

Implications of silicon-carbide (SiC) technology on all electric ships

Timothy J. McCoy, PhD, PE
ConverTeam

Charles H. Brown, MEng, PE
BMT Syntek, Inc.

John V. Amy, Jr., PhD, PE
BMT Syntek, Inc.

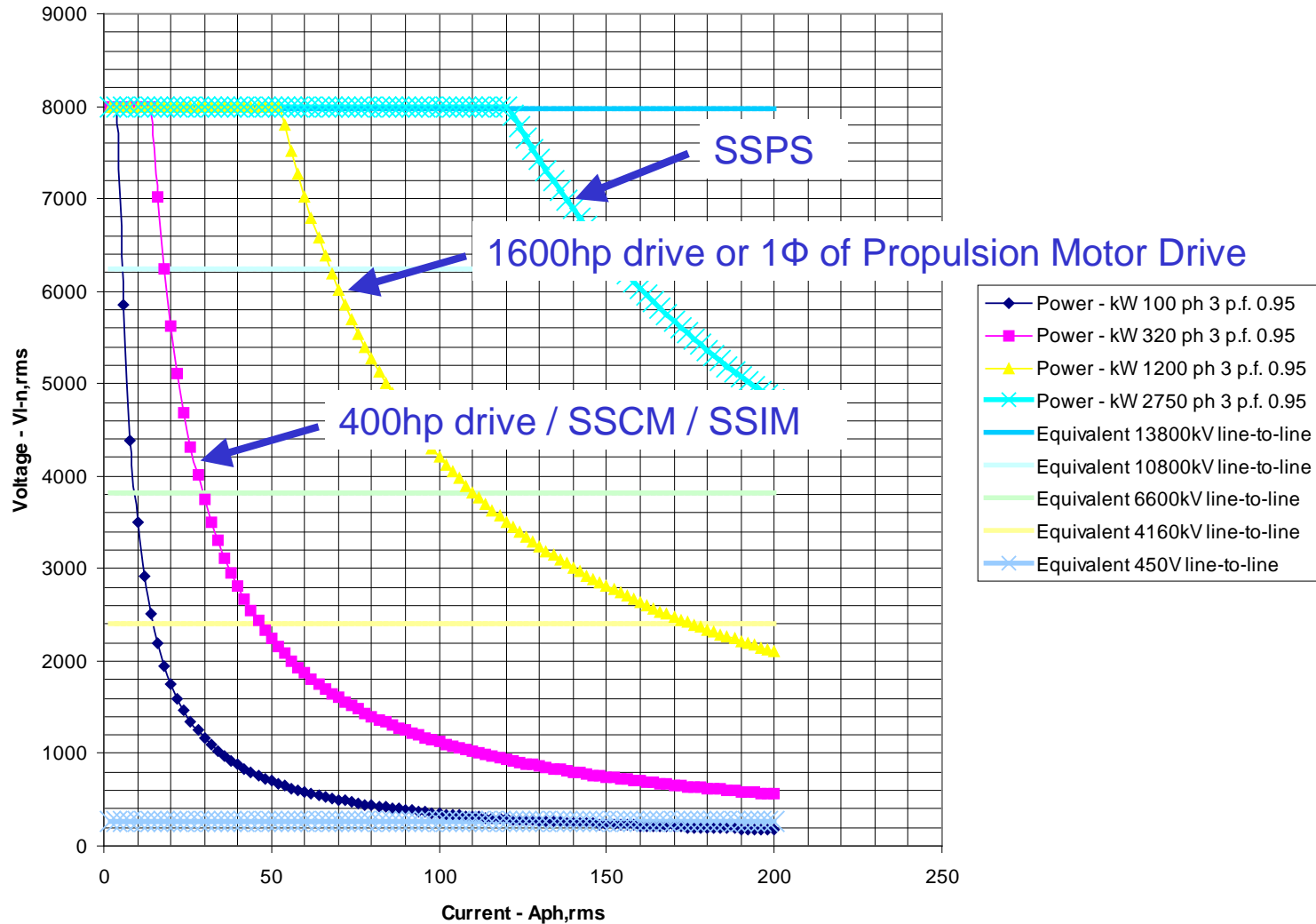
Cyril F. Krolick, PhD
BMT Syntek, Inc.

Sharon Beermann-Curtin
Defense Advanced Research Projects Agency (DARPA)

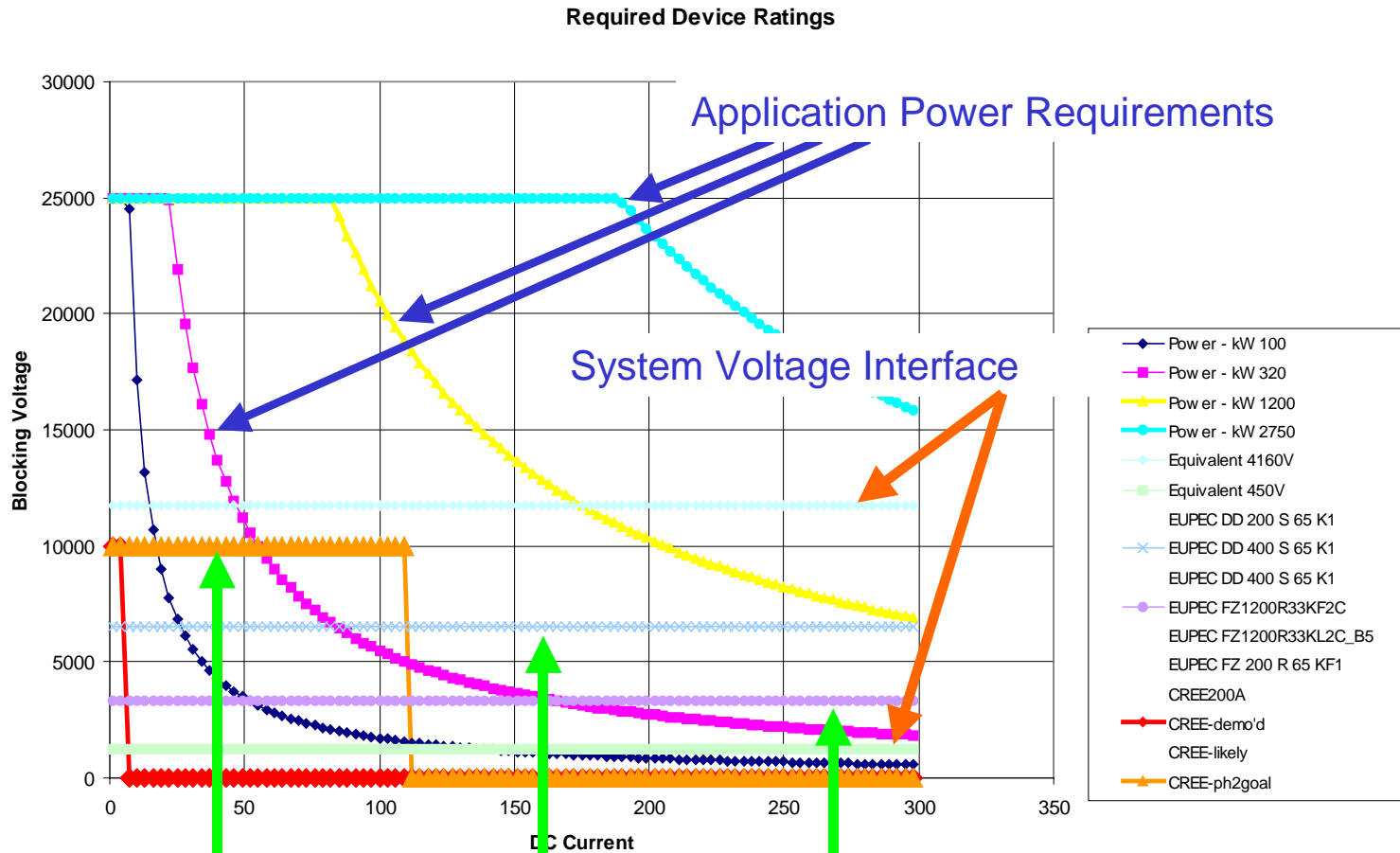
Shipboard Power Converter Applications

- Frequency Converters
- Electric propulsion drives
- Electromagnetic aircraft launching and recovery systems
- Point-of-use power converters for electric distribution systems
- Integrated power distribution systems
- Auxiliary motors and drives
- High energy weapon systems
- Pulse power systems
- Energy storage systems

Converter voltage vs. current requirements – Isopower Curves



Required device ratings



10kV SiC device, 6500V Si IGBT, 3300V Si IGBT device ratings

Device Applications

- 10kV is a useful blocking voltage rating
- Simple topologies considered with standard de-rating practices
 - Single device H bridge
 - Series (2) devices H bridge
 - Three level
- Current ratings must increase.
 - 75-100A Rating for 320kW application
 - 150-200A Rating for 1200kW application

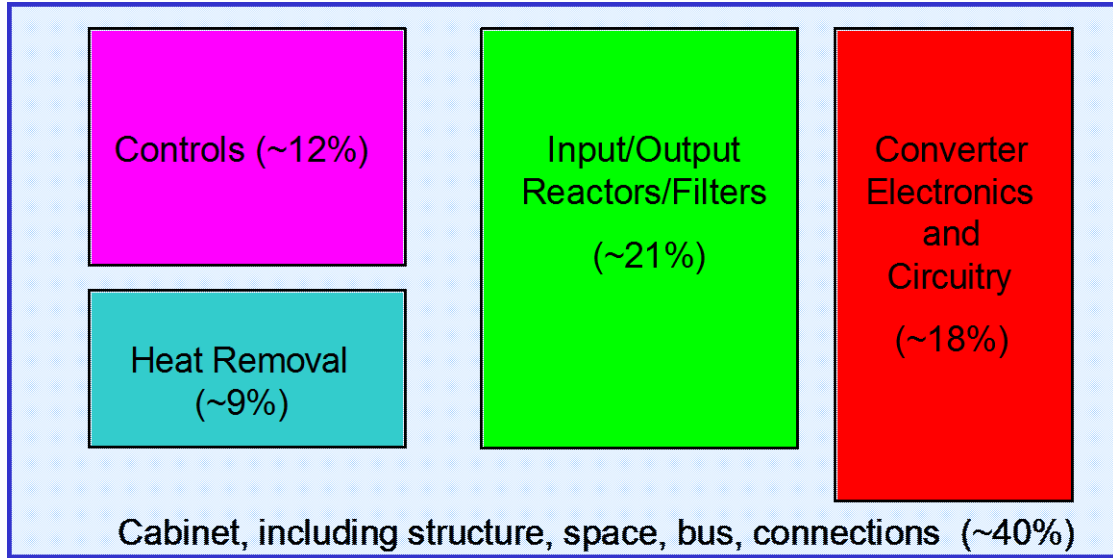
Characteristics of Si vs. SiC

- SiC devices will have 5-30 times higher breakdown voltage than Si allowing the use of single devices vice series devices for practical Naval high voltage applications.
- Higher breakdown voltage of SiC allows thinner devices and increased doping levels, thereby reducing the on-state resistance. On-state resistance (R_{on}) will be ~300 times lower with SiC than Si.
- SiC has higher thermal conductivity which reduces thermal resistance, R_{th-jc} . This can be seen to be a ratio of 3.27 higher for SiC.
- SiC can operate at higher temperatures (up to 600°C).
- Forward and reverse characteristics of SiC do not vary with temperature as much as Si, therefore SiC devices are expected to be more stable.
- SiC devices will have better reverse recovery characteristics, thereby reducing switching losses vs. Si devices.
- SiC is extremely radiation hard due to the wider bandgap.

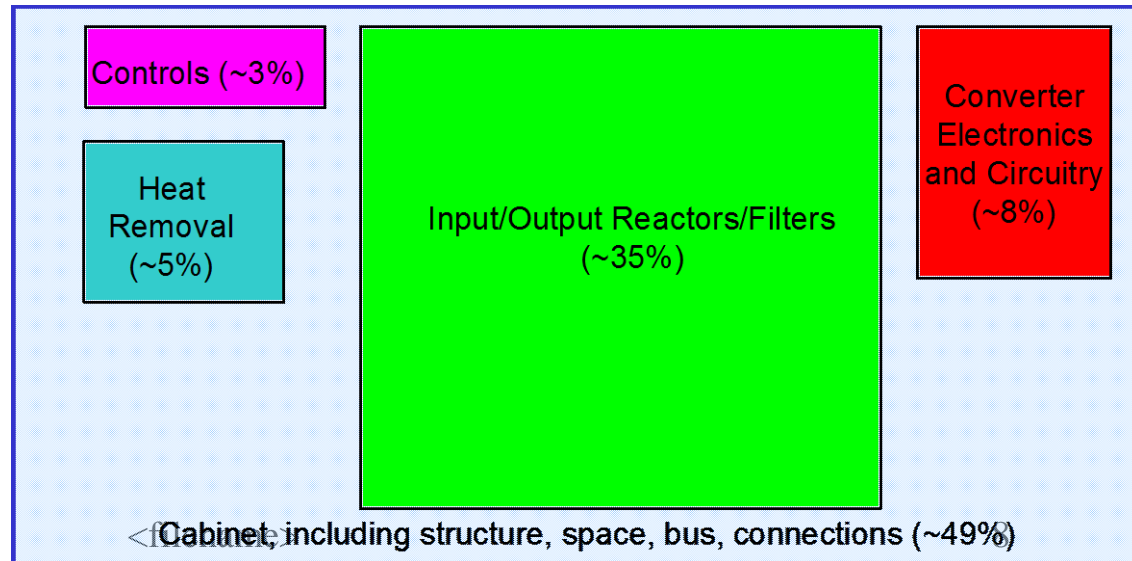
What SiC characteristics mean for converter designers ...

- Increased Blocking Voltage
- Increased Switching Frequency
- Reduced conduction losses
- Reduced switching losses

Relative Volumes



Larger Converters
(~1,200 kW)



What SiC characteristics mean for converter designers ...

- Increased Blocking Voltage
 - Fewer devices not significant in themselves
 - Simpler topology, fewer gate drives etc are significant
- Increased Switching Frequency (4x)
 - Reduced size/weight of passive components
 - 4% volume / 5% weight reduction
- Reduced conduction losses
 - Switching devices ~56% of converter losses
 - 4x reduction in conduction losses -> 21% reduction in converter losses
 - 1% volume / 1.5% weight reduction
- Reduced switching losses
 - Switching devices ~56% of converter losses
 - Competing objectives: SiC less loss per switch event, but switching much more often -> 12% reduction in converter losses
 - No significant change in converter size/weight

Conclusion

- The KEY BENEFIT that SiC devices bring to naval applications is the ability to simplify the design, construction and maintenance of these power converters through the use of single devices. Using single devices (in lieu of series or parallel ones) reduces on a many-for-one basis the supporting components such as gate drives, snubbers, interconnecting buswork, control I/O and other ancillary components. This simplification of these complex systems will make them less costly to design and acquire and more reliable in the field.