EMBARCADOS WEBINAR

Patrocinado por MOUSER ELECTRONICS

Soluções de acionamento de motor industrial de baixa tensão

Criando um legado com SiC

Jeferson Staudt

Business Development Manager
Wolfspeed na Vermont Rep

Wolfspeed®

EMBARCADOS

Patrocinado por

MOUSER ELECTRONICS

Wolfspeed Industrial Low Voltage Motor Drive Solutions

Wolfspeed | STAUDT|JULY 11ST
STAUDT@VERMONT-REP.COM

“Electric motors account for more than 50% of all industrial electricity usage globally and 45% of all global electricity.”

*Source: IEA.org

BUILDING OFF OUR SILICON CARBIDE LEGACY…

Wolfspeed introduced the **world's first** commercially available, fully qualified silicon carbide MOSFET

Wolfspeed makes **> 60%** of the world's silicon carbide today

Wolfspeed has achieved **10+ trillion** silicon carbide device field hours

Wolfspeed has been vertically integrated and making silicon carbide for **35 years**

WOLFSPEED SILICON CARBIDE MOSFETS AND DIODES IN INDUSTRIAL LOW VOLTAGE MOTORS …

ACHIEVE

IE4

EFFICIENCY STANDARDS

DELIVER UP TO

50%

REDUCTION IN SYSTEM LOSSES

ENABLE

Embedded Drives

INTEGRATION OF DRIVES AND MOTORS

ENHANCE

Motor Performance

REDUCED AUDIBLE NOISE, FASTER ROTATION SPEEDS & PRECISE CONROL

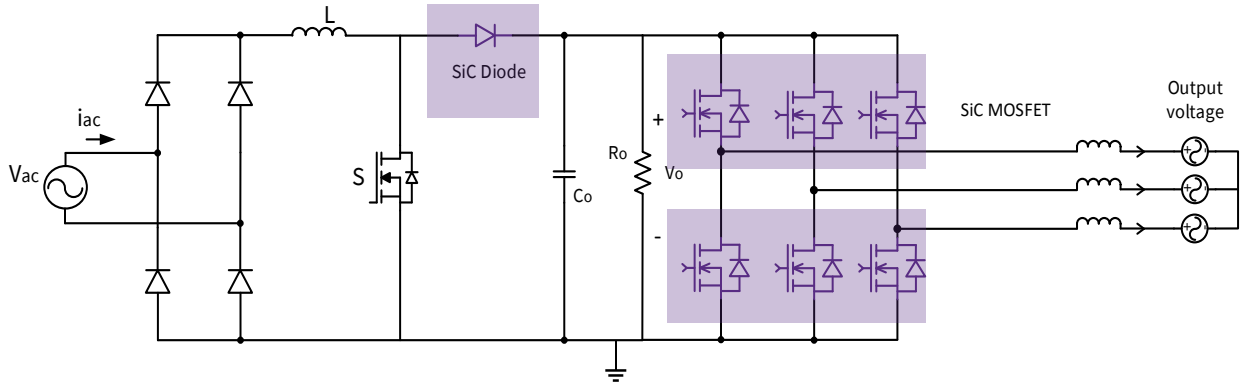
…COMPARED TO TRADITIONAL SILICON POWER DEVICES.

SINGLE-PHASE MOTOR DRIVE SYSTEM (4 KW)

INCREASE EFFICIENCY WITH SIMPLE DROP-IN SIC SOLUTIONS

EXAMPLE: 4 KW, 8 KHZ - NO REDESIGN APPROACH

4 kW, 8 kHz frequency motor simulation @ 100% load

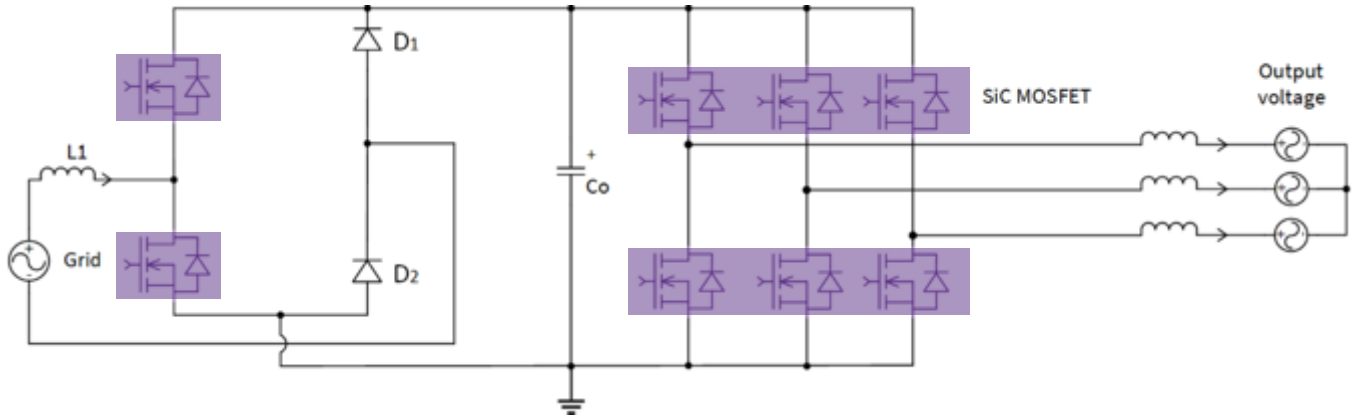


	Upgrading the AC-DC PFC (No redesign Approach)	Upgrading the inverter	= Full silicon carbide solution
HOW	• Replace silicon PIN rectifier with silicon carbide Schottky diode (multiple topologies available)	• Changing the Inverter from IGBT to silicon carbide in same simple 6-switch configuration	• Simple drop-in replacements
WHY	• Most popular upgrade to implement • 0.5% efficiency improvement over silicon boost PFC • **20 W reduced power consumption**	• 0.4% improvement in system efficiency over Si IGBTs • **16 W reduced power consumption**	• Total reduction **in losses of 36 W** • **0.9%** more efficient system • **35% lower overall losses**

GAIN MORE THAN 1% EFFICIENCY WITH FULL SIC SOLUTION

EXAMPLE: 4 KW, 8 KHZ SEMI-BRIDGELESS TP-PFC

4 kW, 8 kHz motor inverter simulation @ 100% load

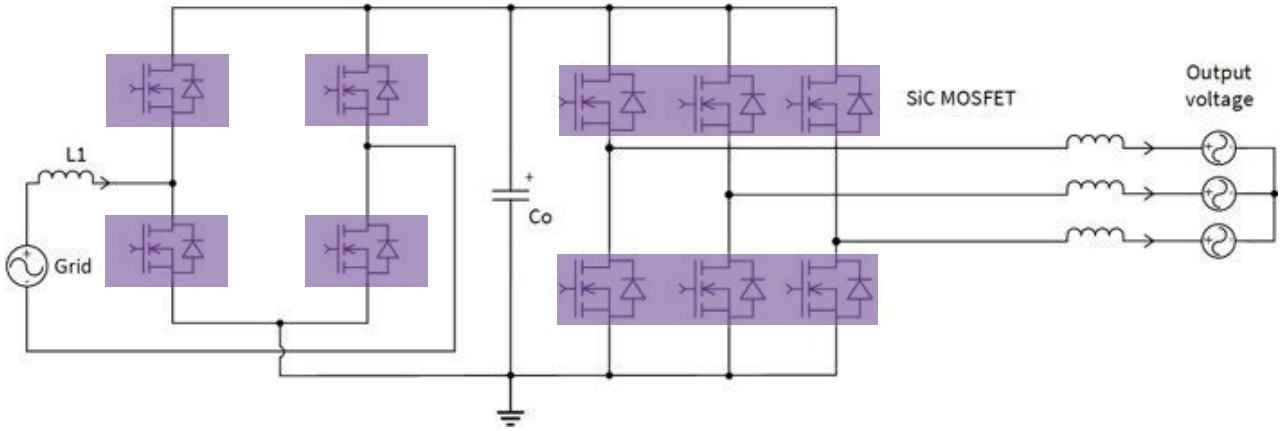


	Upgrading the AC-DC PFC (Redesign Approach): Semi-Bridgeless TP-PFC	Upgrading the inverter	= Full silicon carbide solution
HOW	• Redesigning PFC using semi-bridgeless totem pole topology utilizing silicon carbide MOSFETs	• Changing the Inverter from IGBT to silicon carbide in same simple 6-switch configuration	• Redesigning PFC and • simple drop-in replacements for motor drive
WHY	• 1.0% efficiency improvement over silicon boost PFC • **40 W reduced power consumption**	• 0.4% improvement in system efficiency over Si IGBTs • **16 W reduced power consumption**	• Total reduction **in losses of 56 W** • **1.4%** more efficient system • **55% lower overall losses**

UP TO 60% LESS LOSSES SYSTEM-WIDE WITH WOLFSPEED SILICON CARBIDE

EXAMPLE: 4 KW, 8 KHZ BRIDGELESS TP-PFC

4 kW, 8 kHz motor inverter simulation @ 100% load



	Upgrading the AC-DC PFC (Redesign Approach): Bridgeless TP-PFC	Upgrading the inverter	= Full silicon carbide solution
HOW	• Redesigning PFC using bridgeless totem pole topology utilizing silicon carbide MOSFETs	• Changing the Inverter from IGBT to silicon carbide in same simple 6-switch configuration	• Redesigning PFC and • simple drop-in replacements for motor drive
WHY	• 1.2% efficiency improvement over silicon boost PFC • **48 W reduced power consumption**	• 0.4% improvement in system efficiency over Si IGBTs • **16 W reduced power consumption**	• Total reduction **in losses of 64 W** • **1.6%** more efficient system • **60% lower overall losses**

4 KW SILICON CARBIDE SOLUTION ENERGY SAVINGS

BRIDGELESS TOTEM POLE-PFC + INVERTER

Payback rate scenario:

- You replace competitive 650-V IGBTs in your unit with Wolfspeed 650 V Silicon Carbide MOSFETs. This replacement is more expensive up front.
- You use your unit for 15 years, saving a total of **2,472 kWh / 915 Euros**

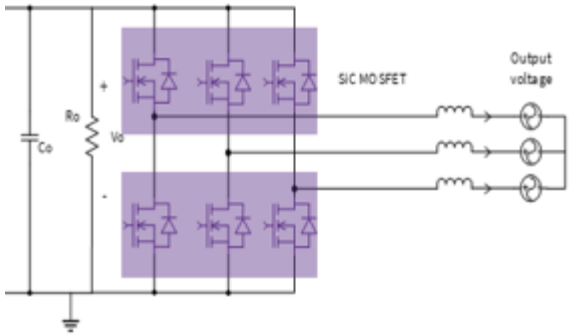
The total cost of ownership for moving to Silicon Carbide:

Rated Power	4000 W
Expected Efficiency Improvement	**1.6 %**
Power Savings	64 W
Annual Operation	8200 Hours
Load Conditions Cumulated	Multiple
kWh/year usage	10299.2 kWh
kWh/year savings	165 kWh
Electricity cost*	0.37 Euro/kWh
Annual Operating Cost*	3,810 Euro
Annual Savings*	61 Euro

*Electricity cost = Germany's rate as of September 2023.
Annual energy savings would vary based on region.

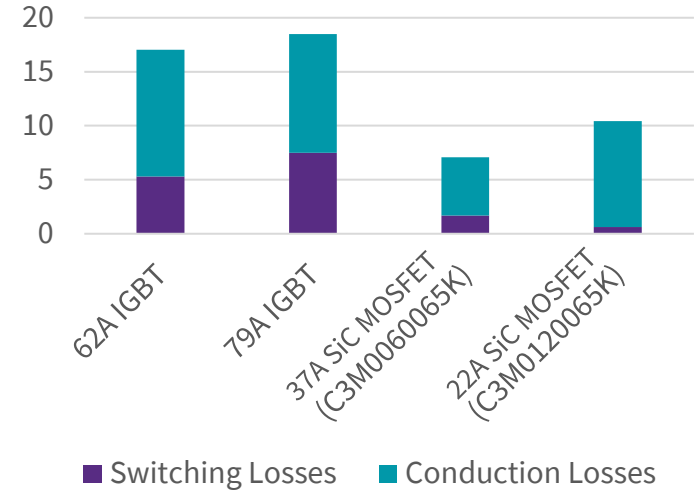
MOTOR DRIVER LOSSES FOR IGBT VS. SILICON CARBIDE MOSFET – 8/16 KHZ (4 KW)

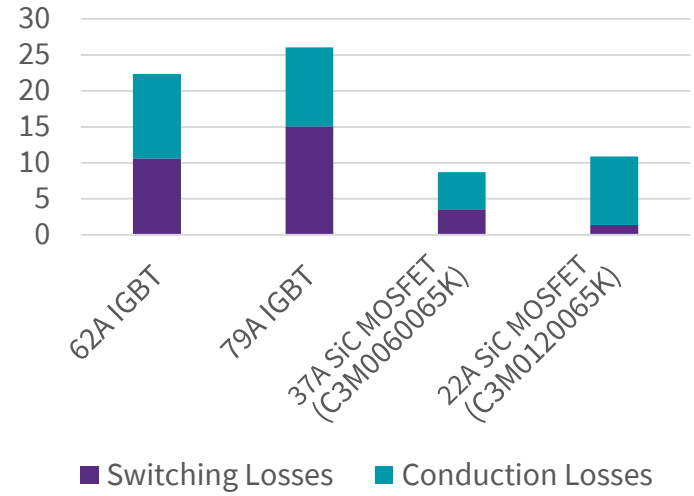
4 kW 8 kHz @ 50% load
*High speed soft switch IGBTs used for evaluation



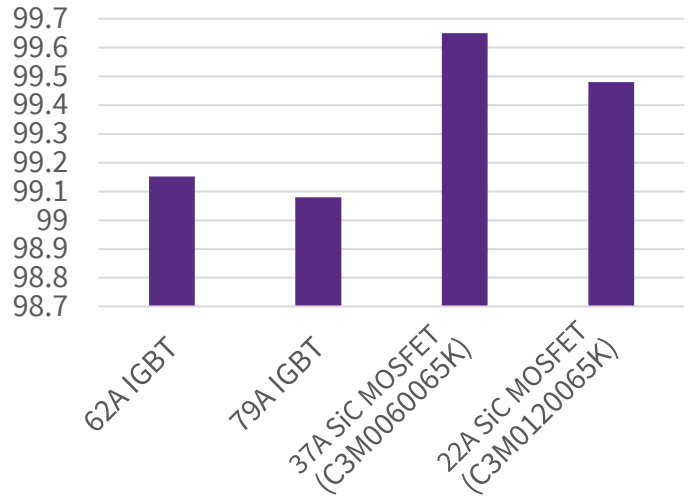
4 kW 16 kHz @ 50% load
*High speed soft switch IGBTs used for evaluation

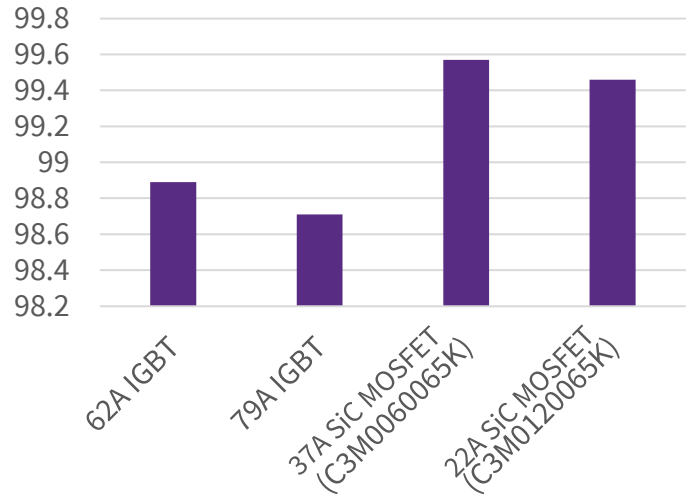
Total losses (W)*





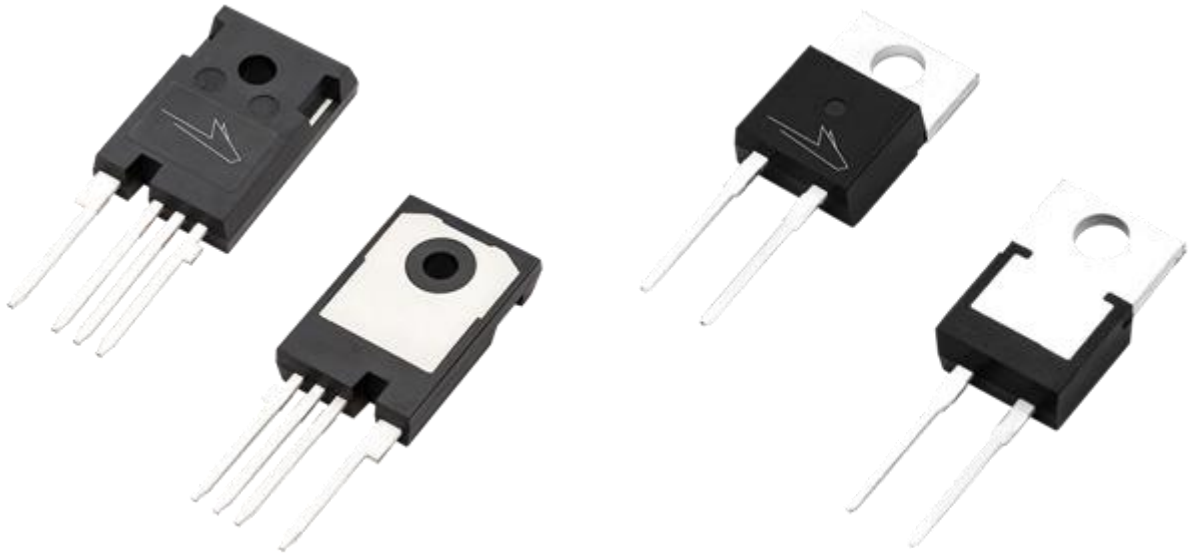
Total efficiency (%)*





BUILD EFFICIENT LV DRIVES WITH 650 V SIC MOSFETS & DIODES

Reach high efficiency standards when you implement a full silicon carbide solution



Achieve up to **1.6% overall increase in efficiency**

When compared to Silicon IGBTs, Wolfspeed's 650 V Silicon Carbide MOFETS provide:

- Low On Resistance and its change over temperature
- Considerably lower switching losses (compared to IGBTs)
- Better thermal performance due to better thermal conductivity

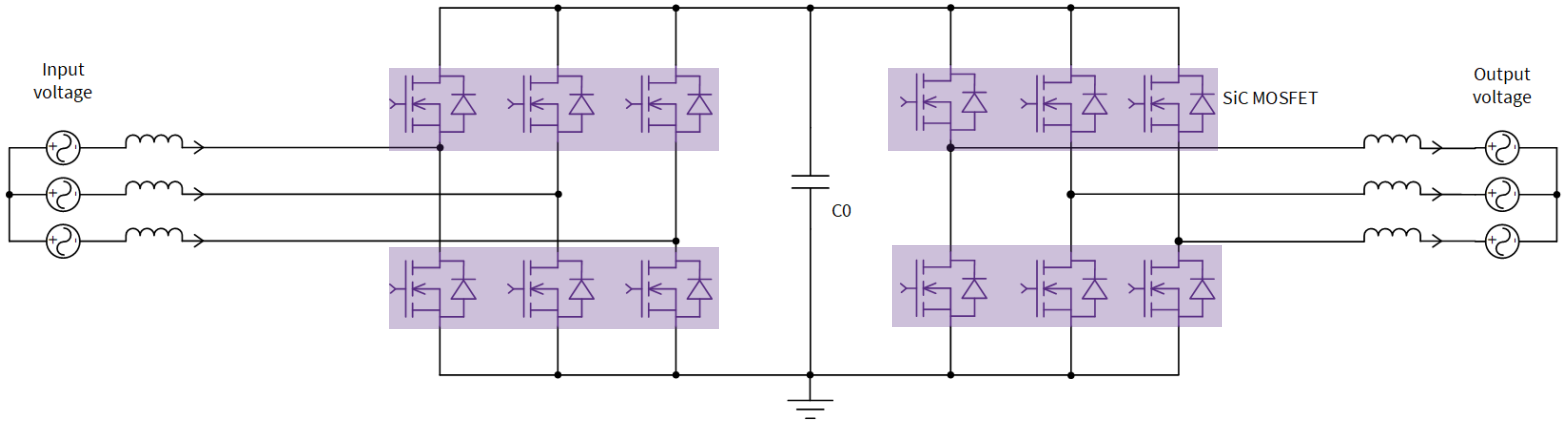
When compared to Silicon diodes, Wolfspeed's 650 V Silicon Carbide diodes provide:

- Magnitudes lower reverse recovery loss and forward recovery voltage
- Temperature-independent switching behavior
- Soft switching aiding in lower EMI
- Better thermal performance

THREE-PHASE MOTOR DRIVE SYSTEM (11 KW)

ACHIEVING GREATER EFFICIENCY WITH SIC IN A 3-PHASE SUPPLY, 11 KW SYSTEM, 8 KHZ INVERTER FREQUENCY

11 kW, 8 kHz motor inverter simulation @ 100% load

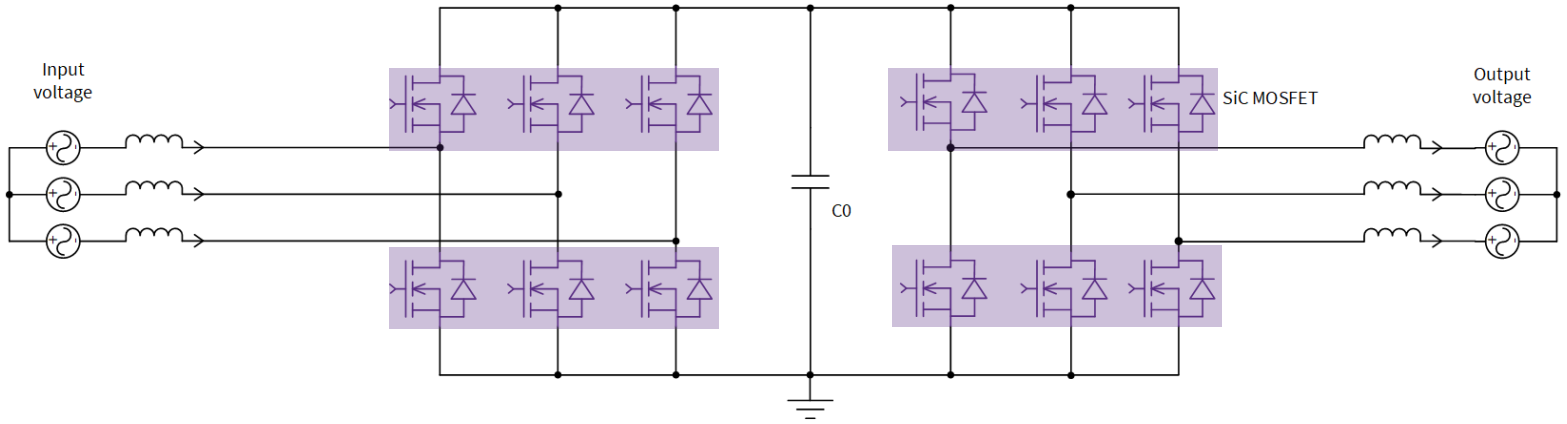


	Upgrading the PFC	Upgrading the inverter	= Full silicon carbide solution
HOW	• Replace IGBT based AFE with silicon carbide MOSFET • C3M0075120K (30A rated) benchmarked against 75A/1200V IGBT • Fsw (SiC): 60kHz vs Fsw (IGBT): 20kHz	• Replace IGBTs with silicon carbide MOSFETs • C3M0075120K (30A rated) benchmarked against 75A/1200V IGBT	• Simple drop-in replacements
WHY	• Most popular upgrade to implement • 0.9 % efficiency improvement over silicon IGBT AFE • Losses reduced by 99 W	• **0.3% efficiency improvement** over IGBTs	• Up to **132 W* reduction in losses** • **1.2%* overall efficiency improvement** • **52% reduction in losses system-wide**

* Higher ambient temperatures would lead to further differences.

ACHIEVING GREATER EFFICIENCY WITH SIC IN A 3-PHASE SUPPLY, 11 KW SYSTEM, 16 KHZ INVERTER FREQUENCY

11 kW, 8 kHz motor inverter simulation @ 100% load



	Upgrading the PFC	Upgrading the inverter	= Full silicon carbide solution
HOW	• Replace IGBT based AFE with silicon carbide MOSFET • C3M0075120K (30A rated) benchmarked against 75A/1200V IGBT • Fsw (SiC): 60kHz vs Fsw (IGBT): 20kHz	• Replace IGBTs with silicon carbide MOSFETs • C3M0075120K (30A rated) benchmarked against 75A/1200V IGBT	• Simple drop-in replacements
WHY	• Most popular upgrade to implement • 0.9 % efficiency improvement over silicon IGBT AFE • Losses reduced by 99 W	• **0.7% efficiency improvement** over IGBTs	• Up to **176 W* reduction in losses** • **1.6%* overall efficiency improvement** • **Achieves IE4 IF original system was IE3** • **60% reduction in losses system-wide**

* Higher ambient temperatures would lead to further differences.

11 KW SILICON CARBIDE SOLUTION ENERGY SAVINGS

8 kHz Inverter Switching Frequency
Payback rate scenario:

- You replace competitive 1200 V silicon power devices in your unit with Wolfspeed 1200 V silicon carbide devices. This replacement is more expensive up front.
- You use your unit for 15 years, saving a total of **5100 kWh / 1890 Euro**

Total cost of ownership for moving to silicon carbide:

Rated Power	11,000 W
Expected Efficiency Improvement	1.2%
Power Savings	132W
Annual Operation	8200 Hours
Load Conditions Cumulated	Multiple
kWh/year usage	28,323 kWh
kWh/year savings	340 kWh
Electricity cost*	0.37 Euro/kWh
Annual Operating Cost*	10,479 Euro
Annual Savings*	126 Euros

16 kHz Inverter Switching Frequency
Payback rate scenario:

- You replace competitive 1200 V silicon power devices in your unit with Wolfspeed 1200 V silicon carbide devices. This replacement is more expensive up front.
- You use your unit for 15 years, saving a total of **6800 kWh / 2520 Euro**

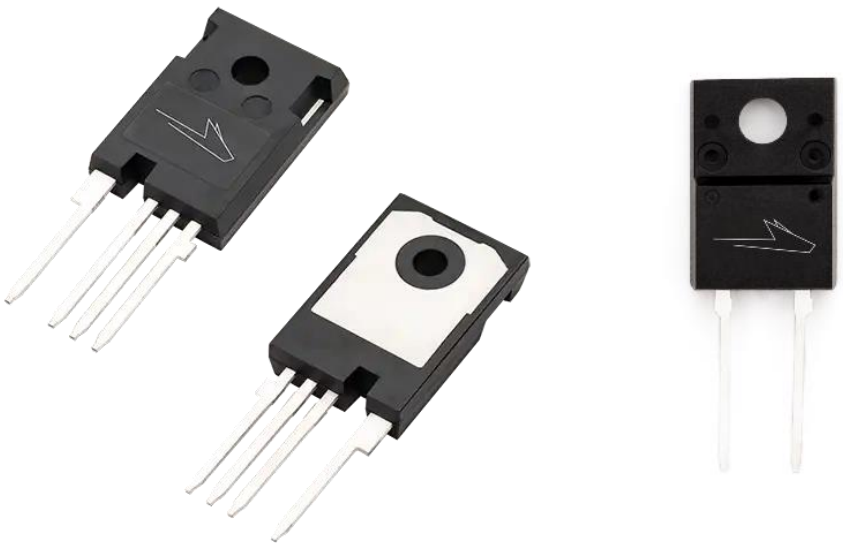
Total cost of ownership for moving to silicon carbide:

Rated Power	11,000 W
Expected Efficiency Improvement	1.6%
Power Savings	176W
Annual Operation	8200 Hours
Load Conditions Cumulated	Multiple
kWh/year usage	28,323 kWh
kWh/year savings	453kWh
Electricity cost*	0.37 Euro/kWh
Annual Operating Cost*	10,479 Euro
Annual Savings*	168 Euro

*Electricity cost = Germany's rate as of September 2023. **Annual energy savings would vary based on region.**

UP TO 60% LESS LOSSES WITH 1200 V SIC MOSFET & SCHOTTKY DIODE

Achieve stringent efficiency standards with ease with Wolfspeed's 1200 V MOSFETs and Schottky diodes



Achieve up to **1.6% overall increase in efficiency**

When compared to Silicon IGBTs, Wolfspeed's 1200 V Silicon Carbide MOFETS provide:

- Low On Resistance and its change over temperature
- Considerably lower switching losses (compared to IGBTs)
- Better thermal performance due to better thermal conductivity

When compared to Silicon diodes, Wolfspeed's 1200 V Silicon Carbide diodes provide:

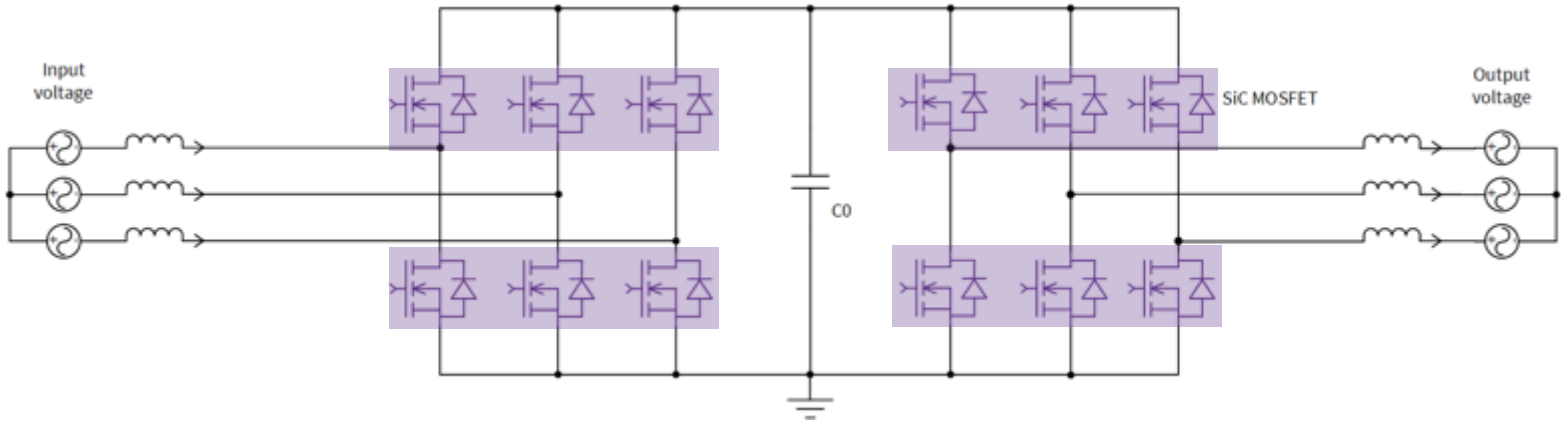
- Magnitudes lower reverse recovery loss and forward recovery voltage
- Temperature-independent switching behavior
- Soft switching aiding in lower EMI
- Better thermal performance
- A package with improved creepage and clearance to withstand hash environments
- HV-H3TRB Rugged

THREE-PHASE MOTOR DRIVE SYSTEM (25 KW)

50% LESS LOSSES IN A 3-PHASE, 25 KW SYSTEM

8 kHz inverter frequency (same heat-sink: 0.8l)

25 kW, 8 kHz motor inverter simulation @ 100% load

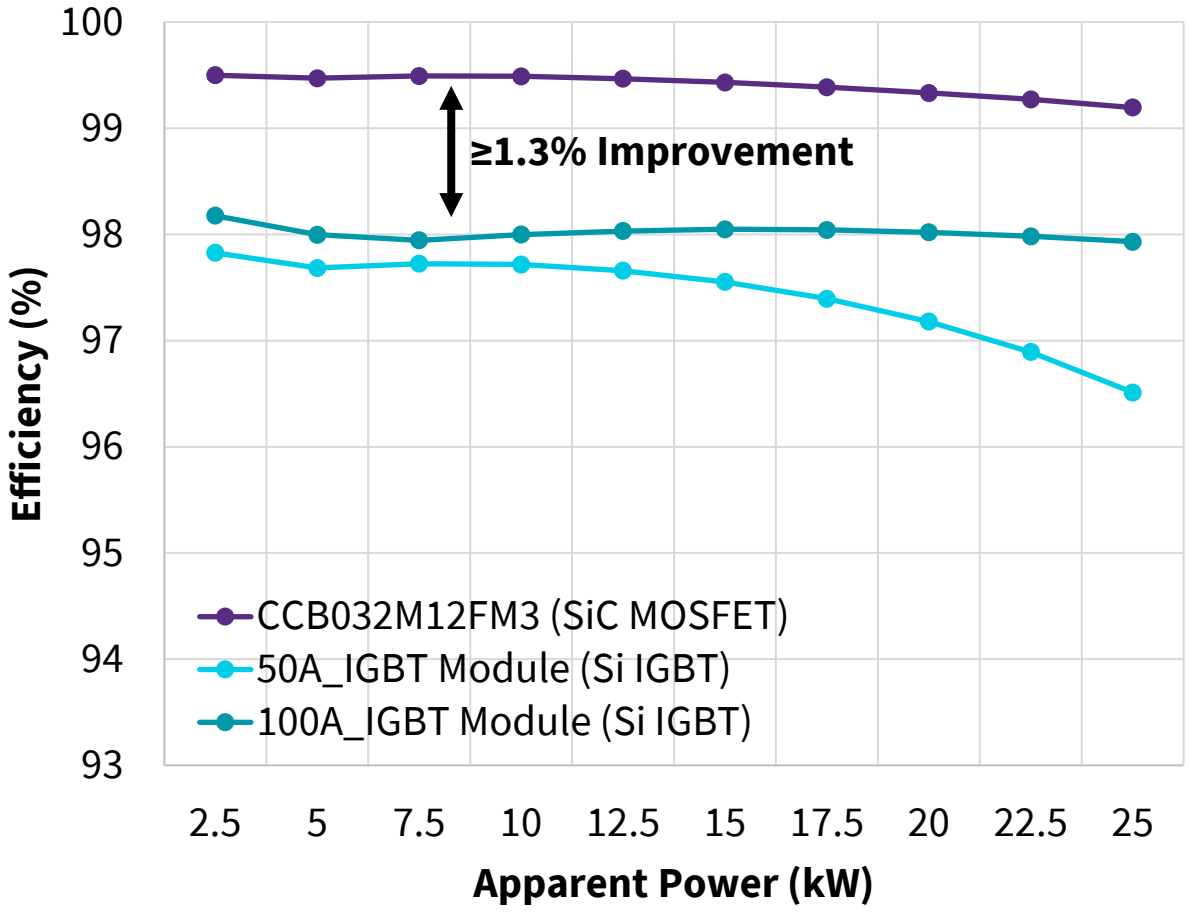


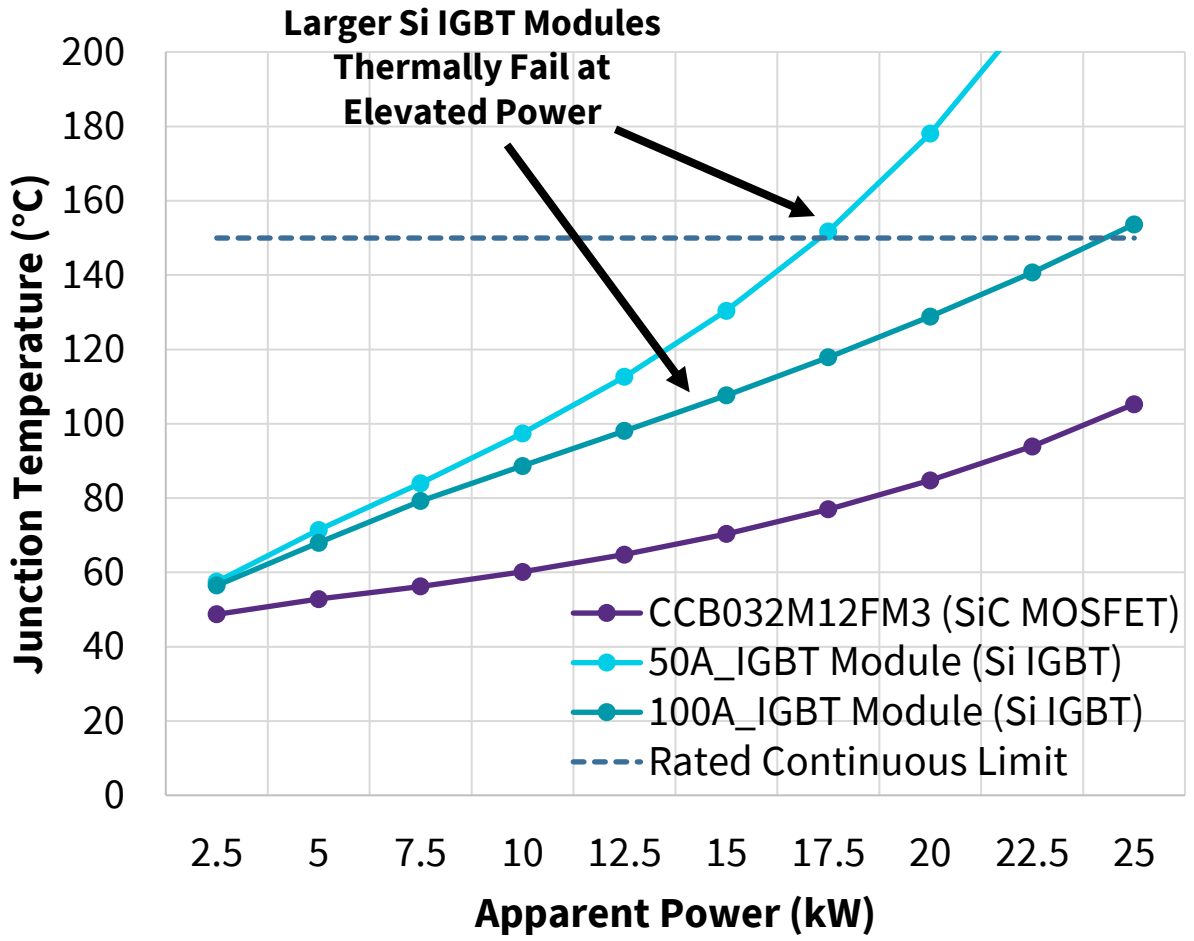
	Upgrading the PFC	Upgrading the inverter	= Full silicon carbide solution
HOW	• Replace IGBT based AFE with silicon carbide MOSFET	• Replace IGBTs with silicon carbide MOSFETs • **Same Heat Sink** (0.8L / 0.9914°C/W)	• Simple drop-in replacements
WHY	• Most popular upgrade to implement • 1.3 % efficiency improvement over silicon boost PFC • Losses reduced by 325 W	• **1.3% efficiency improvement** over IGBTs • Losses reduced by 325 W	• Up to **650 W* reduction in losses** • **2.6%* overall efficiency improvement** • **50% reduction in losses system-wide** • **Achieves IE4 efficiency**

* Higher ambient temperatures would lead to further differences.

SILICON CARBIDE MOSFETS ENABLE SMALLER & COOLER SYSTEMS

SAME HEAT-SINK FOR SILICON AND SIC INVERTER

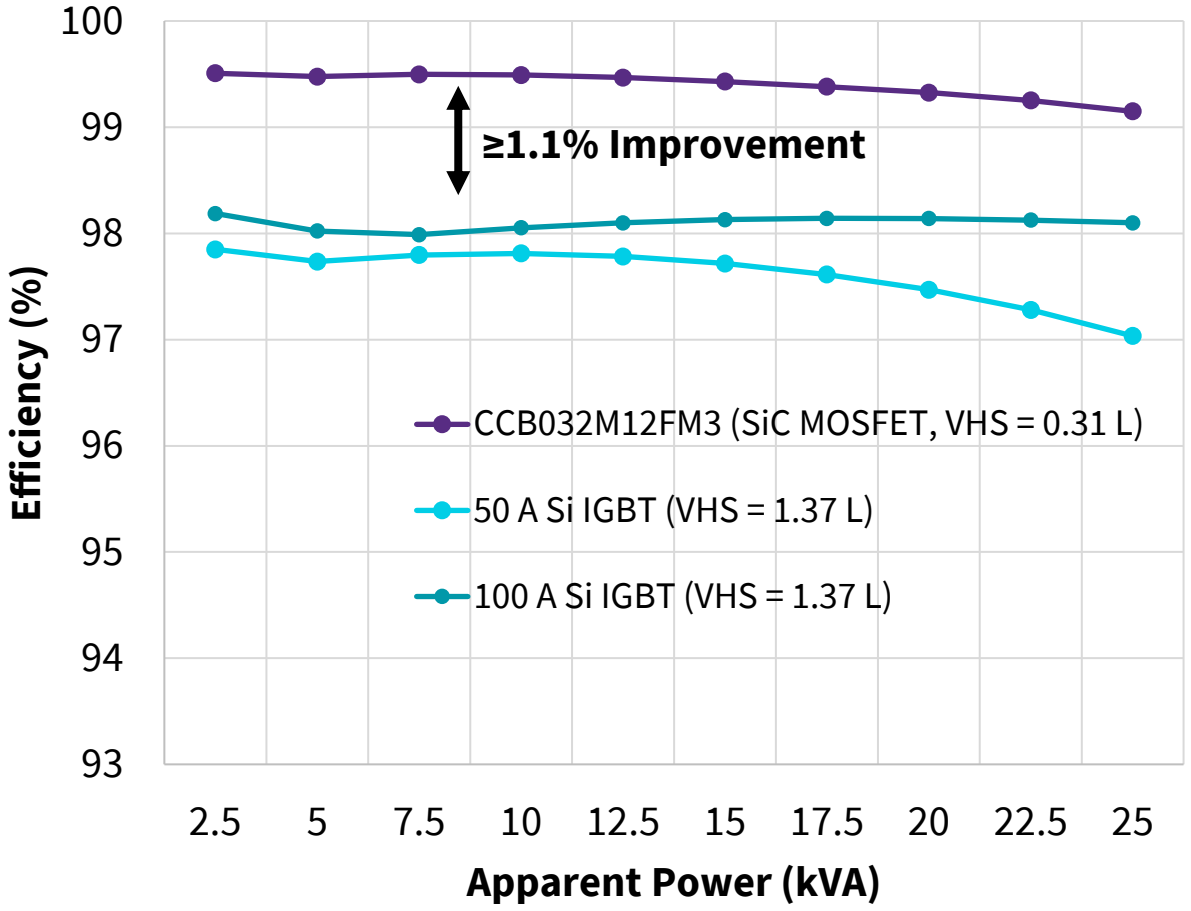


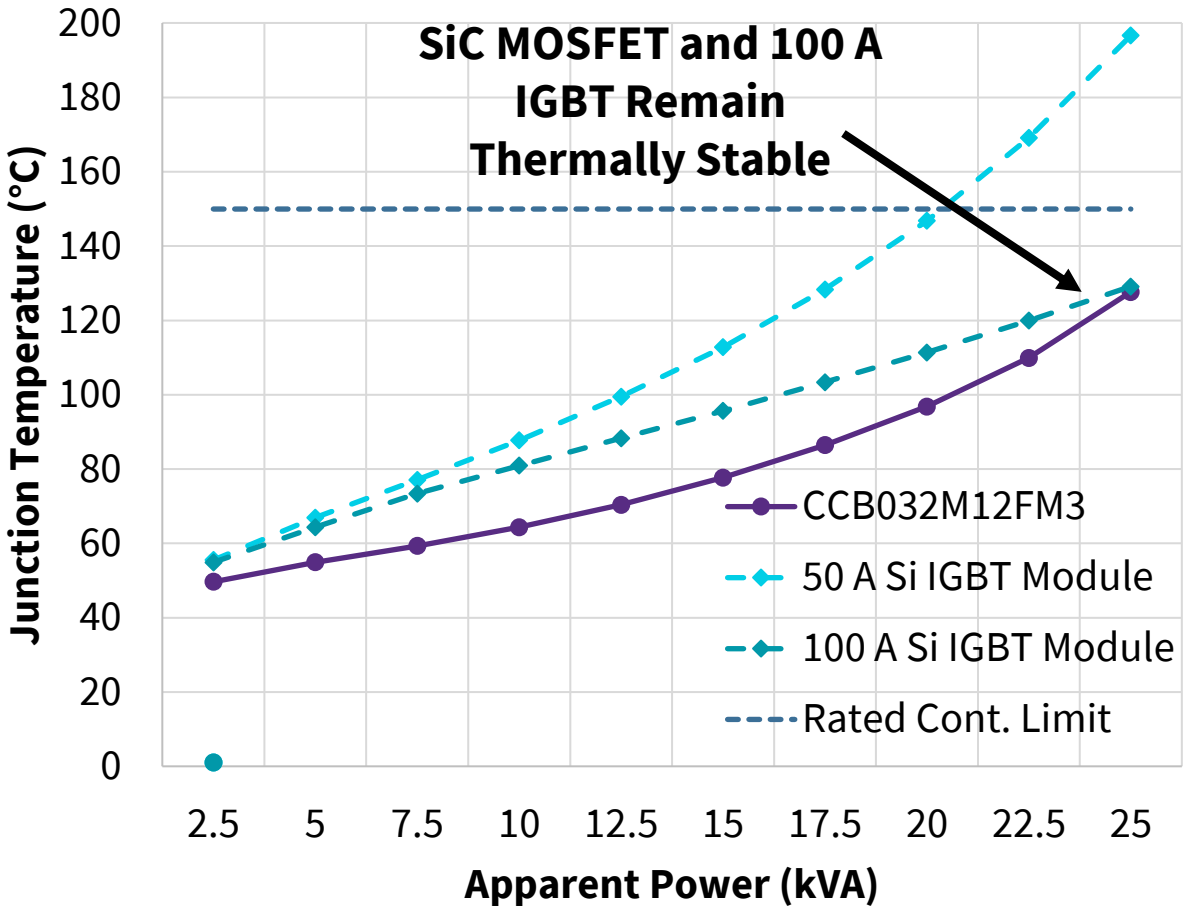


25 KW INVERTER, FSW = 8 KHZ, SAME HEAT SINK : 0.80L (0.99 °C/W)
DIMENSIONS: WS FM3 ➔ 34MM X 63MM, IGBT MODULE➔ 57MM X 63MM

SIC REMAINS COOLER THAN SI EVEN WITH SMALLER HEAT SINKS

77% SMALLER HEAT-SINK (VOLUMETRICALLY) FOR SIC INVERTER



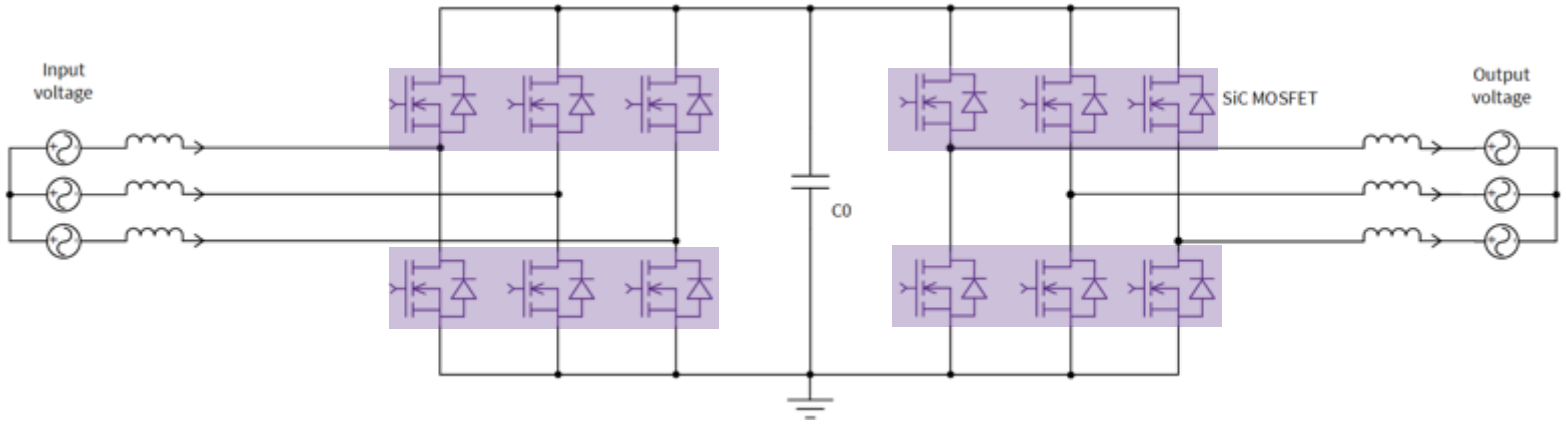


25 KW INVERTER, FSW = 8 KHZ, 77% SMALLER HEAT-SINK FOR SIC INVERTER: 0.31L (1.6°C/W) VS 1.37L (0.73°C/W)
DIMENSIONS: WS FM3 ➔ 34MM X 63MM, IGBT MODULE➔ 57MM X 63MM

SILICON CARBIDE ENABLES COMPACT DRIVES

3-phase supply, 25 kW system, 8 kHz inverter frequency (reduced sic inverter heat-sink)

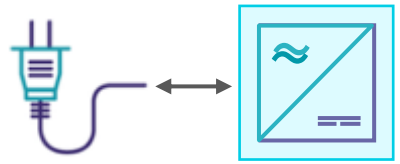
25 kW, 8 kHz motor inverter simulation @ 100% load



	Upgrading the PFC	Upgrading the inverter	= Full Silicon Carbide solution
HOW	• Replace IGBT based AFE with Silicon Carbide MOSFET	• Replace IGBTs with Silicon Carbide MOSFETs • **Reduced SiC Heat Sink** by 77%	• Simple drop-in replacements
WHY	• Most popular upgrade to implement • 1.3 % efficiency improvement over silicon boost PFC • Losses reduced by 325 W	• **1.1% efficiency improvement** over IGBTs • Losses reduced by 275 W • **Similar junction temperature as IGBT with 77% bigger heat sink**	• Up to **600 W* reduction in losses** • **2.4%* overall efficiency improvement** • **Achieves IE4 efficiency**

* Higher ambient temperatures would lead to further differences.

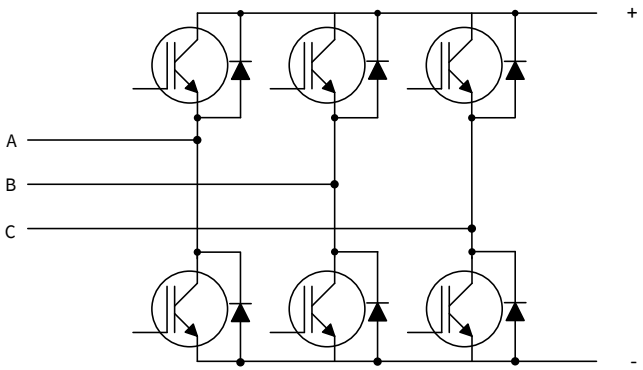
UP TO 50% LESS LOSSES FOR THE SAME COSTS WITH SILICON CARBIDE

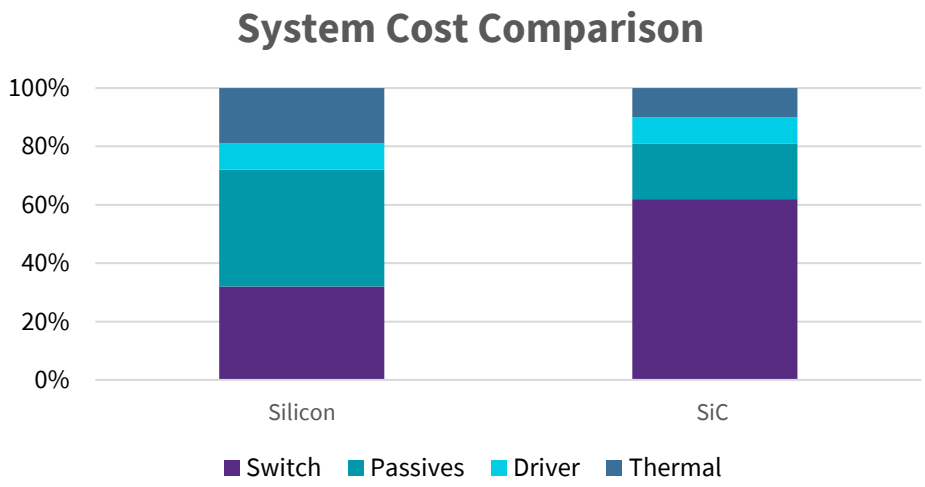


AC Source AC-DC

Silicon IGBT Design

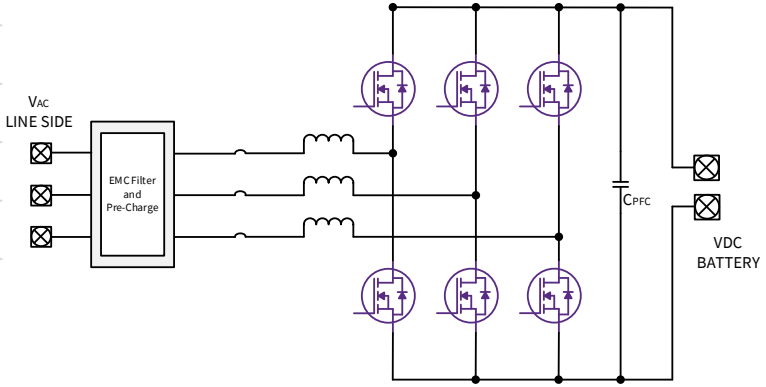
- IGBT 20 kHz
- Power density 3.5 kW/L
- Peak efficiency 97.2%





Wolfspeed Full SiC Design

- SiC MOSFET 45 kHz
- Power density of >4.6 kW/L
- Peak efficiencies of 98.5%



25 KW SILICON CARBIDE SOLUTION ENERGY SAVINGS (8 KHZ INVERTER)

Payback rate scenario:

- You replace competitive 1200 V silicon power devices in your unit with Wolfspeed 1200 V silicon carbide devices. This replacement is more expensive up front.

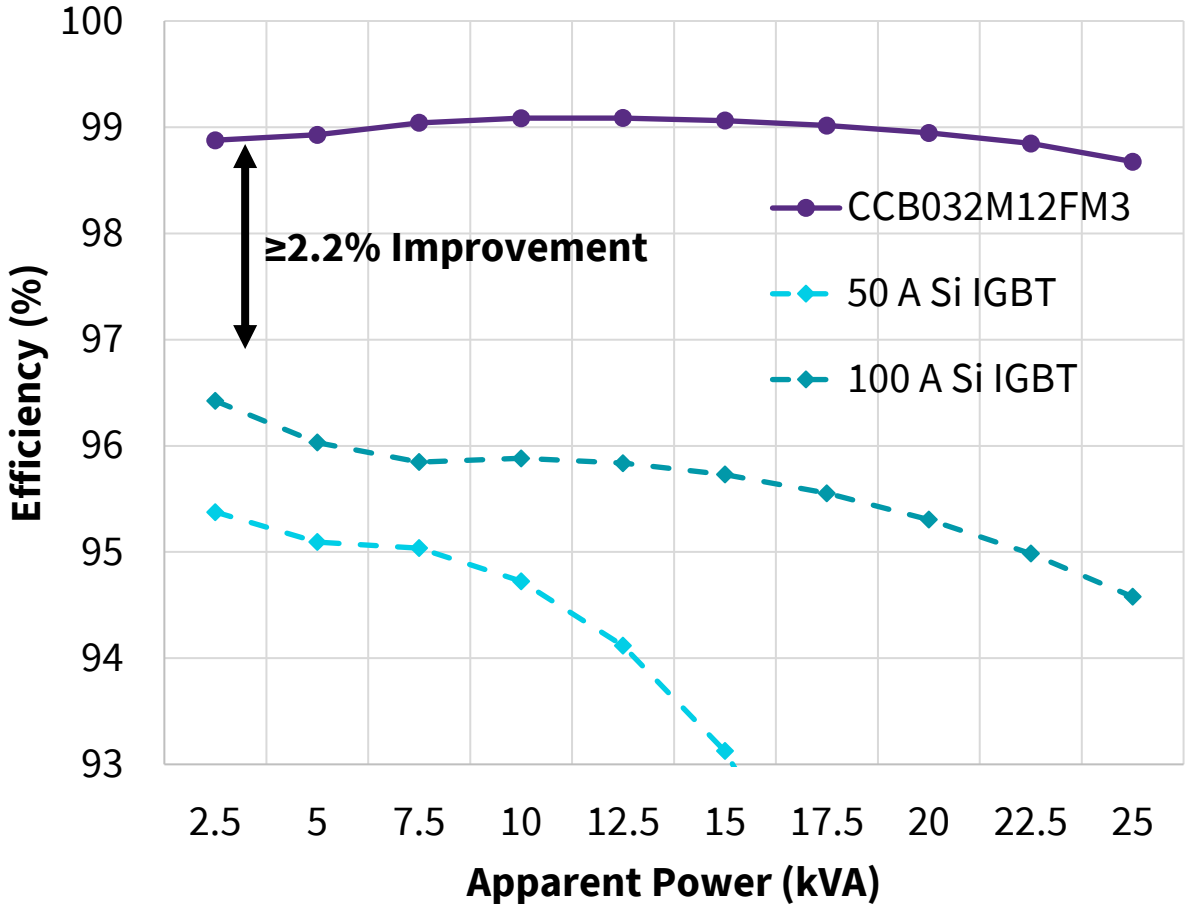
- You use your unit for 15 years, saving a total of **23,173 kWh / 8,574 Euros**

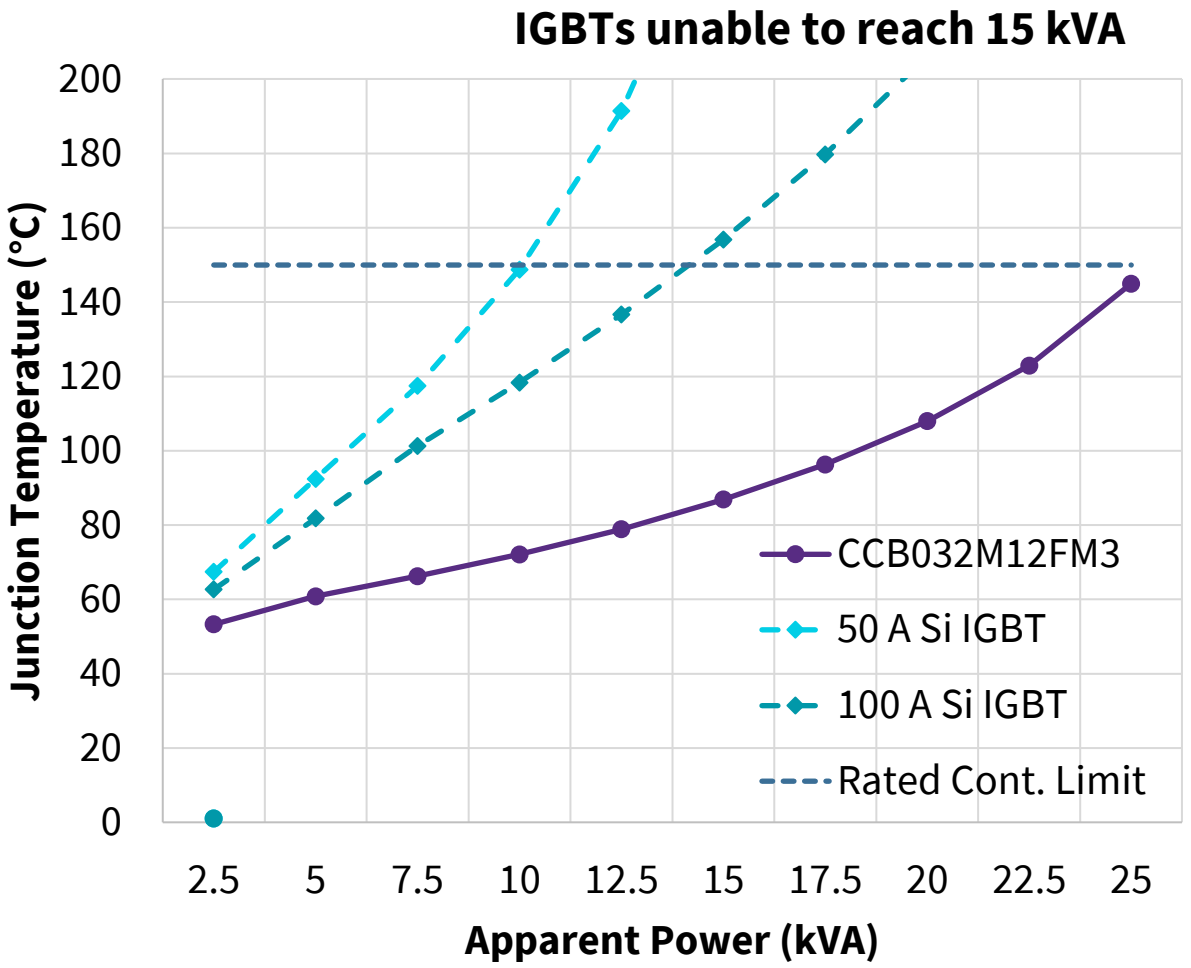
Total cost of ownership for moving to silicon carbide:

Rated Power	25,000 W
Expected Efficiency Improvement	**2.4%**
Power Savings	605 W
Annual Operation	8200 Hours
Average Load Condition	Multiple
kWh/year usage	64,370 kWh
kWh/year savings	1545 kWh
Electricity cost*	0.37 Euro/kWh
Annual Operating Cost*	10,479 Euro
Annual Savings*	572 Euro

*Electricity cost = Germany's rate as of June 2023.
Annual energy savings would vary based on region.

SIC ENABLES SUPERIOR PERFORMANCE EVEN AT HIGHER SWITCHING FREQUENCIES

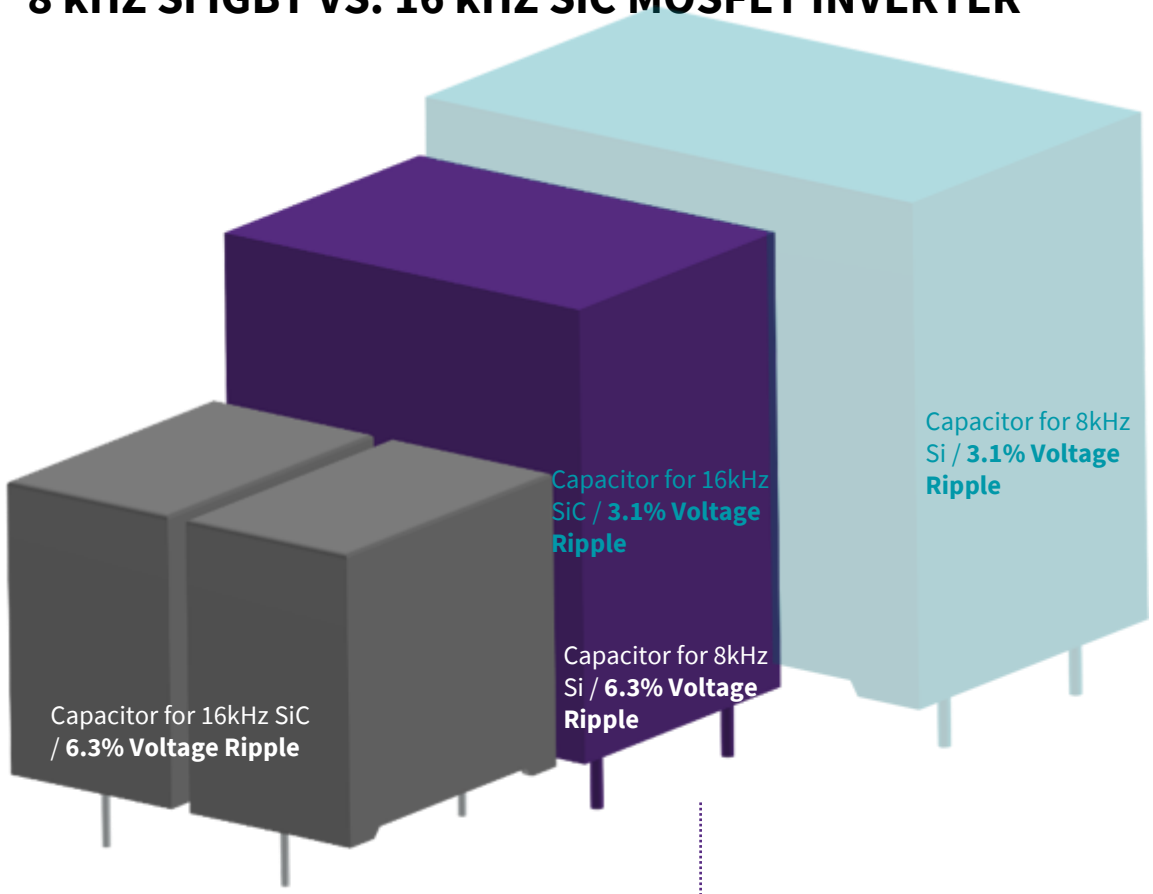




25 KW INVERTER, FSW = 16 KHZ, 41% REDUCED SIC MOSFET HEAT SINK : 0.80L (0.99 °C/W) VS 1.37L (0.73 °C/W)

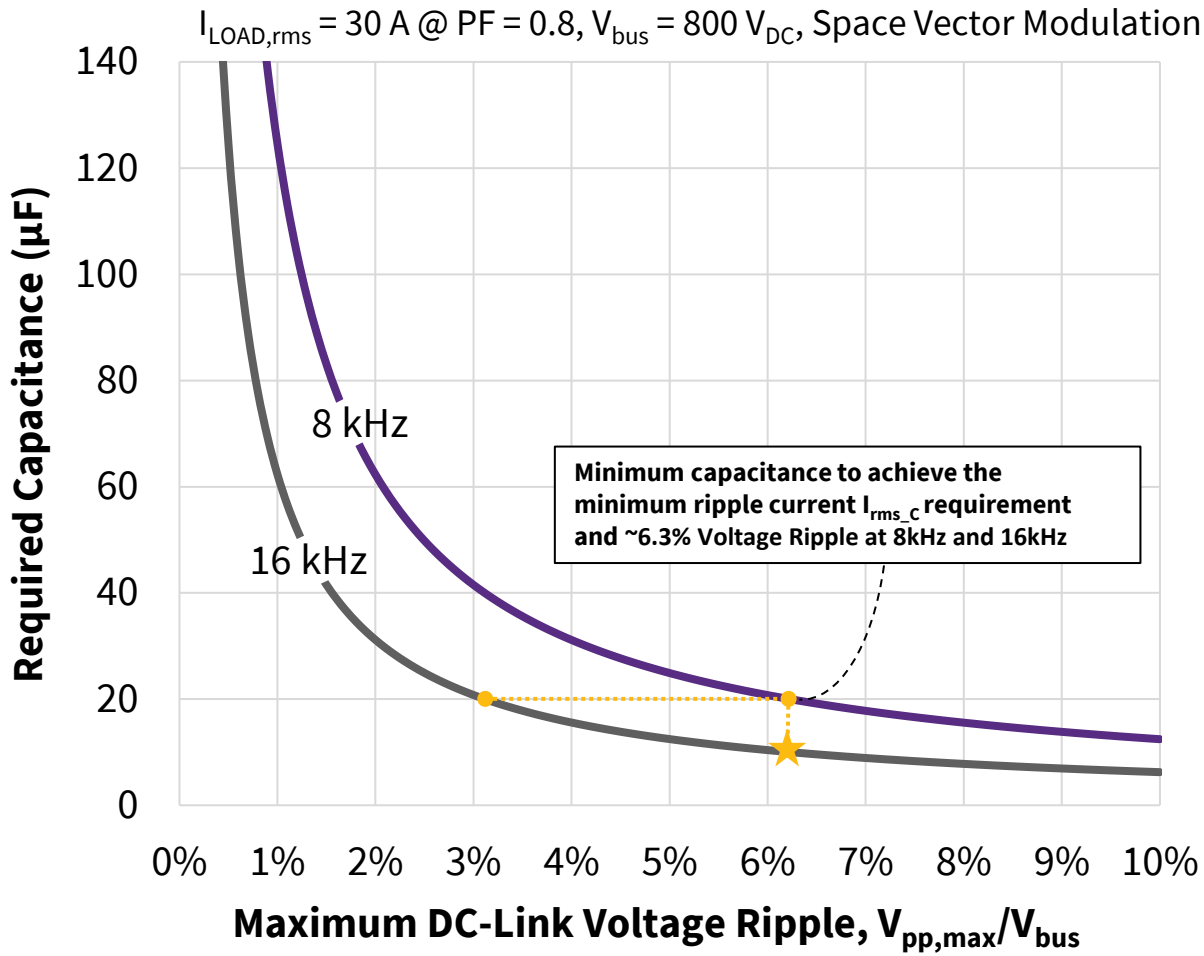
25 KW INVERTER OUTPUT DC-LINK CAPACITOR SIZING

8 kHZ Si IGBT VS. 16 kHZ SiC MOSFET INVERTER



16 kHz SiC Inverter
2× 5 µF
Two to meet I_{rms_C} requirement
34.8 cm³

8 kHz Si IGBT Inverter
1 × 20 µF
One to meet Irms_C requirement
56.7 cm³

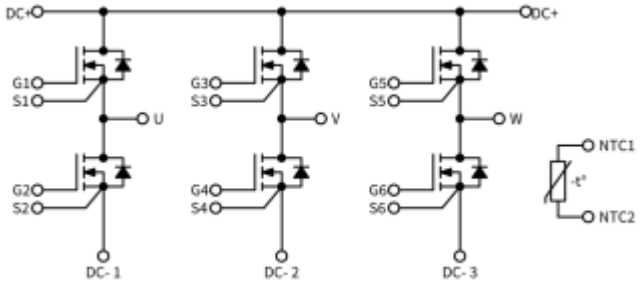


★ 2× decrease in required capacitance and 39% less capacitor volume for same 6.3% voltage ripple

WOLFPACK™ POWER MODULE – ACHIEVE GREATER EFFICIENCY WITH SIC

Wolfspeed WolfPACK™ Six-Pack configuration allows for:

- One part to cover the inverter allowing for more compact motor drive boards
- One part to cover the 3-phase PFC (aka active filter) required in some applications
- Simpler, cost-effective heat sinking and system assembly
- **Up to 600 W* reduction in losses**
- **2.6%* overall increased efficiency**



WOLFSPEED SILICON CARBIDE POWER CONTINUUM

Discrete advantages:

- Maximize design flexibility
- Minimize total BOM cost

1 kW

2.2 kW

3.6 kW

6.6kW

30 kW +

WolfPACK™ Baseplate less Small Modules

Discrete Solutions

Wolfpack FM3

62mm X 33.8mm

Module advantages:

- Maximize power density
- Simplify layout and assembly
- Minimize assembly costs & component counts
- Industry standard & silicon carbide optimized footprints
- The industry's widest full silicon carbide module portfolio

REFERENCE DESIGNS OPTIMIZED FOR INDUSTRIAL MOTORS

3.6 KW BRIDGELESS TOTEM-POLE PFC (CRD-03600AD065N-L)

22 kW BI-DIRECTIONAL AFE CONVERTER (CRD-22AD12N)

250, 300, 600 KW XM3 INVERTER (CRDXX0DA12E-XM3)

7.5 kW FM3 THREE-PHASE MOTOR DRIVE (CRD-07500AA12N-FMC)

25 KW THREE-PHASE FM3 INVERTER (CRD-25DA12N-FMC)

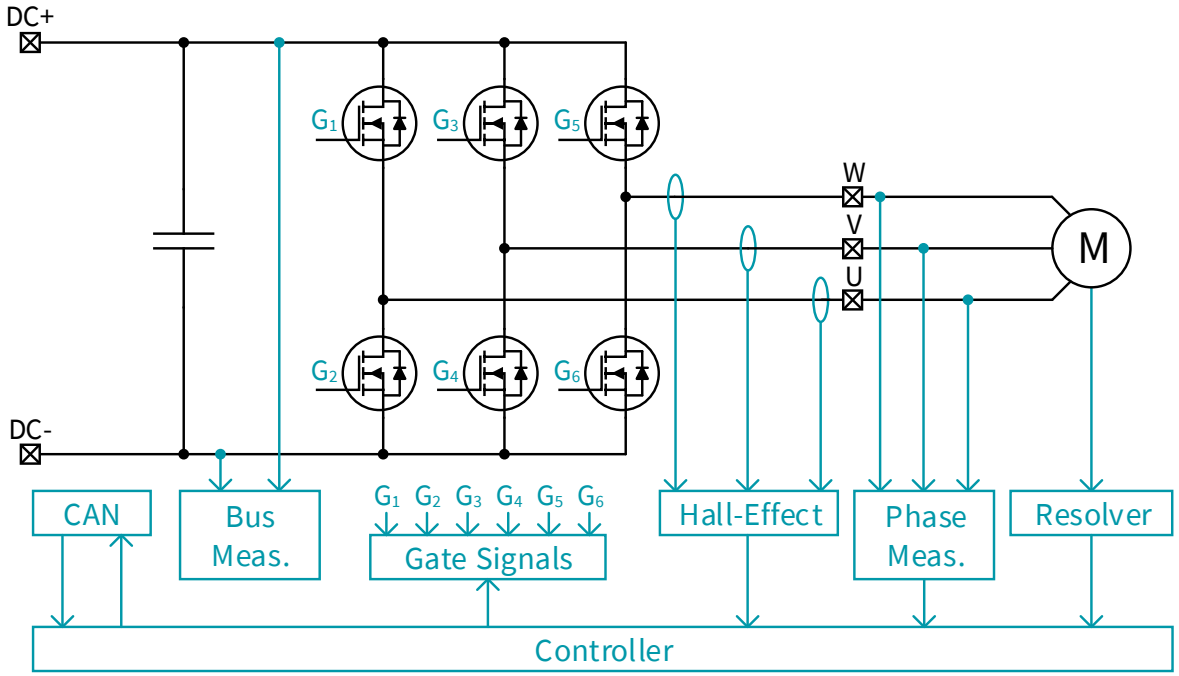
7.5 ~20 kW THREE-PHASE INVERTER (CRD-11DA12N-K)

NEW - 25 KW 3-PHASE FM3 INVERTER

Features a single WolfPACK™ FM3 12 mΩ 6-pack power module with pre-applied TIM

CRD-25DA12N-FMC

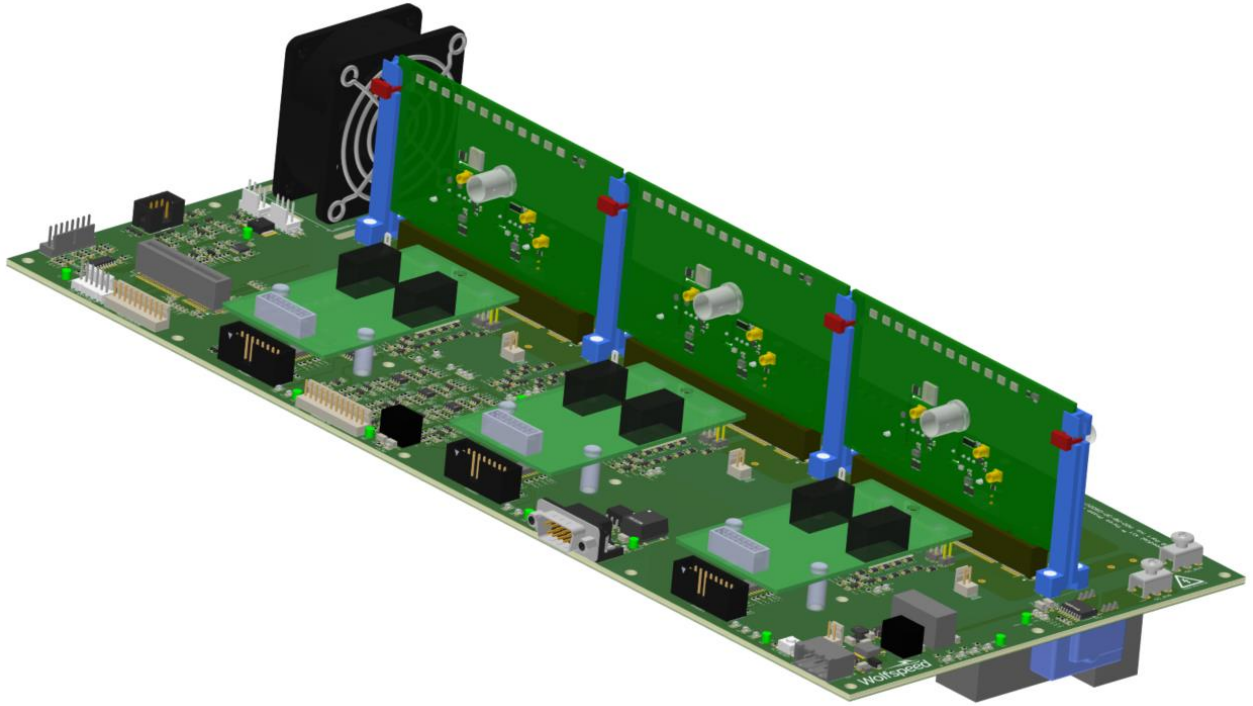
- High efficiency despite an optimized heat-sink for SiC
- High efficiency across a range of switching frequencies
- Can be used in the inverter state as well as in AFE to realize a bidirectional system
- Simple 2-level, 3-phase topology
- Integrated feedback sensors
- Real-time CAN communication
- General-purpose controller
- Customizable firmware
- Forced-air-cooled heat sink
- Baseplate-less module



COMING SOON – SPEEDVAL KIT™ 3-PHASE MODULAR EVALUATION PLATFORM

Rapidly evaluate silicon carbide for industrial motor drives

- A flexible testing solution designed to adapt seamlessly across a range of 5-30 kW motor drive applications
- Testing from 3-5 kilowatt 230 V motors up through 20-30 kW 460 V motors for a wide variety of applications including servo drives, heat pumps and air conditioning, and industrial motors
- Wide range of power daughter cards, control cards and partner gate driver cards

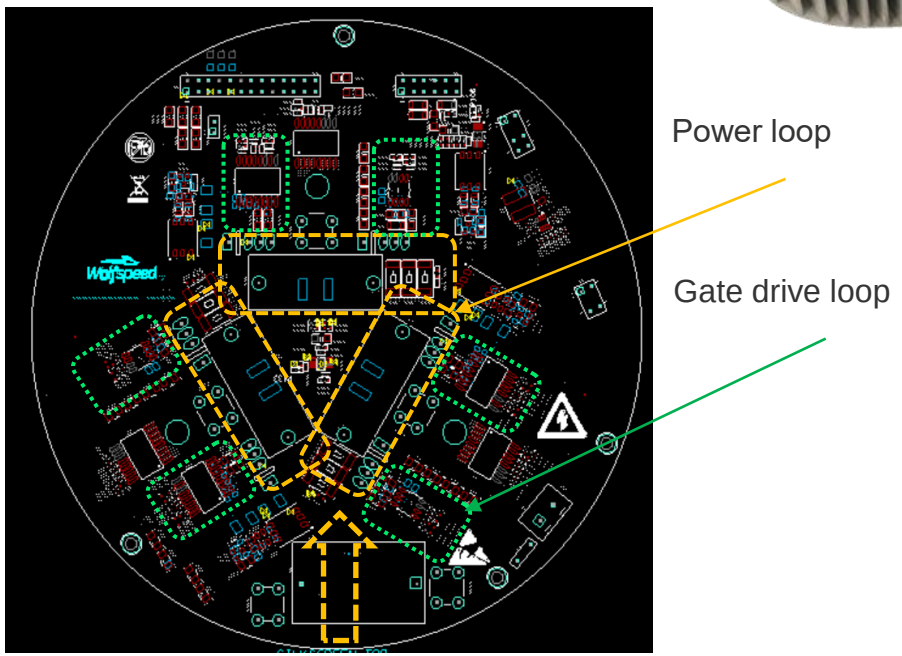


NEW - 11 KW 3-PHASE INTEGRATED MOTOR DRIVE

Features 1200 V C3M silicon carbide MOSFETs in a design characterized for thermals, inductance and circuit operation

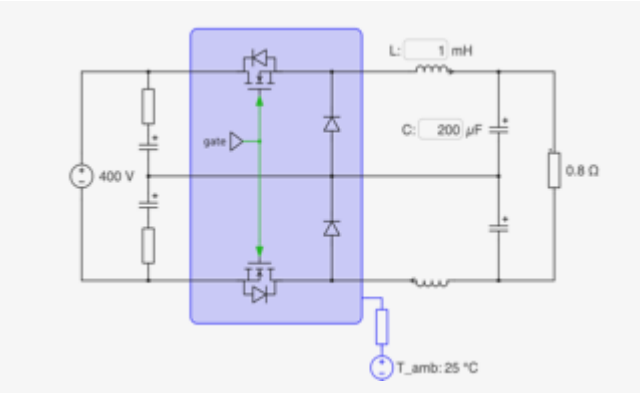
CRD-11DA12N-K

- Input voltage: 550 V– 850 VDC
- Nominal RMS Output Voltage: 380 VL-L
- Output power: 20 kW
- Short circuit protection
- Simple 2-level, 3-phase topology
- Bus derived auxiliary power supply
- Open loop mode for static testing
- Sensorless FOC for PMSM
- Switching frequency: 16/32 kHz
- Efficiency: >98.5% at dv/dt < 15 V/ns
- Forced-air-cooled heat sink



WOLFSPEED SUPPORT AND POWER DESIGN TOOLS

Industry-leading support and partnerships enable faster and easier design with Wolfspeed silicon carbide



Design & Simulation Tools

- ✓ SpeedFit™ online design simulator compares topologies, devices, thermals and efficiency
- ✓ LTSpice and PLECS device models
- ✓ Footprints & 3D models available via Ultra Librarian & Octopart

Power Application Forum

- ✓ Quickly find answers to common problems
- ✓ Staffed by Wolfspeed silicon carbide power experts in our applications teams
- ✓ Responses in ~24 hours

Development Resources

- ✓ Evaluate products in-circuit with SpeedVal Kit™
- ✓ Explore power modules with our evaluation platforms
- ✓ Utilize our purpose-built reference designs to jump-start your design
- ✓ Consult our full suite of app notes

VERMONT REP

https://vermont-rep.com/

- Sao Paulo – Headquarter
- Campinas/RS - Branch
- Porto Alegre/RS - Branch
- Joinville/SC - Branch

We harness the power of silicon carbide to change the world for the better

Wolfspeed® Unleashing the Power of Possibilities™

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