Power Converter Design Options for the 12 kVdc Bus System

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Opportunities and risks of new power electronic technologies aboard the new 10 kton surface combatant

Despite their potential advantages, a compelling reason does not exist at this time for the adoption of SiC switches aboard the first generation of the new 10 kton surface combatant. Much of the anticipated improvements could be realized with standard commercial off-the-shelf Si technology. The advantages of the MMC topology may come at the cost of lower power density. This may discourage its use or at least limit it to few strategic areas.

SiC vs Si Switches	Impact
Higher Voltage Rating (~3x)	Fewer Devices Needed
Faster Switching Speeds	Lower Switching Losses Smaller Reactive Components
Lower On-State Voltage	Lower Conduction Losses
Higher Temperatures Rating	Operation Possible at T>200 °C
Higher Thermal Conductivity (°3x)	Higher Current Rating
ADVANTAGES	**ISSUES TO CONSIDER**
Reduction of Reactive Components	Larger Impact of Parasitic Reactances
Circuit Operating at Higher Speed	Latency Effects More Serious
Reduction of Audible Noise	EMI Emission More Difficult to Manage
Higher Power Density	Possibly Higher Loss Density
Operation at Higher Temperatures	All Other Components Must be Rated Higher

2017 ESRDC Study: MMC converter designs using Si and SiC modules (Converters rated for 6 kVdc bus and Shipboard Duty)

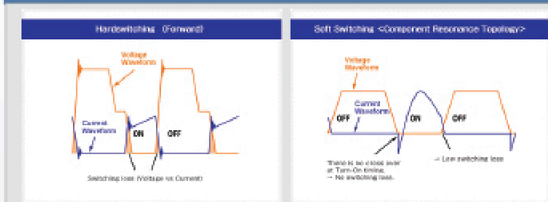
	Si IGBT	SiC MOSFET (1)	SiC MOSFET (2)
Rated Power MW	1.25	1.75	2.90
Power Density (MW/m3)	0.137	0.169	0.220
Power Density SiC/Si, % up	-	23.4	60.6

(1) Conventional design
(2) Optimized selection of passive components

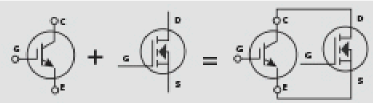
Alternative Design Approaches Exist to Minimize Switching Losses Using Conventional Si technology

Two independent techniques for reducing switching losses, which can also be combined for maximum advantage:

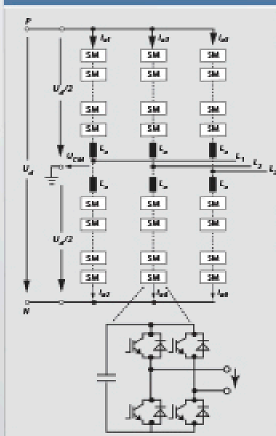
Soft-switching: forcing semiconductors to switch at zero voltage or zero current (switching losses = 0)



Hybrid Switching – Parallel Operation of IGBT and MOSFET switches combines faster switching of MOSFET with lower conduction losses of IGBT



Full Bridge Modular Multi-Level Converter (MMC)



Advantages
- Modular Construction
- Nearly Sinusoidal Voltages/Currents
- No Need for AC Filters
- No DC Bus Capacitor
- Fast Control
- Fault Blocking Capability

Disadvantages
- Complex Control
- Potential Circulating Currents
- More challenging power density
  - Possibly lower than other topologies
- Reliability:
  - larger number of components
  - more limited field experience)

Comparison of Various MV Converter Topologies

ITEM	2L-VSI 2 - level voltage source inverter	3L-NPC 3 - level neutral point clamped	3L-CHB 3 - level cascaded H-Bridge	3L-FC 3 - level flying capacitor	PWM CSI PWM current source
Redundant states	~	YES	YES	YES	~
Control complexity	LOW	~	~	HIGH	LOW
Capacitor voltage balance required	NO	YES	YES	YES	NO
Modularity	YES	NO	YES	YES	YES
Fault tolerance	GOOD	~	GOOD	GOOD	GOOD
Regenerative design complexity	~	~	HIGH	~	LOW
Isolated dc bus supplies	NO	NO	YES	NO	NO
Auxiliary capacitors needed	NO	NO	NO	YES	NO
Auxiliary diodes needed	NO	YES	NO	NO	NO
Freewheeling diodes needed	YES	YES	YES	YES	NO
Load filter capacitance needed	~	~	NO	~	YES
Load filter inductance needed	~	~	NO	~	NO
Suitable for low switching frequencies	~	YES	YES	NO	YES
Harmonics, dv/dt output	HIGH	MEDIUM	LOW	MEDIUM	LOW
Dc link inductor needed	NO	NO	NO	NO	YES
Dc link capacitor needed	YES	YES	YES	YES	NO
Inherent open circuit protection	YES	YES	YES	YES	NO
Inherent short circuit protection	NO	NO	NO	NO	YES
Potential LC resonances	~	~	~	YES	YES
Dynamic response	GOOD	GOOD	GOOD	GOOD	POOR
Efficient control at fractional loads	GOOD	GOOD	GOOD	GOOD	POOR
Scalability	NO	~	YES	YES	YES

Study Conclusion

3L-CHB is the antecedent topology to the MMC.

All topologies scored within ± 8% of average.

The 3L-NPC scored highest.

The 2L-VSI scored closest to the average.

At the time, no compelling choice emerged.

Conclusions

SiC switches will be the preferred long term choice for MV converters in the MW power range. However, SiC may not be a near term option due to high manufacturing costs and uncertain availability

- Technology solutions currently exist for utilizing Si materials in high performance MV converters with 12 kV dc, e.g.: Soft Switching topologies, Hybrid switches
- MMC topology advantages must be evaluated against a possible reduction of power density
- SiC and advanced Si topologies both represent an advancement of the state of the art
- Innovative designs should be evaluated and those that reduce the risks of implementation should be preferred

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