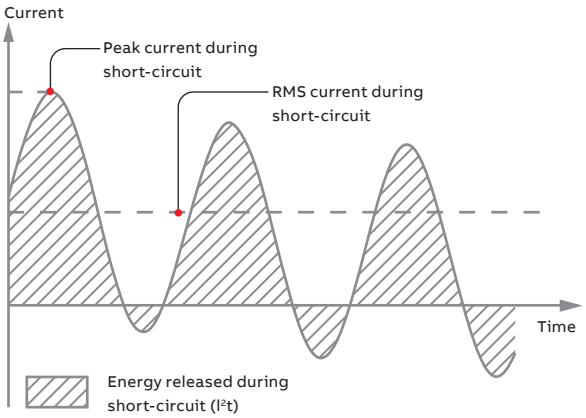
PCS Short-Circuit Protection

The prospective short-circuit current is defined by the peak current, which represents the maximum current potentially flowing during a short-circuit with negligible impedance, along with the electrical energy generated by the Root Mean Square (RMS) current and the duration of the short-circuit.

Short-circuit current curve under specification of Icc



Short-circuit current curve under specification of Icw



The protection of the PCS depends on the characteristics of the short-circuit protection device (e.g., fuse).
The design is influenced by the following factors:

- **Conditional short-circuit current (Icc):** The RMS value of the prospective short-circuit current.
- **Minimum required prospective short-circuit current (Icp,mr):** The RMS value of the minimum prospective short-circuit current. Compliance of the selected protection devices is demonstrated through evaluation or testing.

The design must ensure that the selected short-circuit protection device can open the short-circuit current, and that the PCS can withstand the high current peaks and energy. The design is driven by:

- **rated short-time withstand current (Icw)** which is the RMS value of short-time current, specified in terms of time and current.
- **rated peak withstand current (Ipk)** which is the value of peak short-circuit current that can flow under specified conditions.

Specifying short-time withstand capability Icw is the most challenging protection solution for the PCS DC side, as the downstream system must endure both high current peaks and higher energy levels (I^2t). This is especially critical for DC buses with 1500 V and high prospective short-circuit currents, as the high I^2t energy levels might pose a safety risk and increase the design cost.

ABB DC Protection and Switching Devices for 1500V

ABB offers a wide variety of protection and switching solutions – from well-established technologies to the latest innovations – with all advantages to empower you.

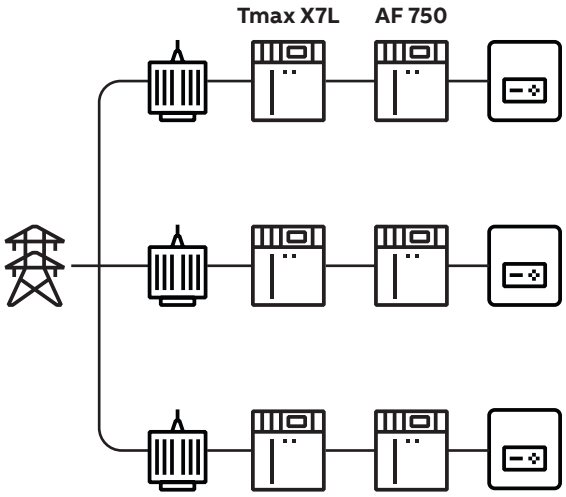
				
	OT(M)-135	**T7D-PV/E**	**EMAX2 MS/DC-E E4.2**	**GF**
Current range	1600 – 4000 A	1600 A (1200 A in UL)	4000 A (3200 A in UL)	875 – 1325 A
Standards	IEC 60947-3	IEC 60947-3 UL489B	IEC 60947-3 UL489B UL489F	IEC 60947-4-1 UL508B
Utilization Categories	DC-20B	DC-22A1	DC-22A [1] DC-PV2	DC-PV3 [2]
Remote Operation	Optional	Mandatory	Optional	Yes
Electrical Operations	NA	500 [3]	500	50000 [4]
Mechanical Operations	10000	20000	15000	50000
Rated Short-time withstand current Icw	100 kA	19.2 kA (1s)	100 kA	9.5 kA (1s)
Rated short-circuit making capacity Icm	NA	19.2 kA	100 kA	1 kA
Rated conditional short-circuit current Icc	-	186 kA	100 kA	100 kA
Maximum Cut-off Current Fuse	220 kA	86 kA	-	58 kA
Typos	-	2xABAT15C800-AIA	-	PSC/2x73/1800A
Voltage at fuse opening	-	1680	-	856 V
Dimensions	614x232x131.5 mm	280x268x178 mm	510x371x270 mm	253x304.5x300 mm
Weight	11 kg	14 kg	120 kg for fixed frame IV	14.3 kg

1) Category A designed for rate particular operational current these devices are designed for frequent use, the declared number of operating cycles is equal to or higher than the number of operating cycles in IEC60947-3
2) At 1325 A
3) Number of operations when opening with coil
4) For 70 A load current.

Reference Architectures

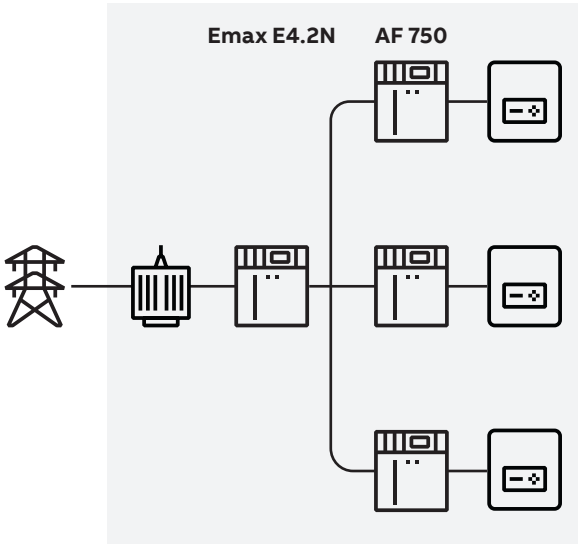
Power Conversion System Modularity - AC Side

Paralleled at grid connection



AC side
AF 750 (1050A – AC1) contactor for switching and protection provided by a fuse or a circuit breaker
Tmax XT7L M 1000 3p In=1000A circuit breaker for protection and isolation, equipped with Ekip Modbus TCP communication module and Ekip Touch Measuring LSI, as well as with the shunt open release (YO) , shunt closing release (YC) and motor operator to open/close remotely.
OVR T1-T2 3L 12.5-440s P QS + OVR T1-T2 12.5-440s P QS to protect against overvoltages coming from the AC Utility

Paralleled in the skid

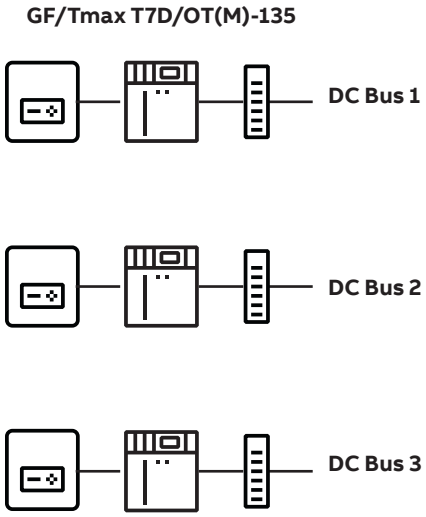


AC side
AF 750 (1050A – AC1) contactor for switching on each inverter branch
Emax E4.2N 4000 3p main circuit breaker for protection and isolation, equipped with Ekip Modbus TCP communication module and Ekip Touch Measuring LSI, as well as with the shunt open release (YO) and YC and motor to open/close remotely
Emax E4.2N 4000 3p Ekip Touch LSI main circuit breaker for protection and isolation, equipped with Ekip com Modbus TCP communication module and with the YO/YC and motor to open/close remotely
Emax E4.2N 4000 3p Ekip Hi-Touch LSI main circuit breaker for protection and isolation, equipped with Ekip com Modbus TCP communication module and with the YO/YC and motor to open/close remotely
OVR T1-T2 3L 12.5-440s P QS + OVR T1-T2 12.5-440s P QS to protect against overvoltages coming from the AC Utility
TVOC-2 + RELT Module for Arc Flash Mitigation

Reference Architectures

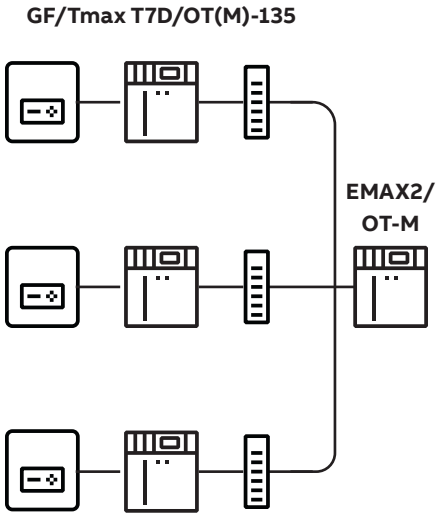
Power Conversion System Modularity - DC Side

Paralleled at grid connection



DC Side
GF contactors for switching combined with fuses on each inverter branch. The 2 poles are fitted with special arcing contacts enabling bi-directional breaking of currents up to 750VDC per pole
Tmax T7D/PV-E M 1250 4p switch disconnector coordinated with a fuse for short circuit protection as given in the Table on page 12. The switch disconnector is equipped with the YO/YC and the motor operator to open/close remotely
OT(M)-135 for switching no load and DC-20 applications
OVR PV T1-T2 10-1500 P TS QS to protect against overvoltages

Paralleled in the skid



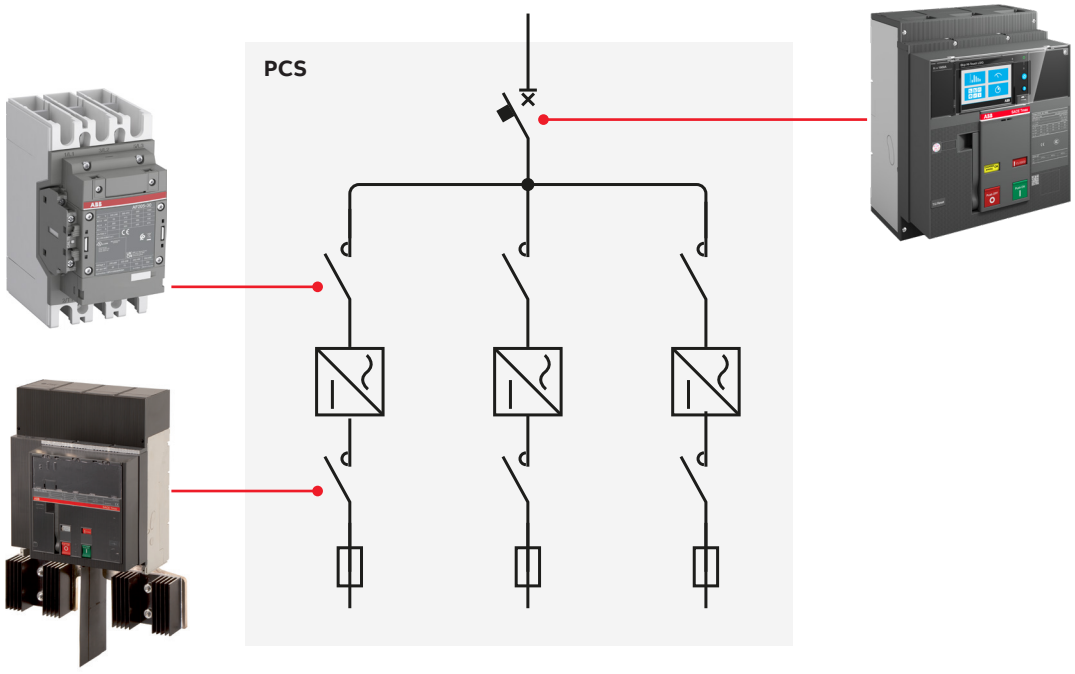
DC Side
GF contactors for switching combined with fuses on each inverter branch. The 2 poles are fitted with special arcing contacts enabling bi-directional breaking of currents up to 750VDC per pole
Tmax T7D/PV-E 1250 4p switch disconnector coordinated with a fuse for short circuit protection as given in the Table on page 12. The switch disconnector is equipped with the YO/YC and the motor operator to open/close remotely
OT(M)-135 for switching no load and DC-20 applications
E4.2S MS-DC/E 4000 4p switch disconnector equipped the YO/YC and motor to open/close remotely
OVR PV T1-T2 10-1500 P TS QS to protect against overvoltages

Applications

Switching and protection for third party PCS in BESS

ABB's offering for IEC Utility Scale applications – 1° application scenario

PCS with 3 inverters per 1MWh module



AC side
AF 750 (1050A – AC1) contactor for switching and protection provided by a fuse or a circuit breaker
Tmax XT7L M 1000 3p In=1000A main circuit breaker for protection and isolation, equipped with Ekip Modbus TCP communication module and Ekip Touch Measuring LSI, as well as with the shunt open release (YO) , shunt closing release (YC) and motor operator to open/close remotely
Tmax XT7L M 1000 3p In=1000A Ekip Touch Measuring LSI main circuit breaker for protection and isolation, equipped with Ekip com Modbus TCP communication module and with the SOR SOR, YC/YO and motor operator to open/close remotely
Tmax XT7L M 1000 3p In=1000A Ekip Hi-Touch LSI main circuit breaker for protection and isolation, equipped with Ekip com Modbus TCP communication module and with the SOR, YC/YO and motor operator to open/close remotely
OVR T1-T2 3L 12.5-440s P QS + OVR T1-T2 12.5-440s P QS to protect against overvoltages coming from the AC Utility
TVOC-2 + RELT Module for Arc Flash Mitigation

DC side
Tmax T7D switch disconnector for switching combined with fuses on each inverter branch.
OT1600E02-135 main disconnector for DC20 application
OVR PV T1-T2 10-1500 P TS QS surge protective device to protect against overvoltages

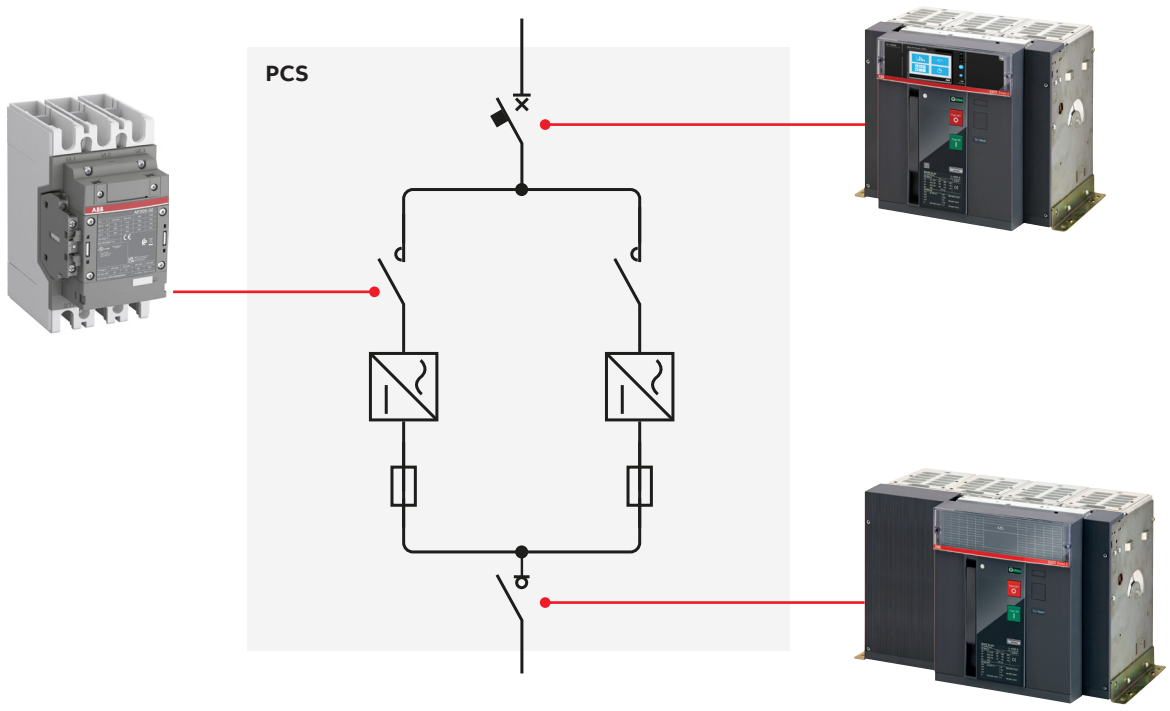
(YO) Opening Release; (YC) Closing Release

Applications

Switching and protection for third party PCS in BESS

ABB’s offering for UL Utility Scale applications – 2° application scenario

PCS with 2 inverters per 2MWh module



AC side
AF 1250 contactor for switching on each inverter branch
Emax E4.2S-A 2500 3p main circuit breaker for protection and isolation, equipped with Ekip Modbus TCP communication module and Ekip Touch Measuring LSI, as well as with the shunt open release (YO) , shunt closing release (YC) and motor operator to open/close remotely
Emax E4.2S-A 2500 3p Ekip Touch LSI main circuit breaker for protection and isolation, equipped with Ekip Modbus TCP communication module and Ekip Touch Measuring LSI, as well as with the shunt open release (YO) , shunt closing release (YC) and motor operator to open/close remotely
Emax E4.2S-A 2500 3p Ekip Hi-Touch LSI main circuit breaker for protection and isolation, equipped with Ekip Modbus TCP communication module and Ekip Touch Measuring LSI, as well as with the shunt open release (YO) , shunt closing release (YC) and motor operator to open/close remotely
OVR T1-T2 3L 12.5-440s P QS + OVR T1-T2 12.5-440s P QS to protect against overvoltages coming from the AC Utility
TVOC-2 + RELT Module for Arc Flash Mitigation

DC side
Fuses installed on each module to protect the converter combined with a main **Emax E4.2S-A MS-DC/E 4000 4p switch disconnector**, equipped with the YO/YC and motor to open/close remotely.
OVR PV T1-T2 10-1500 P TS QS surge protective device to protect against overvoltages

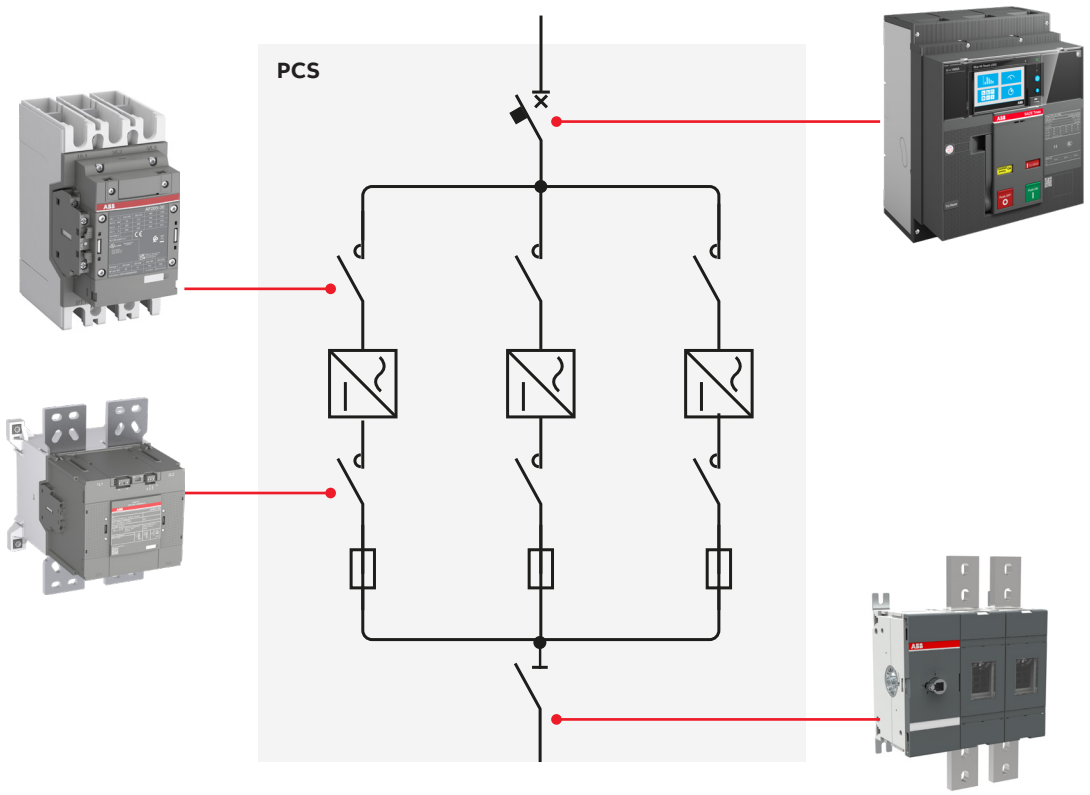
(YO) Opening Release; (YC) Closing Release

Applications

Switching and protection for third party PCS in BESS

ABB's offering for IEC Utility Scale applications – 3° application scenario

PCS with 3 inverters per 1MWh module



AC side
AF 205 (350A – AC1) **contactors** for switching on each inverter branch
Tmax XT7L M 1000 3p In=1000A main circuit breaker for protection and isolation, equipped with Ekip Modbus TCP communication module and Ekip Touch Measuring LSI, as well as with the shunt open release (YO) , shunt closing release (YC) and motor operator to open/close remotely
Tmax XT7L M 1000 3p In=1000A Ekip Touch Measuring LSI main circuit breaker for protection and isolation, equipped with Ekip Modbus TCP communication module and Ekip Touch Measuring LSI, as well as with the shunt open release (YO) , shunt closing release (YC) and motor operator to open/close remotely
Tmax XT7L M 1000 3p In=1000A Ekip Hi-Touch LSI main circuit breaker for protection and isolation, equipped with Ekip Modbus TCP communication module and Ekip Touch Measuring LSI, as well as with the shunt open release (YO) , shunt closing release (YC) and motor operator to open/close remotely
OVR T1-T2 3L 12.5-440s P QS + OVR T1-T2 12.5-440s P QS to protect against overvoltages coming from the AC Utility
TVOC-2 + RELT Module for Arc Flash Mitigation

DC side
Tmax T7D switch disconnector for switching combined with fuses on each inverter branch
OT1600E02-135 main disconnector for DC20 application
OVR PV T1-T2 10-1500 P TS QS surge protective device to protect against overvoltages

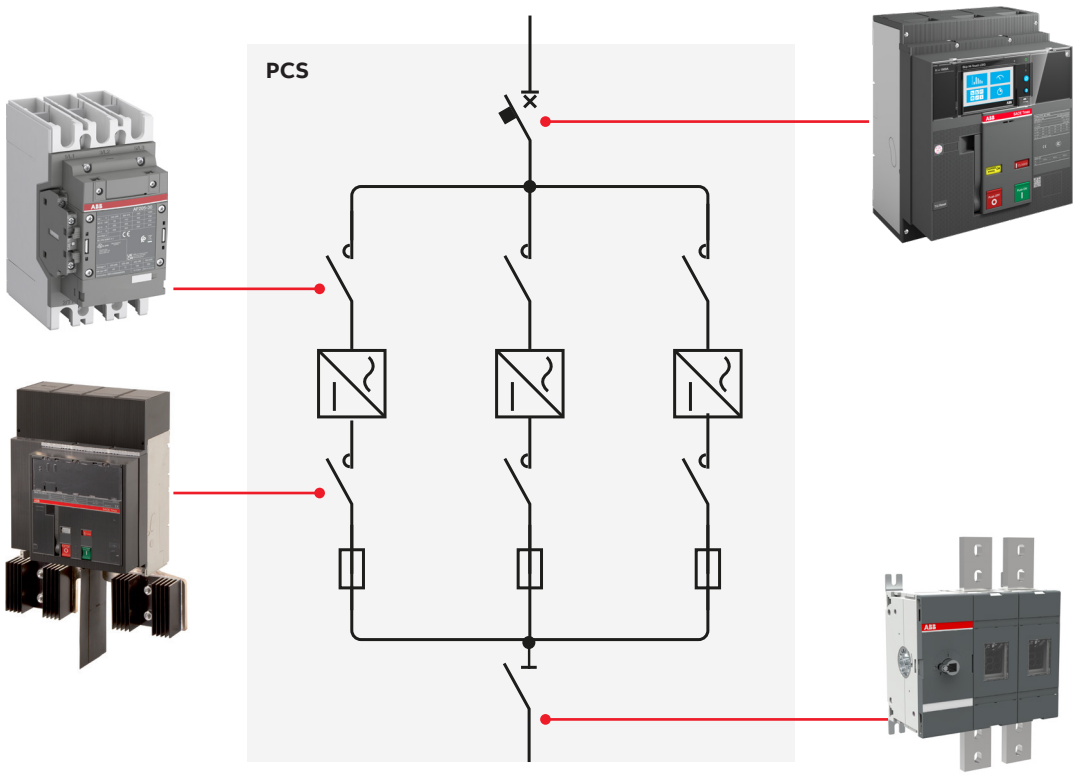
(YO) Opening Release; (YC) Closing Release

Applications

Switching and protection for third party PCS in PV

ABB's offering for IEC Utility Scale applications – 3° application scenario

PCS with 3 inverters per 1MWh module



AC side
AF 205 (350A – AC1) **contactors** for switching on each inverter branch
Tmax XT7L M 1000 3p In=1000A main circuit breaker for protection and isolation, equipped with Ekip Modbus TCP communication module and Ekip Touch Measuring LSI, as well as with the shunt open release (YO) , shunt closing release (YC) and motor operator to open/close remotely
Tmax XT7L M 1000 3p In=1000A Ekip Touch Measuring LSI main circuit breaker for protection and isolation, equipped with Ekip Modbus TCP communication module and Ekip Touch Measuring LSI, as well as with the shunt open release (YO) , shunt closing release (YC) and motor operator to open/close remotely
Tmax XT7L M 1000 3p In=1000A Ekip Hi-Touch LSI main circuit breaker for protection and isolation, equipped with Ekip Modbus TCP communication module and Ekip Touch Measuring LSI, as well as with the shunt open release (YO) , shunt closing release (YC) and motor operator to open/close remotely
OVR T1-T2 3L 12.5-440s P QS + OVR T1-T2 12.5-440s P QS to protect against overvoltages coming from the AC Utility
TVOC-2 + RELT Module for Arc Flash Mitigation

DC side
Tmax T7D switch disconnector for switching combined with fuses on each inverter branch as per the Table on page 12
OT1600E02-135 main disconnector for DC20 application
OVR PV T1-T2 10-1500 P TS QS surge protective device to protect against overvoltages

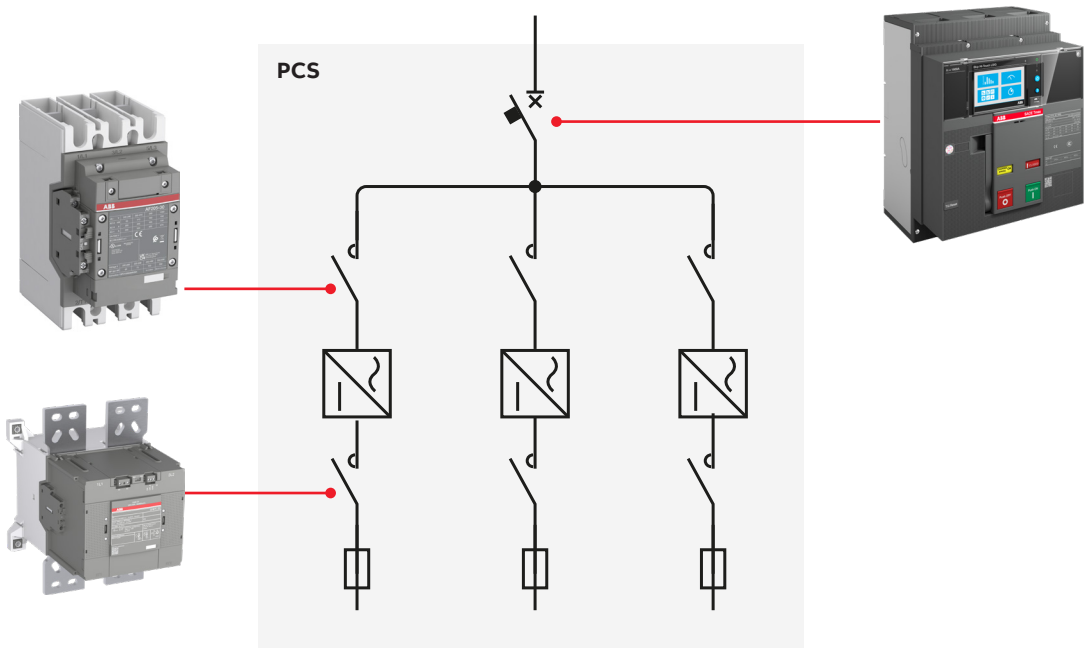
(YO) Opening Release; (YC) Closing Release

Applications

Switching and protection for third party PCS in Fuel Cell

ABB’s offering for IEC Utility Scale applications – 3° application scenario

PCS with 3 inverters per 1MWh module



AC side
AF 205 (350A – AC1) **contactors** for switching on each inverter branch
Tmax XT7L M 1000 3p In=1000A main circuit breaker for protection and isolation, equipped with Ekip Modbus TCP communication module and Ekip Touch Measuring LSI, as well as with the shunt open release (YO) , shunt closing release (YC) and motor operator to open/close remotely
Tmax XT7L M 1000 3p In=1000A Ekip Touch Measuring LSI main circuit breaker for protection and isolation, equipped with Ekip Modbus TCP communication module and Ekip Touch Measuring LSI, as well as with the shunt open release (YO) , shunt closing release (YC) and motor operator to open/close remotely
Tmax XT7L M 1000 3p In=1000A Ekip Hi-Touch LSI main circuit breaker for protection and isolation, equipped with Ekip Modbus TCP communication module and Ekip Touch Measuring LSI, as well as with the shunt open release (YO) , shunt closing release (YC) and motor operator to open/close remotely
OVR T1-T2 3L 12.5-440s P QS + OVR T1-T2 12.5-440s P QS to protect against overvoltages coming from the AC Utility
TVOC-2 + RELT Module for Arc Flash Mitigation

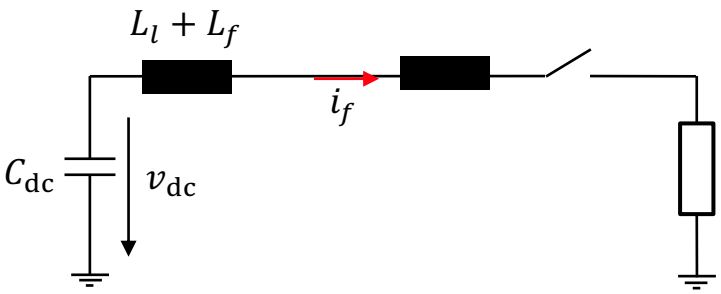
DC side
GF 875 contactors for switching combined with fuses on each inverter branch. The 2 poles are fitted with special arcing contacts enabling bi-directional breaking of currents up to 750VDC per pole
OVR PV T1-T2 10-1500 P TS QS surge protective device to protect against overvoltages

(YO) Opening Release; (YC) Closing Release

T7D and ABAT Fuse Coordination Test

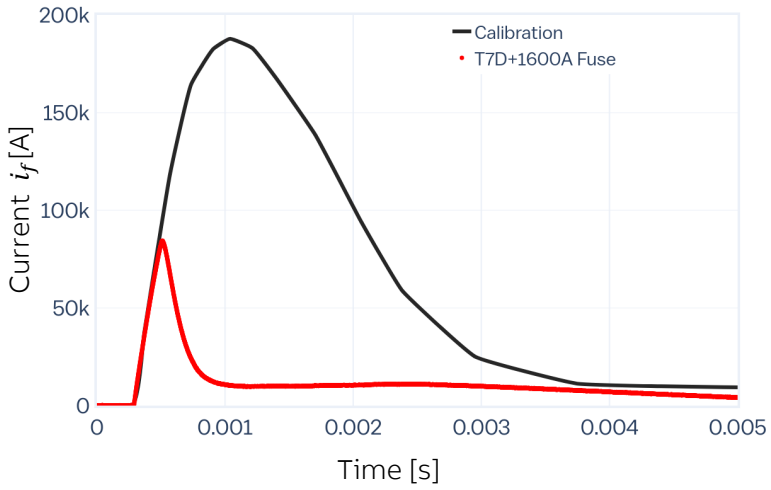
188 kA prospective short-circuit current

Test Setup parameters



Parameter	Value
C_{dc}	150 mF
L_l+L_f	2.5 µH
$V_{dc}(t=0)$	1780

Test Results



In the coordination test, a prospective short-circuit current of 188kA was configured. Several tests were conducted to validate the reliable operation of the devices for both conducting and interrupting the short-circuit current. These tests were performed across different voltage levels and aimed to confirm the maximum short-circuit withstand capability of the devices.

The T7D device demonstrated the ability to sustain a short-circuit current of 150kA at voltages exceeding 1000V DC. When combined with the ABAT fuses, the coordination effectively limits both the short-circuit current and the short-circuit energy to less than one half of the prospective in this test. This successful coordination ensures the reliable protection of the electrical system in the event of a short circuit, mitigating potential hazards and maintaining system integrity.
Due to test setup limitation, the test duration was limited to less than 10ms.

To discover more

CONTACT US

Do you have a similar project and are searching for the right Application configuration?
Contact us and talk to our experts!

RATE US

Your opinion matters! Let us know if you found the document useful and how can we improve!

ABB S.p.A.
Electrification Business Area
Smart Power Division
5, Via Pescaria
I-24123 Bergamo - Italy
Phone: +39 035 395.111

new.abb.com/low-voltage

9AKK108470A3850 - 2025.01