High Power Semiconductor Technology

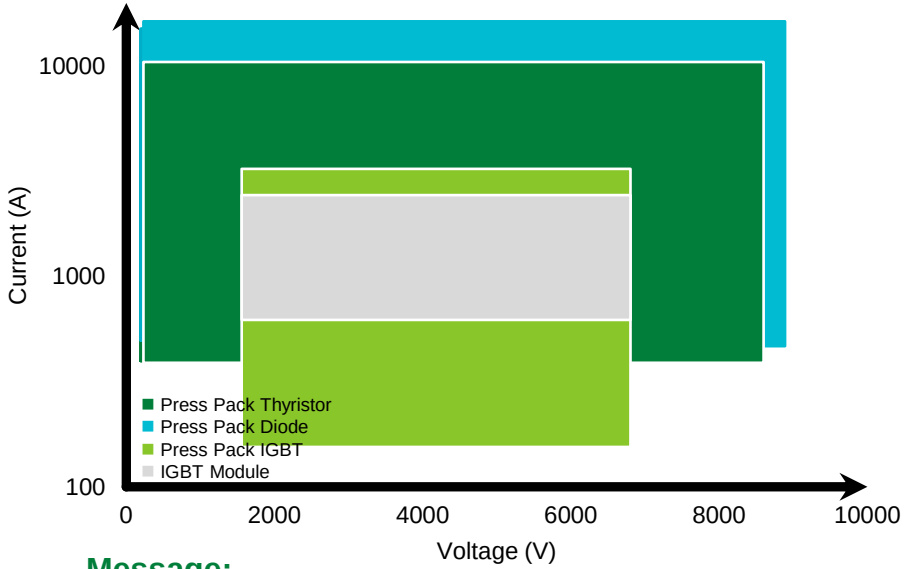
Bradley Green

January 2024

Littelfuse®

Expertise Applied | Answers Delivered

High Power



Message:

- One of the widest portfolios of high-power semiconductors on the market with leading edge Press Pack IGBT technology. Suited for Industrial Controls, Transportation, Heavy Industry and Energy sectors, we offer standard products and bespoke stack solutions tailored to customer needs.

Bipolar

- Range of Thyristor and Diode technology available delivering products to suit a wide range of applications and needs.
- Product flexibility allowing customization to meet customer exact design needs
- Engineering support to assist in device selection, mechanical considerations and cooling requirements.

Press Pack IGBT

- Failure to short circuit allowing n+ redundancy.
- Simple mechanical design for medium and high voltage systems.
- Enhanced power cycling capability providing product robustness in the field.
- High package rupture tolerance.

Stacks

- 80 years of experience in stack design.
- Designed 100% to customer requirements.
- Dedicated global electrical, thermal and mechanical design team.
- 100s kW to 10s MW.

High Power Module

- 3300V and 4500V IGBT modules in 2024 – 2025 offering fully independent alternative supply channel to Infineon, ABB, Mitsubishi.
- Product flexibility allowing customization to meet customer exact design needs

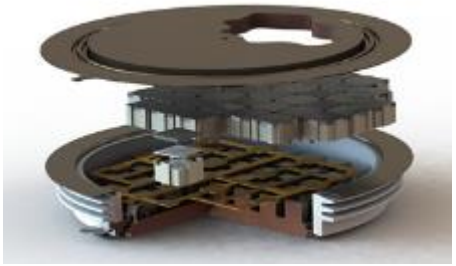
Market Applications

- **Industrial controls**
  - High Power & MV Drives
  - Soft starts
  - UPS, Static Transfer Switch
- **Medical**
- **Heavy industry**
  - Induction melting
  - Billet heating
  - Oil, Gas & Mining
  - Electrochemical / Hydrogen
- **Transportation**
  - Rail / Shipping
  - Mining, Agricultural vehicles
  - Propulsion & Aux systems
  - Commercial Charging (EV)
- **Energy**
  - Static VAr compensators
  - Transmission & distribution
  - Wind turbine converters
  - Solar, BESS
  - Pulse Power & Big Science

Products

5000+ parts

- Press Pack devices
  - Thyristors
    - Phase Control, Distributed Gate & Gate Turn Off (GTO)
    - 200V-6500V (8500V*), 400A-8800A
    - Pulse Thyristors 50kA++ / 2500V-4500V
      - Options for >200kA peak and di/dt > 30kA/us
  - Diodes
    - Rectifier, Fast Recovery, Sonic Fast Recovery Diodes
    - 200V-6800V (9000V*), 500A-12,000A
  - IGBTS
    - Press Pack IGBT
    - 1700V-6500V, 115A-3000A
    - 3.3kV & 4.5kV Module release 2024 - 2025



* 8.5kV & 9.0kV in development

High Power Bipolar

Phase Control thyristors product matrix

Voltage	25mm	30mm	38mm	38mm	43mm	43mm	50mm	56mm	59.5mm	69mm	77mm	77mm	83mm	96mm	115mm
600V			N2154	option	N3229 & N2783	option	N2900		N4316 & N3597	option	N6974	N6012	NX408		
1400V	B0470 (1600V)	B0870 (1600V)	N1366 & B1370	B1230 (1600V)	N2083 & N1817	option	B1815 (1600V)		N3022 & N2520	option	N4940	N4085 (1200V)	option	option	option
1800V	B0470 (1600V)	B0800	N1263 & B1265	B1115	N1806 & N1581	option	B1725 & N1718	N2600	N2593 & N2015	N3565 & N3175	N4472	N3380	NX318	NX522	option
2200V		B0713	N1174	N1052	N1651 & N1449	option	N1547	NX591	N2367 & N2191	option	N3904	N3533	N4340	NX521	N8800 & N7905
2800V		B0713 (2500V)	option	N0910	option	NX304	N1467	N2055	option	N3165 & N2830	option	N3029	N3790	N6405 & N5715	N8440
3600V				N0646		option	N1132	N1725		N2655 & N2385		N2418	N3620	N5415 & N4845	N7585
4500V				N0616		option	N0882	N1560		NX498		N2172	N2825	N4650 & N4165	N5910 & N5320
5200V														N4240	
Package	**19mm**	**25mm**	**32mm**	**34mm**	**38mm**	**38mm**	**47mm**	**50mm**	**50mm**	**66mm**	**68mm**	**73mm**	**75mm**	**85mm**	**100mm**
15mm	WC	YC	JK		QK				MK		HK				
26mm				LC	QL	QA	NC	MC	ML	HA		ZD	TJ	EA	FA
35mm				LG		QE		ME		HE		ZC	TE	EE	FE
26mm RR												ZV			
35mm RR												ZT	R&D	EW	FV
			Wespack		Wespack				Wespack		Wespack				

- One of the most comprehensive ranges of standard phase control thyristors in the industry
- Optimized to give low conduction losses and intended for line frequencies up to 400Hz
- Suitable for line voltages from 230V up to 1000V
- Hermetically sealed package

Phase Control Thyristors

- Industrial DC Drives, controlled rectifiers, marine/rail propulsion systems, wind power convertors, electrochemical power supplies and soft starts

Phase Control thyristors product matrix

Voltage	25mm	30mm	38mm	38mm	43mm	43mm	50mm	56mm	59.5mm	69mm	77mm	77mm	83mm	96mm	115mm
600V			N2154	option	N3229 & N2783	option	N2900		N4316 & N3597	option	N6974	N6012	NX408		
1400V	B0470 (1600V)	B0870 (1600V)	N1366 & B1370	B1230 (1600V)	N2083 & N1817	option	B1815 (1600V)		N3022 & N2520	option	N4940	N4085 (1200V)	option	option	option
1800V	B0470 (1600V)	B0800	N1263 & B1265	B1115	N1806 & N1581	option	B1725 & N1718	N2600	N2593 & N2015	N3565 & N3175	N4472	N3380	NX318	NX522	option
2200V		B0713	N1174	N1052	N1651 & N1449	option	N1547	NX591	N2367 & N2191	option	N3904	N3533	N4340	NX521	N8800 & N7905
2800V		B0713 (2500V)	option	N0910	option	NX304	N1467	N2055	option	N3165 & N2830	option	N3029	N3790	N6405 & N5715	N8440
3600V				N0646		option	N1132	N1725		N2655 & N2385		N2418	N3620	N5415 & N4845	N7585
4500V				N0616		option	N0882	N1560		NX498		N2172	N2825	N4650 & N4165	N5910 & N5320
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15mm	WC	YC	JK		QK				MK		HK				
26mm				LC	QL	QA	NC	MC	ML	HA		ZD	TJ	EA	FA
35mm				LG		QE		ME		HE		ZC	TE	EE	FE
26mm RR												ZV			
35mm RR												ZT	R&D	EW	FV
			Wespack		Wespack				Wespack		Wespack				

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Phase Control Thyristors

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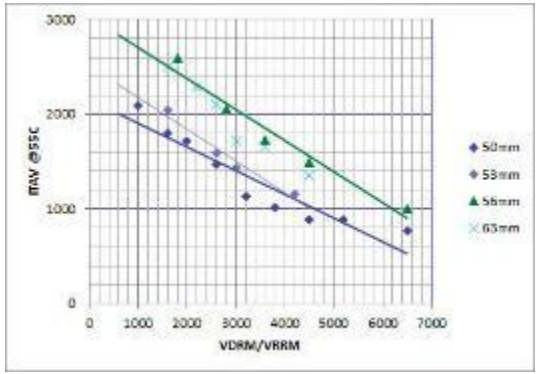
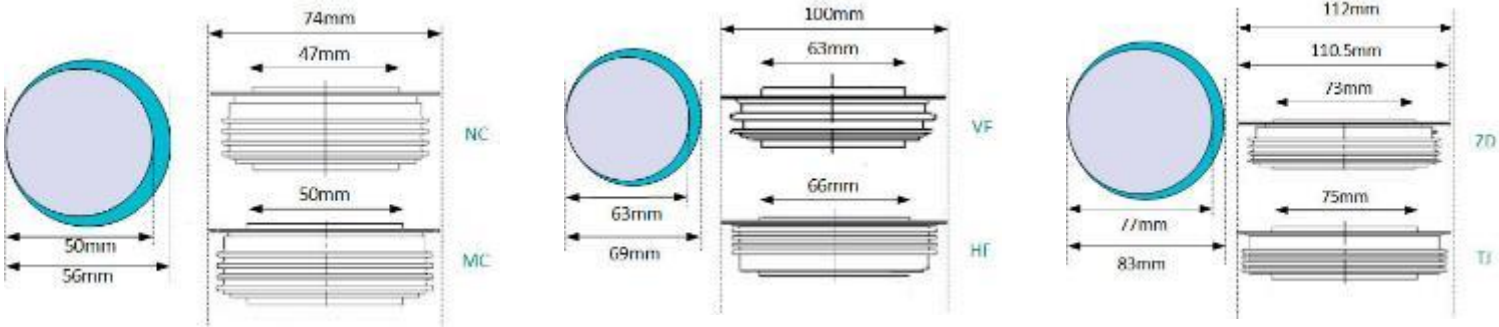
High power density devices – Thyristor & Diode

- New parts have several improvements over the old designs
  - Better die design with optimised active area
  - Improved mechanical design with much lower thermal resistance
  - Improved thermal cycling performance
- **56mm** same mechanical footprint as NC outline (50mm die)
  - 25% to 45% higher current rating than 50mm die device
- **69mm** same mechanical footprint as VF outline (63mm die)
  - 30% to 50% more current rating than the 63mm die device
- **83mm** almost same mechanical footprint as ZD outline (77mm die)
  - 15% to 45% more current rating than the 77mm design



56mm Thyristor example



Rectifier diode product matrix - Capsules

Voltage	25mm	30mm	38mm	38mm	43mm	43mm	50mm	50mm	56mm	59.5mm	69mm	77mm	77mm	83mm	96mm
600V			Option	Option	Option	Option	W5102	W4534	W7045	WX210	Option	Option		Option	Option
1500V	W0944		W2340	W2058 (1400V)	Option	Option	Option	Option	W5636	Option	Option	Option	W8405 (1400V)	W9830	Option
2200V	W0642 (2400V)	W1263 (2500V)	W1980	W1748 (2500V)	W3455	W2840	W4295	W3270	W4767	W5334	Option	Option	W5838	W8570	W121C & W108C
2800V			W1730	W1524 (3000V)	W3305	WX329	W3409	W2624	W3842	W5130	Option	Option	W5282 (3000V)	Option	W106C
3500V		W1074 (3200V)	Option	W1411 (3600V)	Option	Option	Option	Option	W3708	Option	Option	Option	W5092	W6672	W8400
4000V		Option		Option		Option		W2134	W3477		W4550			W5984	WX565
Package	**19mm**	**25mm**	**32mm**	**34mm**	**38mm**	**38mm**	**44mm**	**47mm**	**50mm**	**50mm**	**66mm**	**68mm**	**73mm**	**75mm**	**85mm**
15mm	WC	YC	JK		QK		NK			MK		HK			
26mm		YH		LC		QA		NC	MC		HA		ZD	TJ	EC
35mm				LG							HE		ZC	TE	ED
26mm RR															
35mm RR													ZY	TY	EY
			Wespack		Wespack		Wespack			Wespack		Wespack			

- Our comprehensive range of standard rectifier diodes offer class leading performance and reliability
- Hermetically sealed package
- Optimized to give low conduction losses and intended for line frequencies up to 400Hz
- High temperature alloyed die construction with high overload capacity for arduous applications

- Rectifiers for variable speed drives, traction converters, trackside substations, welding and DC power supplies.

Rectifier Diodes

Medium voltage product matrix

Thyristors

Voltage	30mm	38mm	43mm	50mm	56mm	66mm	77mm	83mm	96mm	115mm
3600V		option	option		option	option		option	K5453	option
4500V		option	option	K0890 (4200V)	K1270	K1785		option	K4215	option
5200V		option	option		K1210	Option		option	K4005	option
6500V		K0349 & K0443	option	K0769	option	K1351	option	K2325 & K2085	K3745	K4320
8500V		option	option		KX500	option		option	option	option
Package	**25mm**	**34mm**	**38mm**	**47mm**	**50mm**	**63mm**	**73mm**	**75mm**	**85mm**	**100mm**
15mm										
26mm		LC/LN	QA	NC	MC	HA	ZD	TJ	EA	FA

Diodes

Voltage	30mm	38mm	43mm	50mm	56mm	69mm	77mm	83mm	96mm	115mm
4500V	W0507	W1185 & W1185	Option	W2054	W3082	WX608	W4096	Option	Option	
4800V	Option	Option	Option	W1856	W2899	Option	W3743 (5000V)	W5139	W8245 & W7395	
6000V	Option	W1032 & W0925	Option	W1520	W2115	W3090 & W2830		W4205	W6360 & W5715	
6800V	Option	W0790 & W0880	Option	Option	W1975	W2865		W3630	Option	WX645
9000V		Option	Option	Option	Option	Option		Option	WX639	
Package	**25mm**	**34mm**	**38mm**	**47mm**	**50mm**	**66mm**	**73mm**	**75mm**	**85mm**	**100mm**
15mm	YC									
26mm	YH	LC	QA	NC	MC	HA	ZD	TJ	EC	FA
35mm		LG				HE	ZC	TE	ED	FE

- MV application place additional demands on semiconductors
- Hermetically sealed packages
- As voltage increases, so do switching losses and turn off time to a point where they are a significant factor
- Our patented distributed gate thyristor architecture ensures excellent switching losses over a wide range of voltages, currents and di/dt up to 400Hz
- Provides significant benefits in series applications

- Medium Voltage Drives & Soft Starts
- Utility applications such as HVDC, Statcom, excitation and transfer switches.

MV Thyristors

Rectifier Diodes

Press-pack IGBT portfolio

Voltage	Reverse conducting - with integral anti-parallel diode									
1.7kV		T0600	T0960		T1680		T2520			
3.3kV	*T0140*		*T0425*		*T0710*	*T1065*			*T2000*	
4.5kV	T0115		T0340		T0600	T0900			T1600/1800	T2000
6.5kV				T0258			T0600	T0900		T1290
	Discrete IGBTs									
1.7kV		T0840	T1440		T2520		T3840			
3.3kV		T0285	T0640		T1000	T1500			T3000	
4.5kV		T0240	T0510		T0800	T1200			T2400	T3000
6.5kV				T0385			T0900	T1375		T1890
Package	34mm	47mm	63mm	66mm	75mm	85mm	96mm	110mm	125mm	132mm
26mm	QC	NC	VC		TC	EB/EC	AC		GB	BB
30mm				HF			AF	DF		BF

3000A 4500V Largest IGBT in the world

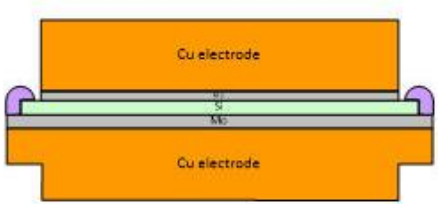
- Many of our STATCOM customers are working with the 3000A 4500V IGBT and 3000A 4500V companion diode in our stack designs for multiple 100's MVA projects.
- HVDC, FACT's, Thermal and Hydro Power plants, Active Var compensators, offshore and wind farm convertors, Frequency changers, transportation, multi level medium voltage drives (including DFIM) for various applications including Power Generation, Marine, Oil & Gas industries.
- Gate drivers also available.

Press Pack IGBT's and Gate Drives

Diodes for PP-IGBT – HP sonic FRD

	Discrete HP sonic FRD										
Voltage	**30mm**	**38mm**	**43mm**	**50mm**	**56mm**	**63mm**	**69mm**	**83mm**	**91mm**	**96mm**	**115mm**
1.7kV				E1680							
3.3kV			NPP		E1500				E3000		
4.5kV			E0460	E0660	EX611		E1250	E1800	E2400	E3000	E4000
6.5kV								E1780	EX642		EX556
Package	**25mm**	**34mm**	**38mm**	**47mm**	**50mm**	**63mm**	**66mm**	**75mm**	**85mm**	**85mm**	**100mm**
14mm				NH							
26mm	YH	LC	QC	NC	MC	VF	HC	TC	EC	EC	FD
30mm								TG			

Monolithic diode.
Pressure contact.
Market leading reliability



- Unique manufacturing process leading to very low soft recovery with very high di/dt capability, combined with 150C operation
- Leading class trade-off between conduction and switching loss
- Wide SOA making them ideal as free wheel diodes for snubber less IGBT and IGCT applications

- Transportation, medium voltage drives, induction heating and pulsed power applications

HIgh Power Sonic Diodes

Stacks

Littelfuse®

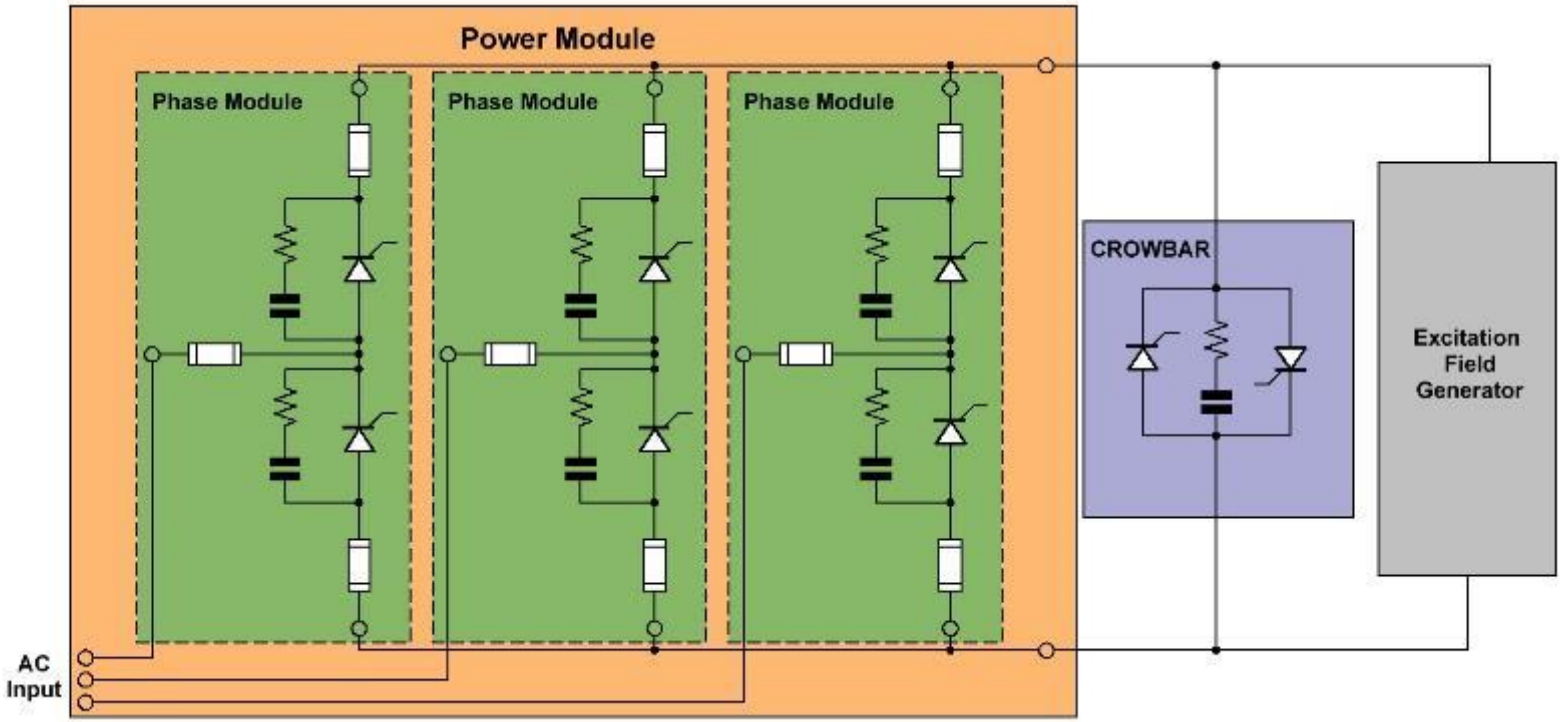
Expertise Applied | Answers Delivered

Production Facilities

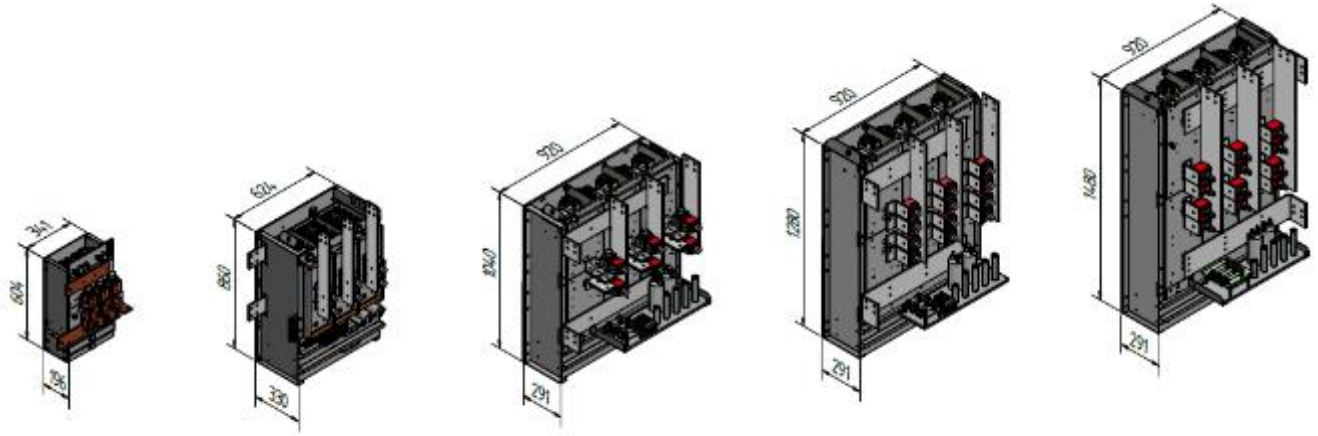
- USA - Dedicated 465m² (5’000ft²) facility, 4 Design Engineers, 4 Technician

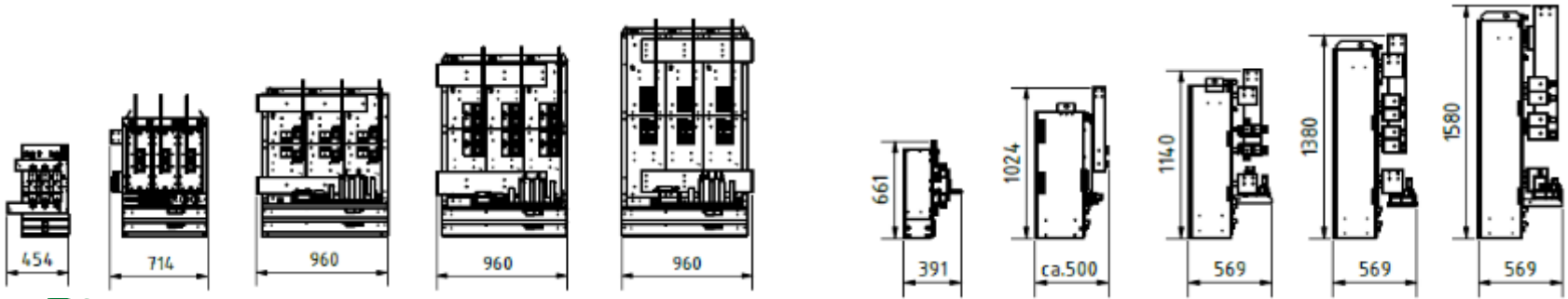
- UK & Germany - Dedicated 200m² (2150ft²) facility, 7 Design Engineers, 5 Technician

Excitation system configuration - example



Standard Excitation Rectifiers





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Rectifier Application – Synchronous condenser

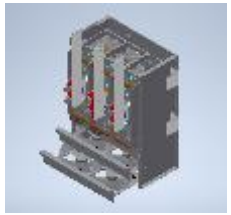
Application

- A synchronous condenser is a DC-excited synchronous motor, whose shaft is not connected to anything but spins freely.
- Purpose is to adjust conditions on the electric power transmission grid by either generate or absorb reactive power.
- Synchronous condensers are an alternative to capacitor banks.
- One advantage is that the amount of reactive power can be continuously adjusted.

Example:
Synchronous condenser/
Phaseshifter 125MVA.
No shaft on left and right side.
Source: Phasenschieber (Maschine) – Wikipedia

Projects

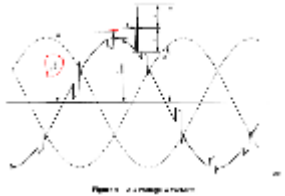
- **Gretna, Fingrid, Pembroke**
- B2-200D with N1718NC200 (low power and low voltage application)
- Twin configuration (1x bridge in operation / 1x bridge in stand by)



B2-200D Thyristor Stack

The “IEC 60146 challenge”

- Customers are introducing the standard IEC 60146 in their specifications.
- One point is to keep voltage spikes below 1.25*Vpeak (with RC or/and clipper).
- For this a simulation model is in developing process.



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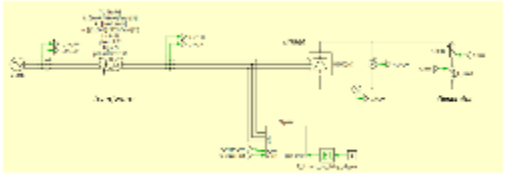
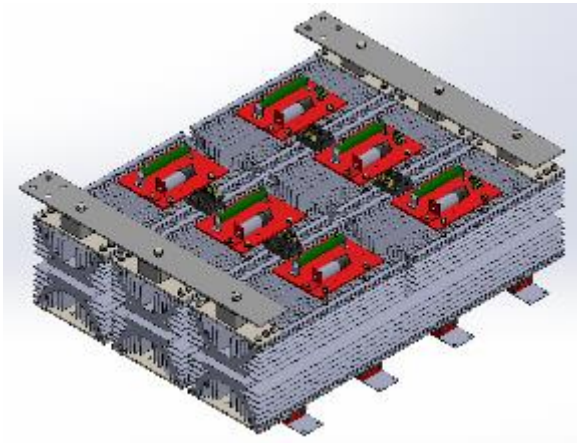


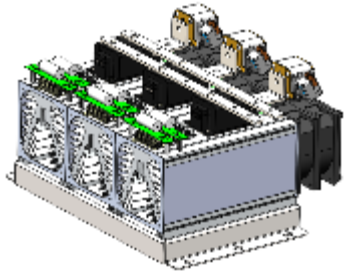
PLECS simulation schematic

Fully Controlled / Un-Controlled Rectifiers

- Over 250 projects worldwide over the last ~20 Years.
- Systems from 50A/1200V up to 2000A/4200V.
- All systems designed to suit customer needs.
- Fully controlled, including fuses.
- Natural air, fans + redundancy solutions.

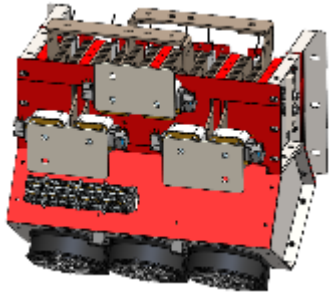


Standard Rectifiers for all Current Levels

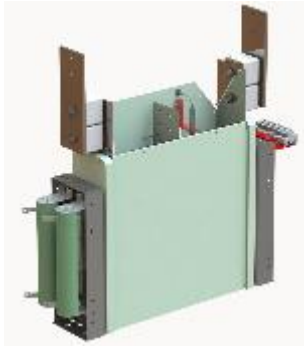


MODULE SOLUTIONS
UP TO 600A

PRESSED ALUMINUM FIN
SOLUTION TO 2000A



COPPER FIN SOLUTION
TO 1500A



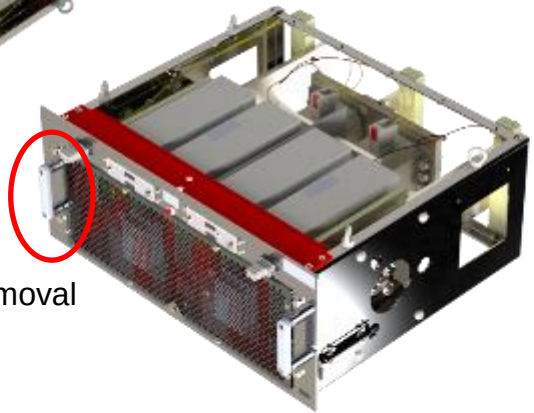
PHASE MODULE
PRESSED ALUMINUM
SOLUTION FOR 3000A

HIGH VOLTAGE (1578V)
1600A SOLUTION USING
EXTRUDED HEAT SINKS

Power Tray Stacks – Ease of replacement

Silver Tipped Blade Connectors

Thyristor 3.5kA Phase Leg

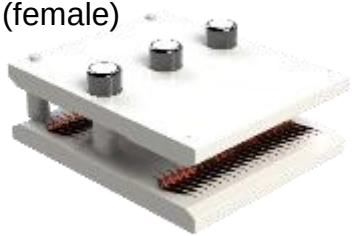


Handles for inserting / removal of tray

Plug & Play

3 x IGBT Inverter Tray
1 x Chopper Tray
1x Rectifier Stack
Cap Bank

Power Connector Receptable (female)



IGBT Inverter Tray on telescopic slides

Quick release water connections

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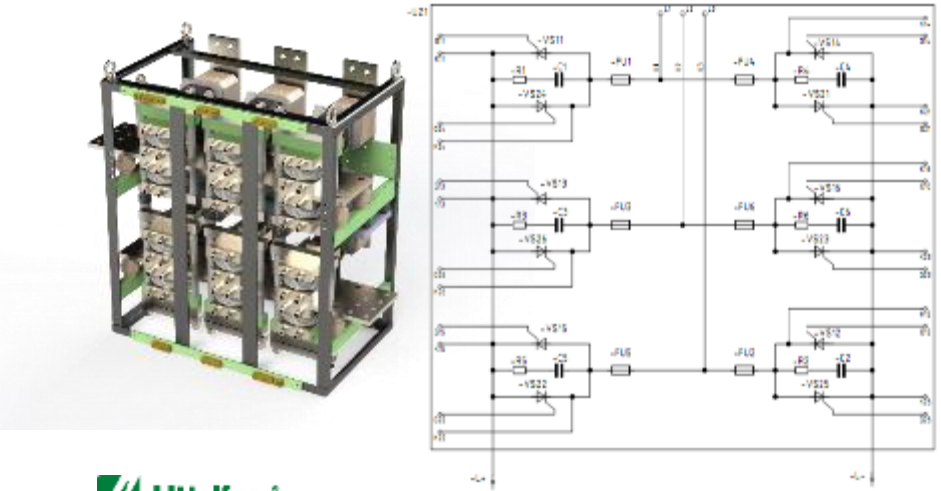
Fully Controlled, 3-Phase, Reversing Bridge Product Line

Problem/Solution

Fully controlled, 3-phase, reversing bridge family of products. All built into rigid, easy to install frames, utilising the latest Thyristor technology supported by RC snubbers, water cooling, fusing and thermal sensors to provide a high-end plug and play system with a focus on reliability and ease of use. Suitable to replace existing, aging systems within the Industrial Controls and Heavy Industry markets.



Typical Fully Controlled, 3-Phase, Reversing Bridge stack topology

Benefits

- Designed into rigid frames, giving ease of installation and a plug and play solution.
- Class leading Thyristor technology provides highly reliable, long lifetime stack.

Features

- RC Snubber networks.
- Water cooling via de-ionized water.
- Line fuse protection.
- Thermal sensors for temperature monitoring.

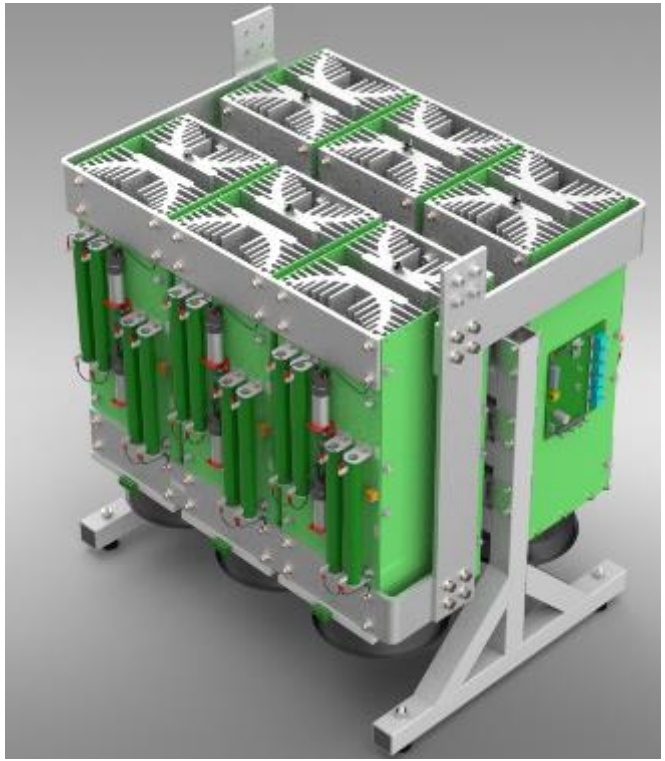
Ratings for Product Line

Stack Part No.	XA2500ZH30WN	XA3150TH30WN	XAKSPCX630W105E8A
Device Used	N2418ZC360	N3620TE360	N5415EA360
$U_{AC\ MAX}$	950V		
U_{DC}	1050V		
I_{DC}	2500A	3150A	6300A
$I_{DC\ OVERLOAD}$ (15s, both directions, every 20 mins)	5000A	6300A	12,600A
Cooling Type	De-ionised water		
Snubber resistor cooling type	Natural Air	De-ionised water	De-ionised water
Ambient Temp	40°C		

Markets/Applications

- Industrial controls
  - Drives
- Heavy industry
  - Induction melting
  - Billet heating

Commercial Vehicles High-Power Charging Rectifiers – Development Product



- Forced air-cooled stack B12C
- 2x 3 phase stacks mounted in close proximity
- Can be configured as follows
  - series to give 1500V 2000A
  - parallel to give 750V 3000A
- Options
  - Line fuses and/or arm fuses.
  - Bespoke busbar arrangements and connections.
  - Bespoke mounting frame with or without castor wheels.
  - PT100 temperature sensors.
  - Thermostats (alarm and trip).
  - Air flow sensors.
  - Redundant fans.
  - SCR firing and control boards.
  - Lifting eyes/lifting brackets.

270MVAr Thyristor Switched Capacitor Valve

Problem/Solution

- A thyristor-switched capacitor (TSC) is a type of equipment used for compensating reactive power in electrical power systems. It consists of a power capacitor connected in series with a bidirectional thyristor valve and usually a current limiting reactor (inductor)
- This is a 3-phase water cooled thyristor valve assembly for TSC applications. Comprises series connected anti-parallel medium voltage thyristors in W1C configuration. Includes suitable water-cooling system, mounting clamps, bus-bars, dynamic sharing / snubber networks, static sharing resistors, top and bottom corona shields and basic insulation.

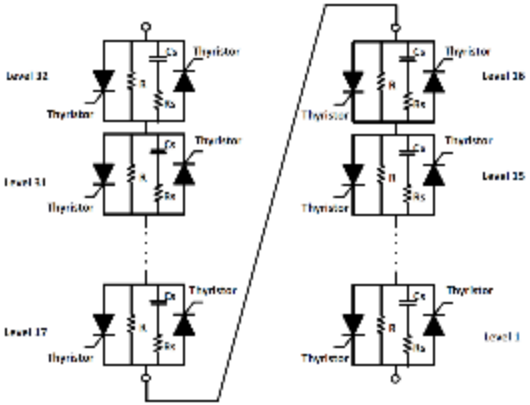
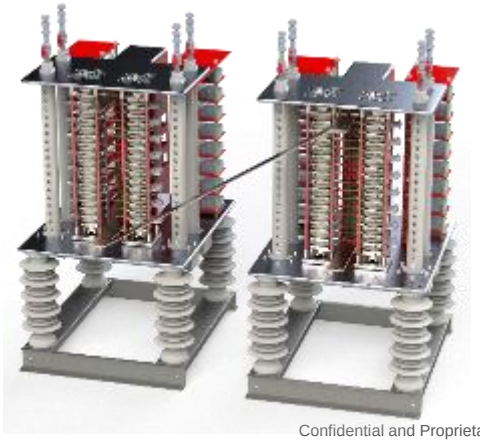


Figure 1 Electrical circuit of TSC valve assembly

Features

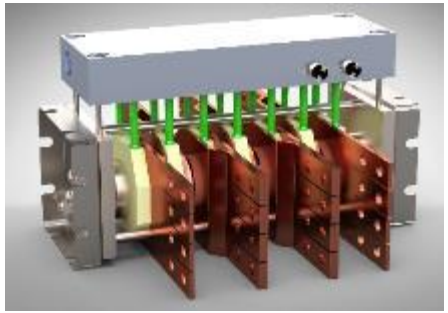
- Rated Voltage : 36 kV, rms (Line-Line)
- Max. Continuous operating voltage : 39.6 kV, rms (Line-Line)
- BIL : 170 Kv
- Thyristor : 32 Levels
- Rated Frequency : 60 Hz +/- 1%
- Rated Power of TSC : 270 MVAr
- Rated phase capacitance TSC : 0.11241 mF
- Assumed VBO protective firing device : 6.2 KV
- Switching impulse : >140 kV peak
- Rated Current of thyristor valve : 2500 Amp, rms
- VDRM, VRRM of stack : >102 kV peak

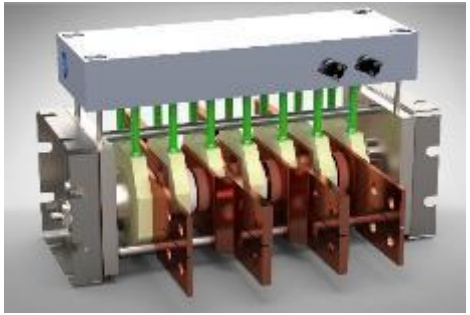


Icebreaker Project - Uncontrolled 6 Phase Bridge with Isolation

Details

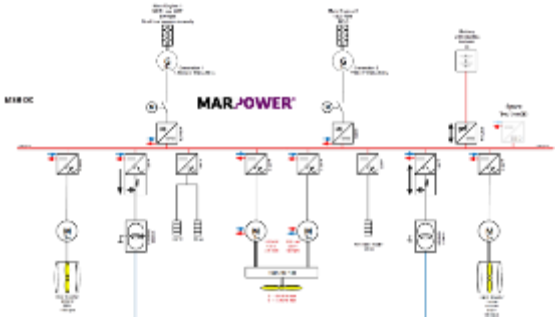
- Used to convert AC power from an icebreaker ship's primary and secondary generators to DC which the ships primary systems and engines run on.
- Each stack has 6 water cooled diodes and 2 N/C temperature switches
- The customer wants to use tap water – we have advised it is possible but will reduce cooling system lifespan.
- 6 off XASB6UX093S081E1A & 6 off XASB6UX093S210E1A

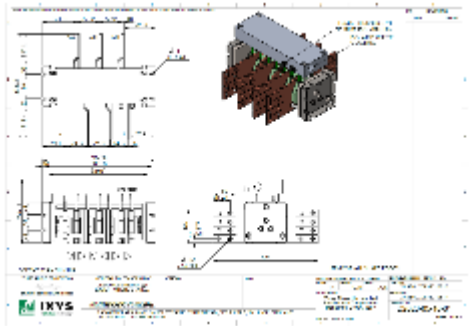




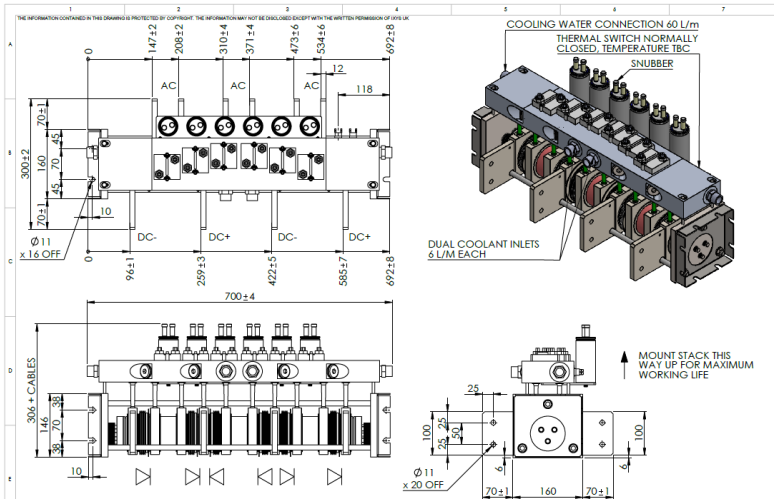
Features for XASB6UX093S081E1A / XASB6UX093S210E1A

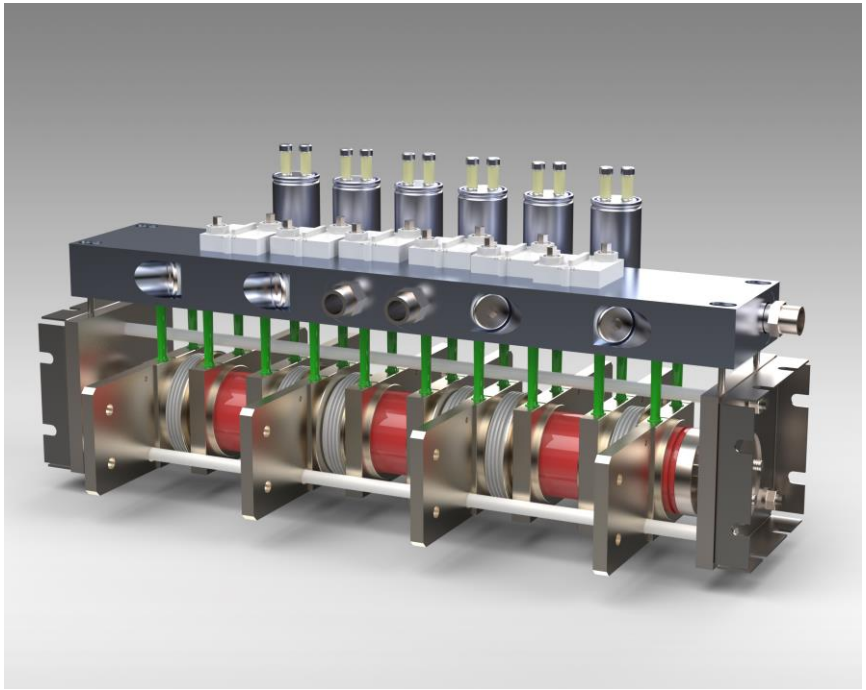
Power	: 750kW / 1900kW
Rated Voltage	: 930V / 930V
Rated current	: 810A / 2100A
Rated Frequency	: 60Hz / 30Hz
Diodes	: W1980JK220 / W3409NK280
Cooling method	: Water Cooled
Minimum order quantity	: 6 / 6



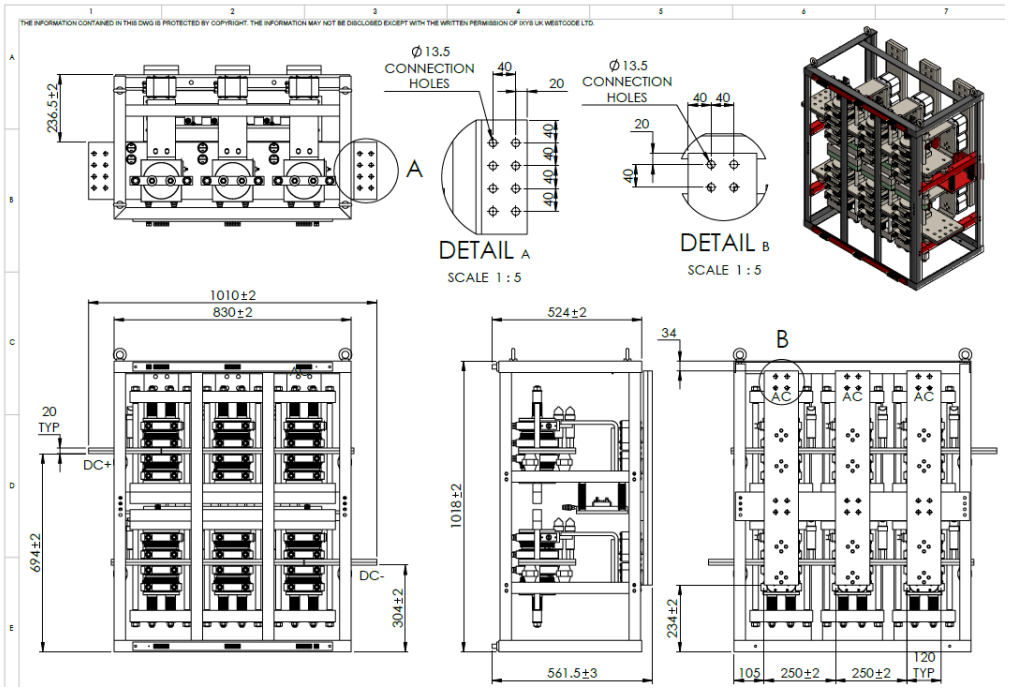


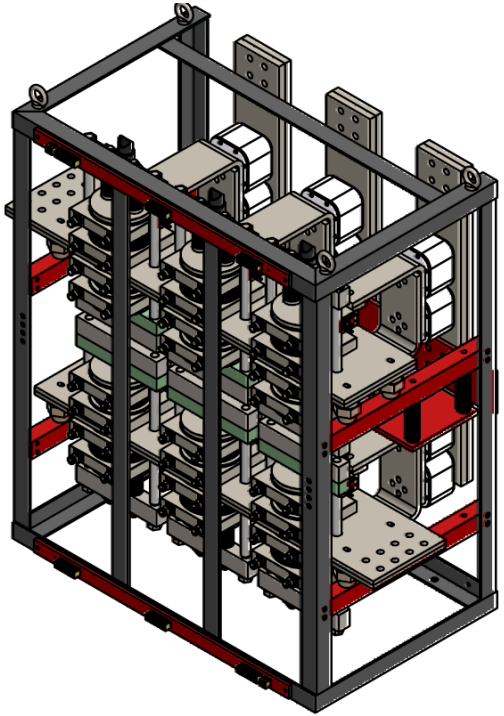
Marine Rectifiers - example





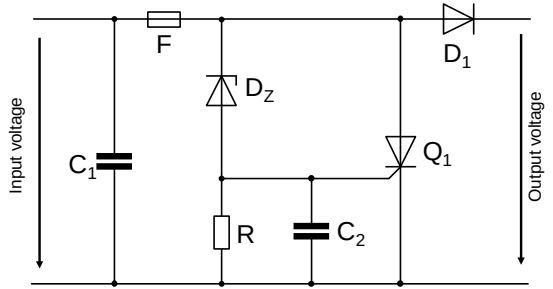
High Power 3ph Rectifier systems – example 1kV 12kA



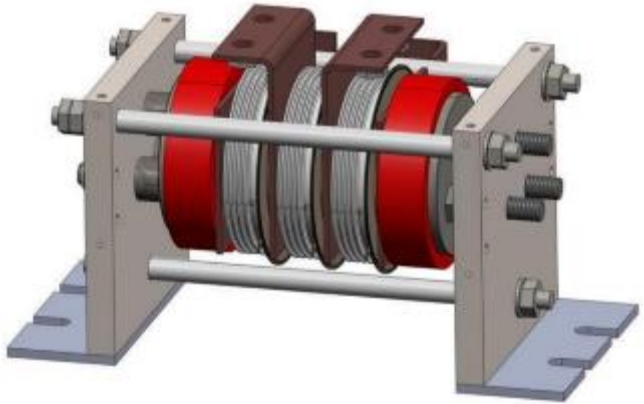


Crowbar Solutions

- Protecting electronic devices in high power applications such as
  - solar inverters for utilities
  - multi access-point EV-charging stations
  - Train and metro systems
- Classical fuses may not be suitable to protect power semiconductors when dealing with high power levels due to incompatible I^2t-value
- Crowbars can be used to handle short circuits and allow enough time for fuses or protecting switch gear to disconnect the short circuit's cause
- In addition, crowbars can be triggered in case of overvoltage and act as a supporting safety measure as well



Basic schematic of a crowbar in a DC-DC-application

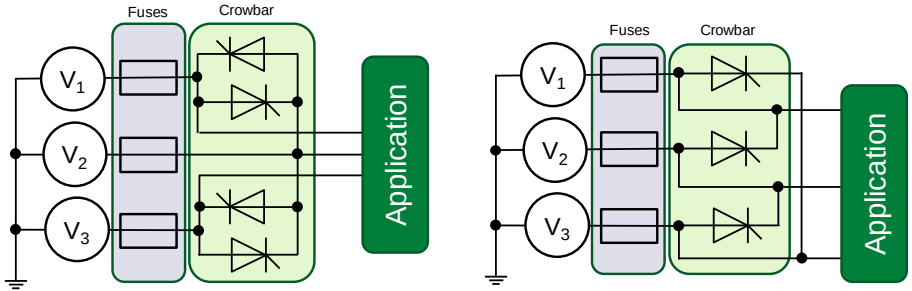


Crowbar-Stack for 3-phase medium-voltage applications

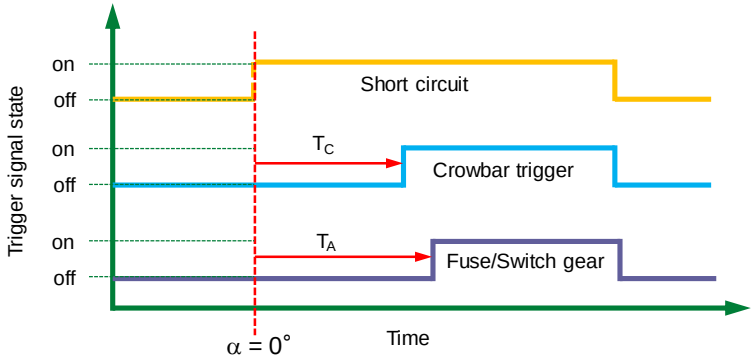
References
M Schultz (2023) Improving High-Power Crowbar design using rupture-enhanced, capsule-style thyristors in medium voltage driven applications. PCIM 2023

Crowbar Solutions

- A similar approach can be followed for AC applications
- Under AC, the thyristors after being triggered, need to maintain the short-circuit condition until the fuse or a circuit breaker has reacted.
- This demands safe operation of the crowbar for at least 50 milliseconds.
- To fulfill the safety function, it is tolerable that the thyristors lose their switching capability as long as the line-to-line connection remains in low-impedance state
- In addition, the thyristors must remain undamaged. Case rupturing may not take place as it may influence the safety function.



Crowbar setup in Y- and Δ-connection



Failure handling, timing diagram