Challenges and Solutions in Modern DC Grids

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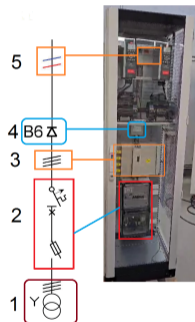
ISETC 2024

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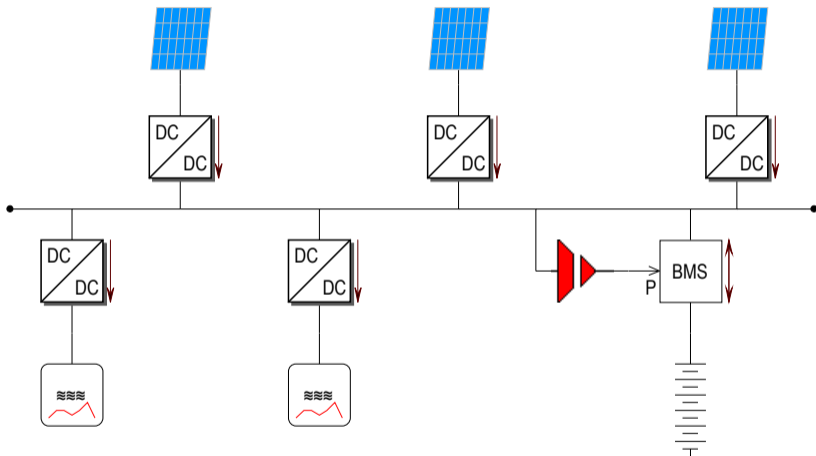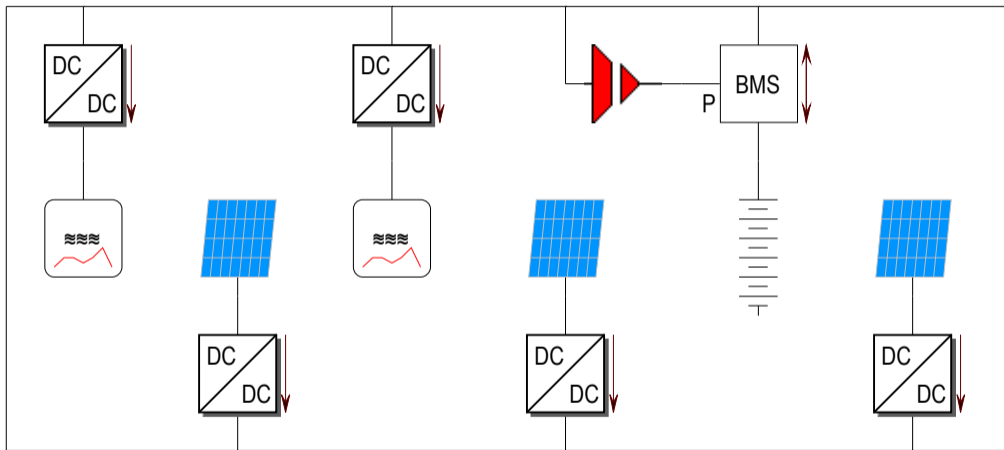November 8 , 2024

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Part 1: Architecture and Definitions

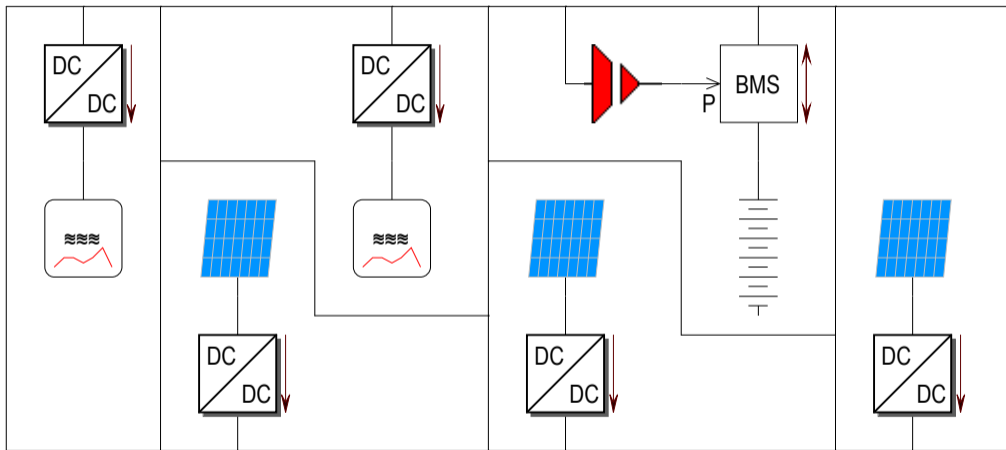DC grid architecture, Radial grid.
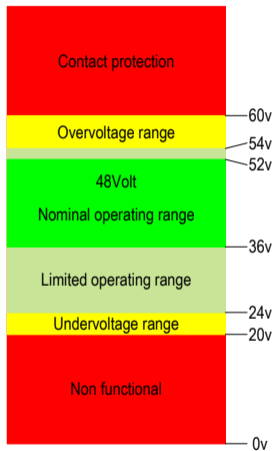
DC grid architecture, Ring grid.

DC grid architecture, Meshed grid.

|	
Contact protection	
	60v
Overvoltage range	54v
	52v
48Volt Nominal operating range	
	36v
Limited operating range	
	24v
Undervoltage range	20v
Non functional	
	0v

Normalization 48v automotive.
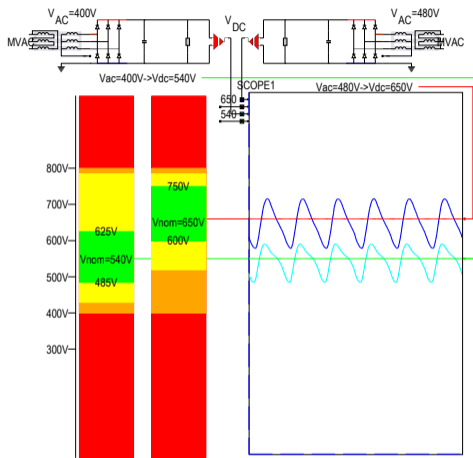
Normalization of two voltage levels by ODCA, where in a Caspoc simulation, the rectified three-phase voltage, $V^1_{AC_{RMS}} = 400V$ and $V^2_{AC_{RMS}} = 480V$ falls into the nominal operation region of $V^1_{Nom} = 540V$ and $V^2_{Nom} = 650V$
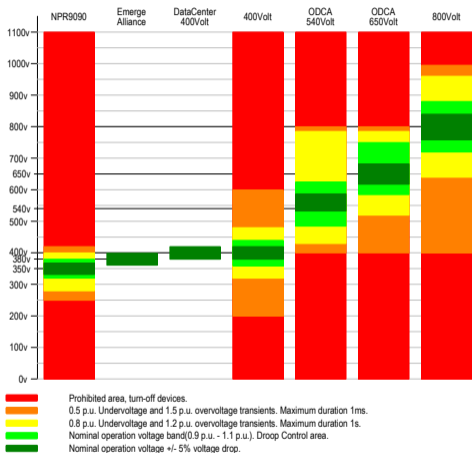
Normalization of voltage levels
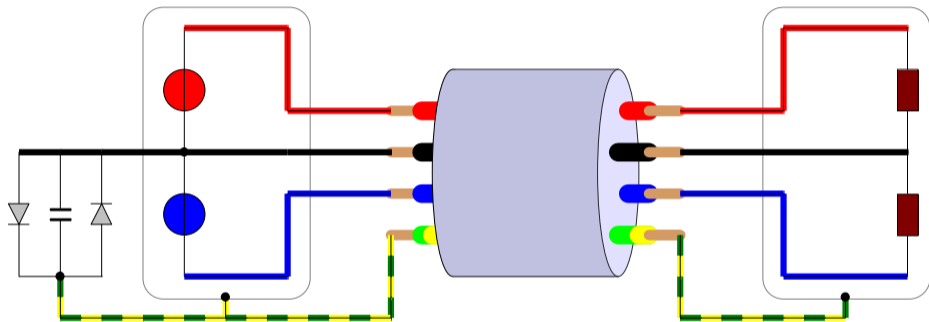
Coloring conventions in a bipolar grid, plus-red, negative-blue, neutral-black, ground protection-yellow/green. The neutral is connected to ground via diodes.
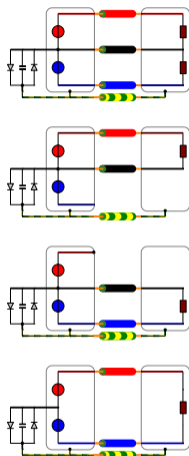
Color conventions in unipolar and bipolar DC grids, from top to bottom: Bipolar, Unipolar-Positive, Unipolar-Negative, Unipolar.

Voltage	Polarity	Color
Positive	P	Red
Neutral	N	Black
Negative	M	Blue

Table: Polarity and color for Bipolar and Unipolar grids and cables.

Zone		
U	Unprotected	Battery Cells, Solar Panels
F	Fuse protected	Busbar, Solar converter
P	Protected Prosumer	AC-DC DC-DC DC-AC
C	Protected Consumer	User Applications
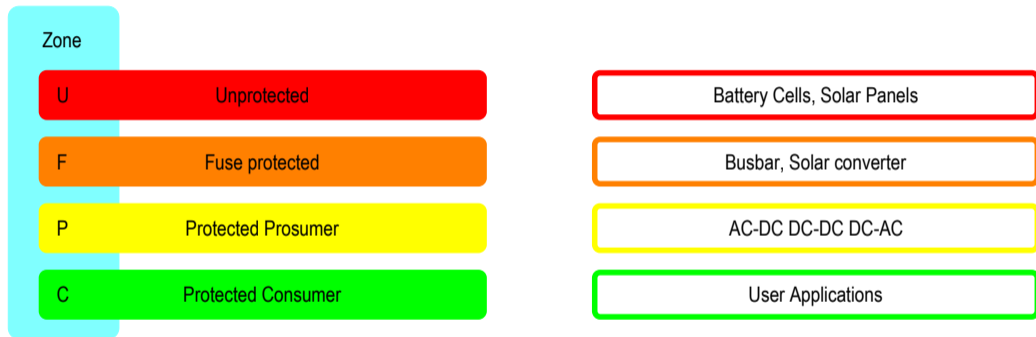
Safety zones(left) in a DC grid and their applications(right).

Part 2: Control and Converters
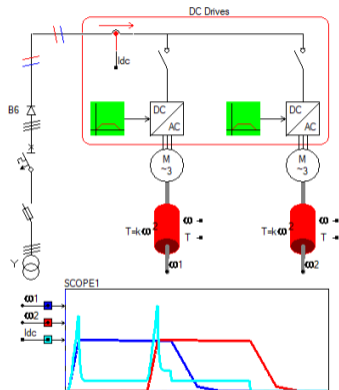
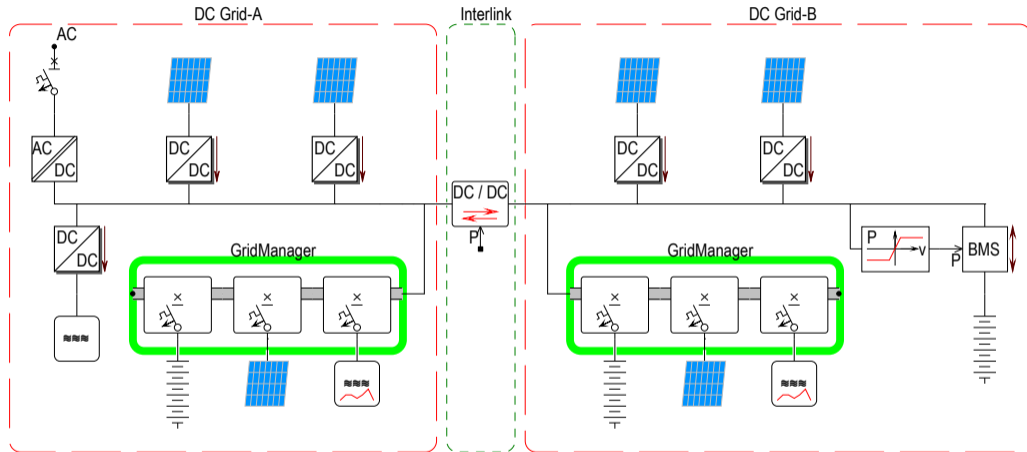Simulation in Caspoc, of a DC grid connected to a B6 rectifier, feeding two variable speed drives. Brake energy from one drive, can be reused by another drive, via the DC grid.

Two DC grids, coupled via an Interlink. Each DC grid has a Grid Manager for interfacing prosumers like a battery, solar panel and a variable power load. Grid-A is connected to an AC grid via an AFE. Grid-B has local storage.
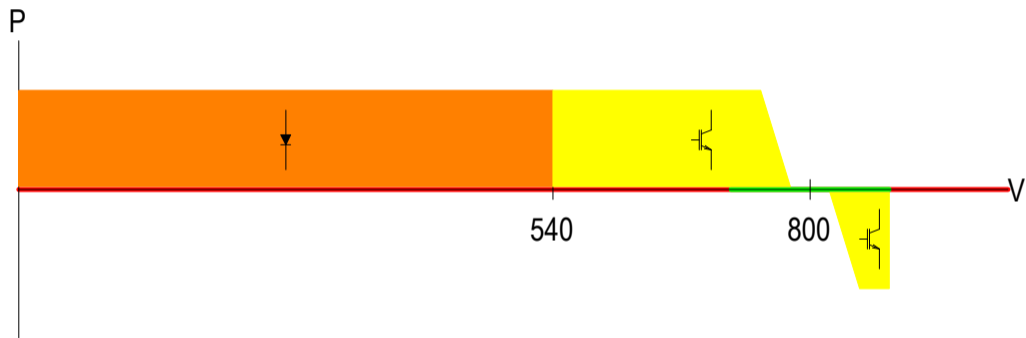
Droop regulation in an Active Front End, only a voltage above 540v can be regulated for a 400volt three-phase AC grid.
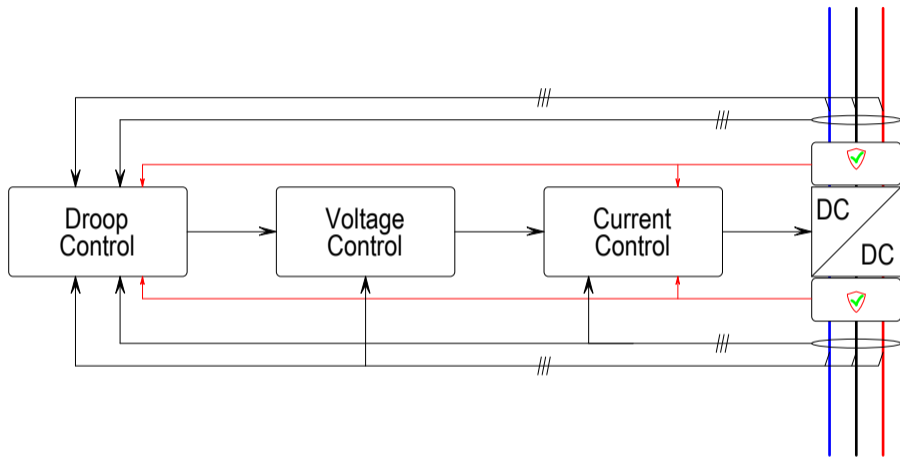
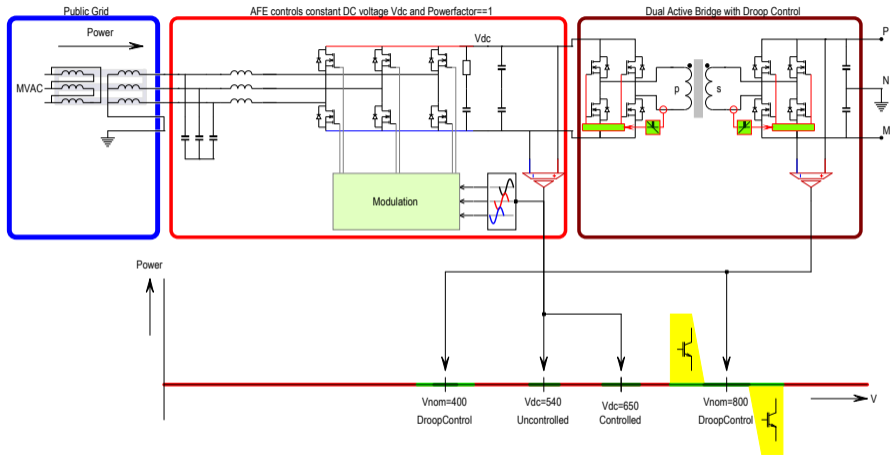Cascaded voltage/current control for each type of DCDC converter. Thew cascaded droop control regulates the voltage level, but also dictates the maximum current, as regulated by the current regulator. The protection on either side of the DCDC converter directly interacts with

Using an extra isolated DCDC converter, a droop control voltage level can be created from a constant DC voltage provided by the AFE.
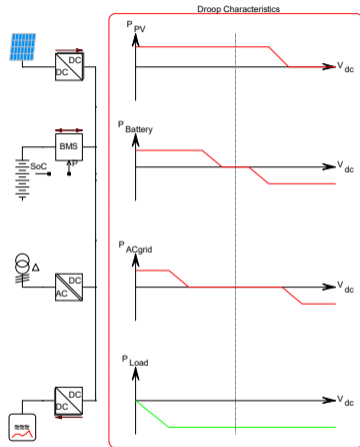
Droop characteristics for prosumers, From top to bottom: solar, battery, AC-grid and consumer.
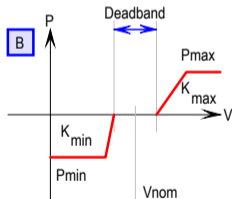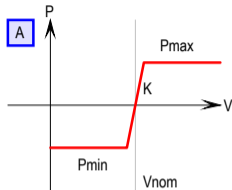
Parameters of the droop characteristic centered at V_{nom} with limits P_{min} and P_{max}. A: Continuous characteristic with gain K. B: Discontinuous characteristic with centered blanking time around V_{nom}, with gains K_{min} and K_{max}.

Table: Bandwidth and reaction time, for each section in the control.

Control	$BW[Hz]$	$\Delta t[s]$
Current Mode	$1MHz$	$< 1\mu s$
Voltage Mode	$1kHz$	$< 1ms$
Droop Mode	$1Hz$	$< 1s$
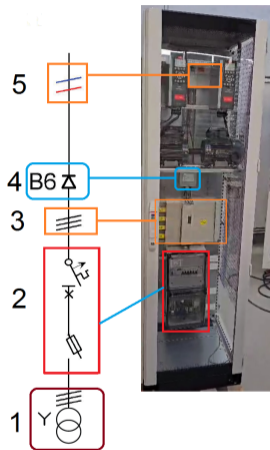
DC distribution busbar with two controlled induction motor drives. From bottom to top:1)AC400V feeder cable, 2)AC over-current and earth leakage protection, 3)AC busbars[L1-L2-L3-N], 4)ODCA compatible B6 rectifier, 5)ODCA compatible 540V DC grid

Part 3: Protection and Safety
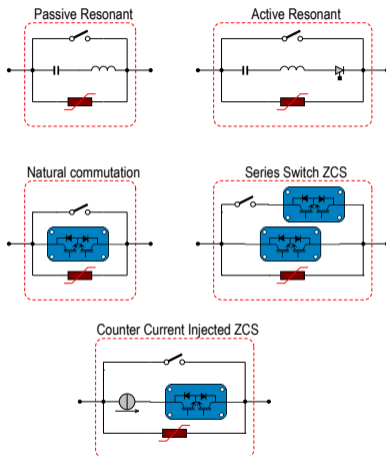
Various types of mechanic, electronic, hybrid and current injected breakers.

Fuse / Mechanical Protection	Electronic Protection					
Fuse	OverCurrent	RoCoC	RCD	ArcDet	Impedance	Inrush
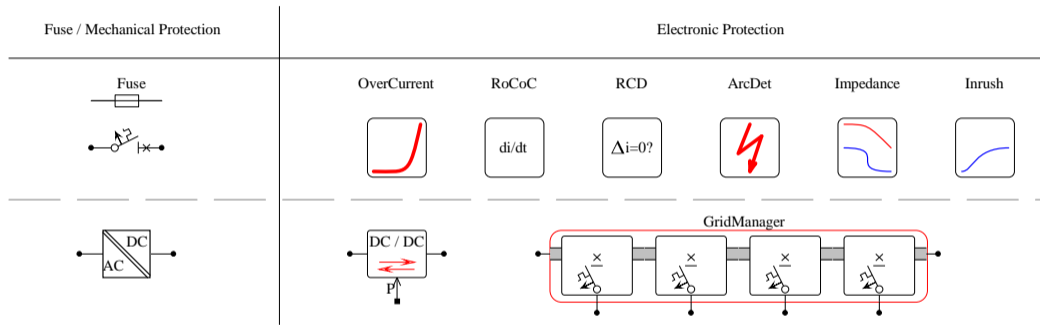
Electronic protection is included in the DCDC converters like the Interlink and Grid Manager. The Active Front End [AFE] has a mechanical breaker and fuse on the AC grid side.
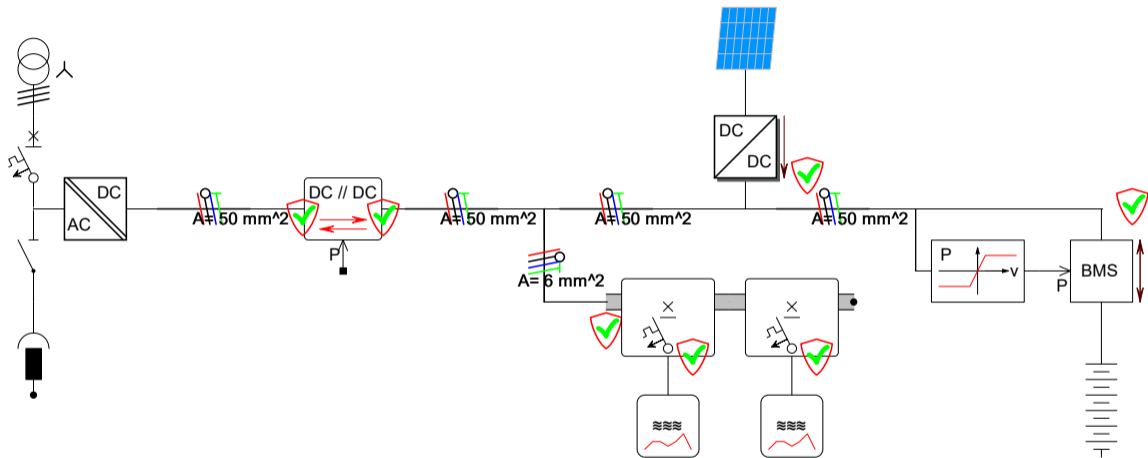
Electronic protection at both sides of the Interlink and at the entry of the Grid Manager. Each terminal connected to a prosumer has electronic protection. The "Shield" icon represents the combination of the electronic protection devices.
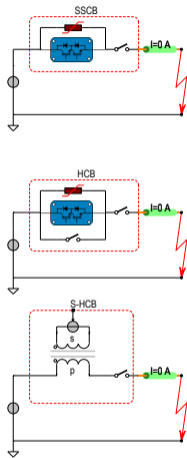
Short Circuit Current Breaker, from top to bottom: Solid State Circuit Breaker, Hybrid Circuit Breaker, Series Counter-voltage Breaker.
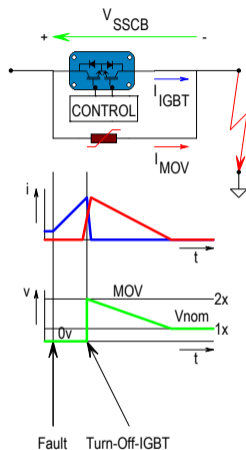
Wavefoms during turn-off in a SSCB. The voltage V_{SSCB} equals the voltage over the MOV, until the current returns to zero. After Turn-off of the SSCB, the voltage over the SCCB equals the nominal grid voltage, until the fault is cleared.
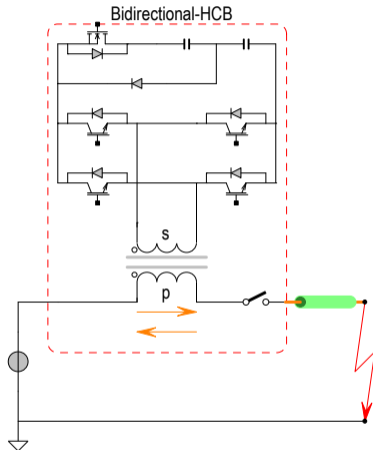
Bidirectional-HCB

Bidirectional solid circuit breaker with counter current injection. Depending on the direction of the fault-current, the full bridge can make either a positive or negative counter-voltage, to cancel the voltage over the mechanical switch.
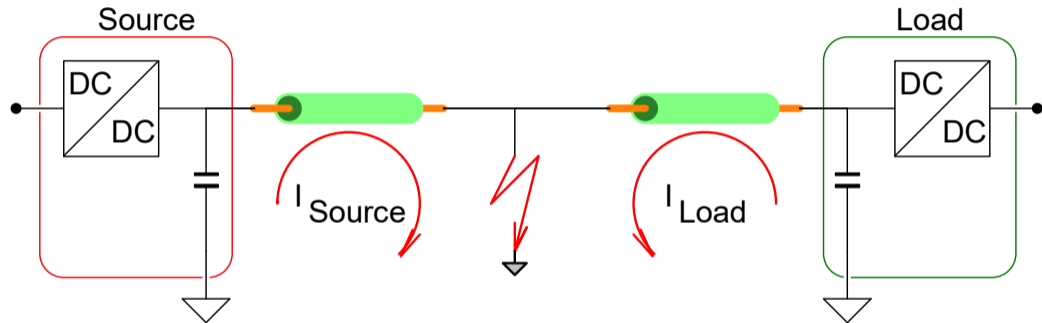
Short circuit current provided by the output capacitor of the source and input capacitor of the load.
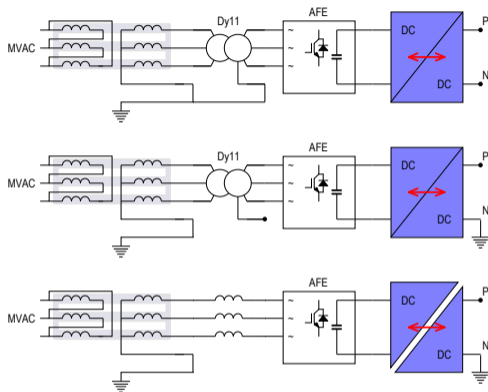
Galvanic isolation between the AC and DC grid. From top to bottom: a)Isolation by the AC transformer, P and N are floating around the midpoint of the secondairy transformer winding. b)Isolation by the AC transformer, the negative terminal N is connected to ground. c)Isolation by the isolated DCDC converter, the negative terminal N is connected to ground.

During maintenance, the same procedure is perform as in AC grids:

- Shut down the system
- Lock the system
- Manual short circuit

- Architecture and Definitions
- Control and Converters
- Protection and Safety

Thank you!
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Mulțumesc!

	NPR9090	Emerge Alliance	DataCenter 400Volt	400Volt	ODCA 540Volt	ODCA 650Volt	800Volt

Prohibited area, turn-off devices.
0.5 p.u. Undervoltage and 1.5 p.u. overvoltage transients. Maximum duration 1ms.
0.8 p.u. Undervoltage and 1.2 p.u. overvoltage transients. Maximum duration 1s.
Nominal operation voltage band(0.9 p.u. - 1.1 p.u.). Droop Control area.
Nominal operation voltage +/- 5% voltage drop.