A high-power inverter based on hybrid switch SiC+IGBT technology

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Agenda

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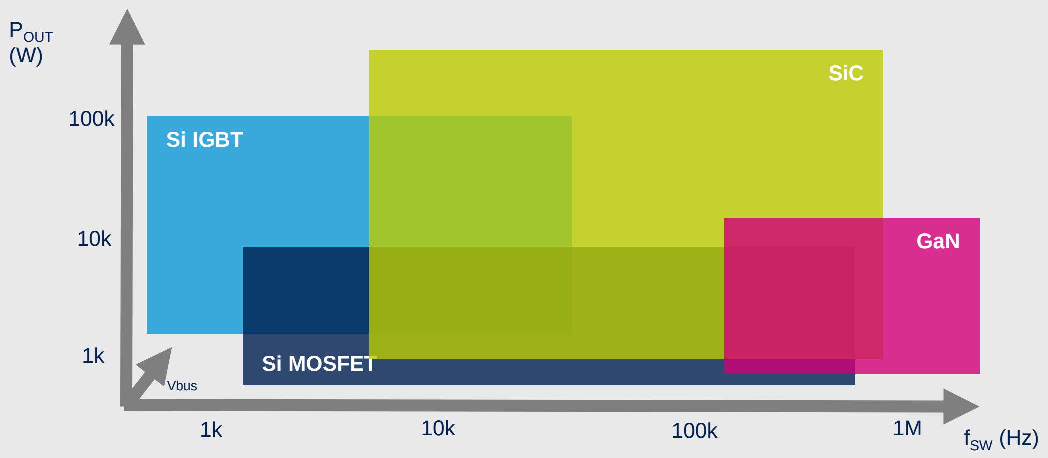
Efficiency increase in high power systems

Power systems using SiC technology

Power technology positioning



- **Efficiency increase**: CO2 emission reduction
- **Power density**: smaller and lighter power unit form factor
- **Cost reduction**: system level cost reduction or lower TCO

High-end industrial

- Solar inverter
- Energy dtorage
- Power supply
- Charging station
- Welding
- Motor drives

Car electrification

- Traction inverter
- OBC
- DC-DC converter

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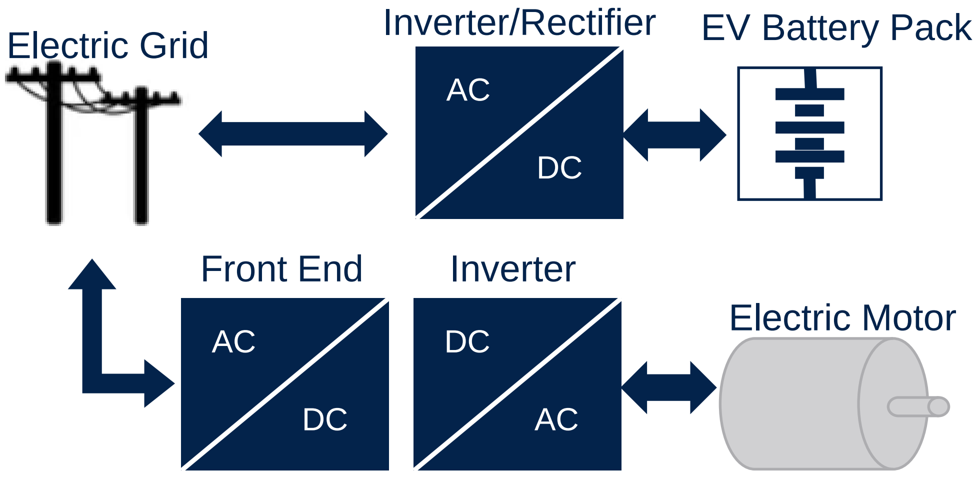
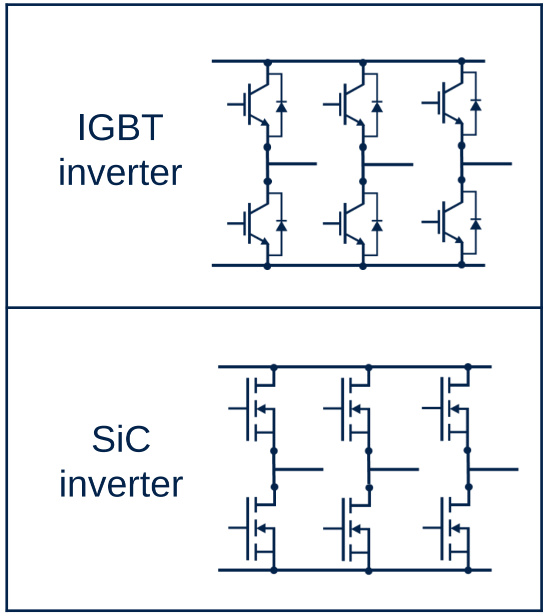
Power technology options for inverter

System level cost - TCO reduction vs efficiency increase





Low-cost inverter

Higher system cost

High-cost inverter

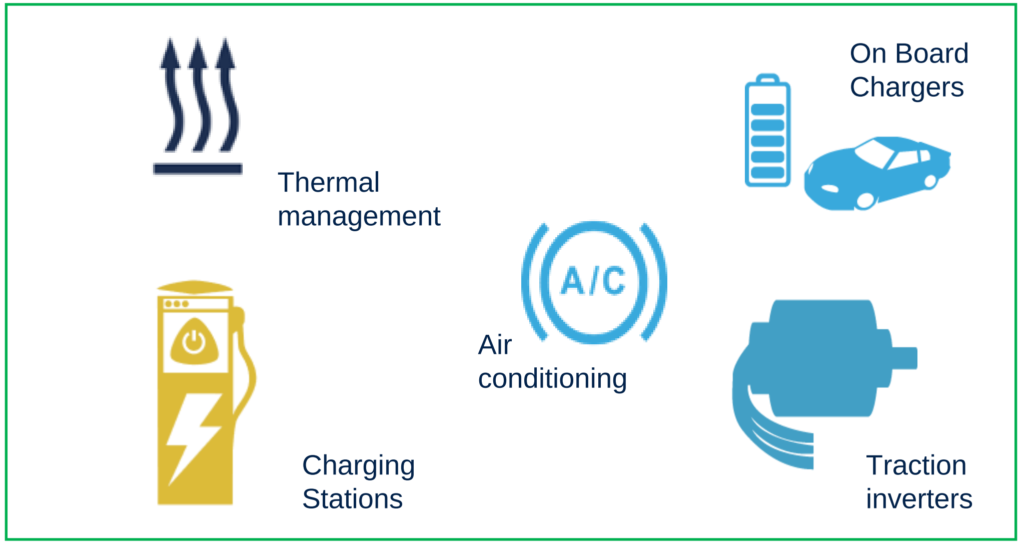
Lower system cost

Main high-power applications adopting SiC

- **Solar inverter**
- **Energy storage**
- **Charging station**
- **Motor drives**
- **Traction inverter**

Trench field stop IGBTs

Solutions for every application in electric vehicles



HIGH SWITCHING FREQUENCY CONVERSION

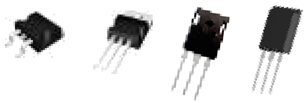
HYBRID Si+SiC

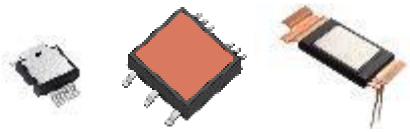
650V - HB series	600V- V series
STGH30H65DFB-2AG **STGSH80HB65DAG**	**STGWA60V60DWFAG**

MOTOR CONTROL

650V - M series	750V - MH series	1200V - MS series
STGST200G65DFAG **STGSB200M65DF2AG**	**STG320MH75FD11AG** ES AV, MP Q1'24	**GWA40MS120F4DAG** **GWA40MS120F4AG**

Dice 

Discrete packages 

Top Side cooling 

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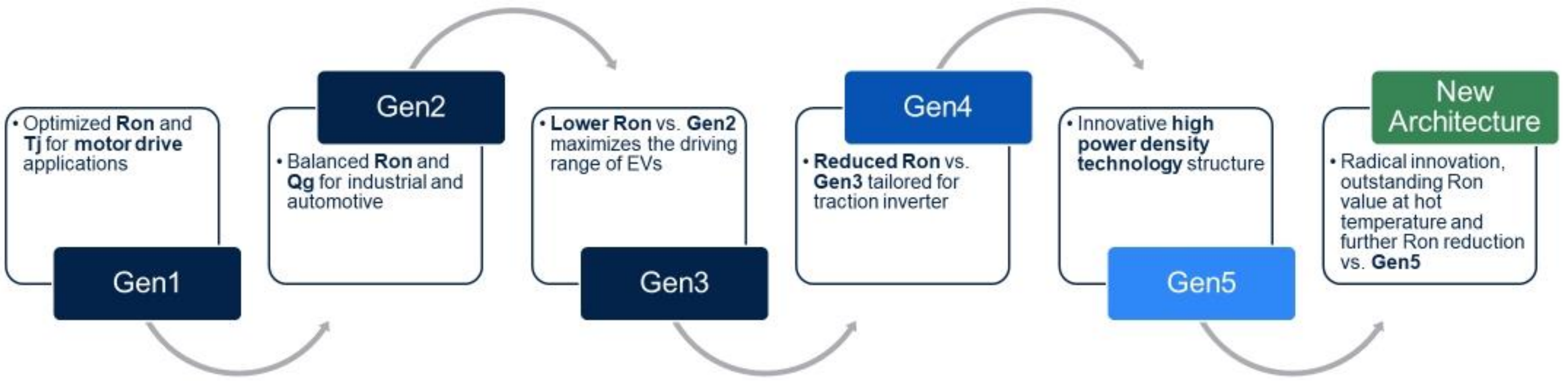
ST silicon carbide technologies

STPOWER STGAP

Focus applications

Traction
OBC, DC-DC
EV Charger
Renewable energy and Storage
UPS
Power supply
Industrial Motors

Product roadmap



In production | In Introduction (Q3/'24) | *In R&D (Q2/'25) | *In R&D (Q4/'26) – New Solution

SiC key facts

In volume production since 2017 with

> **300 million** chips to automotive customers

> **6M BEV** equipped

Advanced packaging

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* Technology qualification with ES available
** Under development

ST silicon carbide manufacturing strategy

Device manufacturing

In volume production with 150 mm since 2017

- > 300 million chips to automotive customers
- Capacity expanded **2.4X** in 2022 vs. 2020

Further +250% of capacity increasing in 2027 vs. 2022

200 mm start production in Catania by 2024

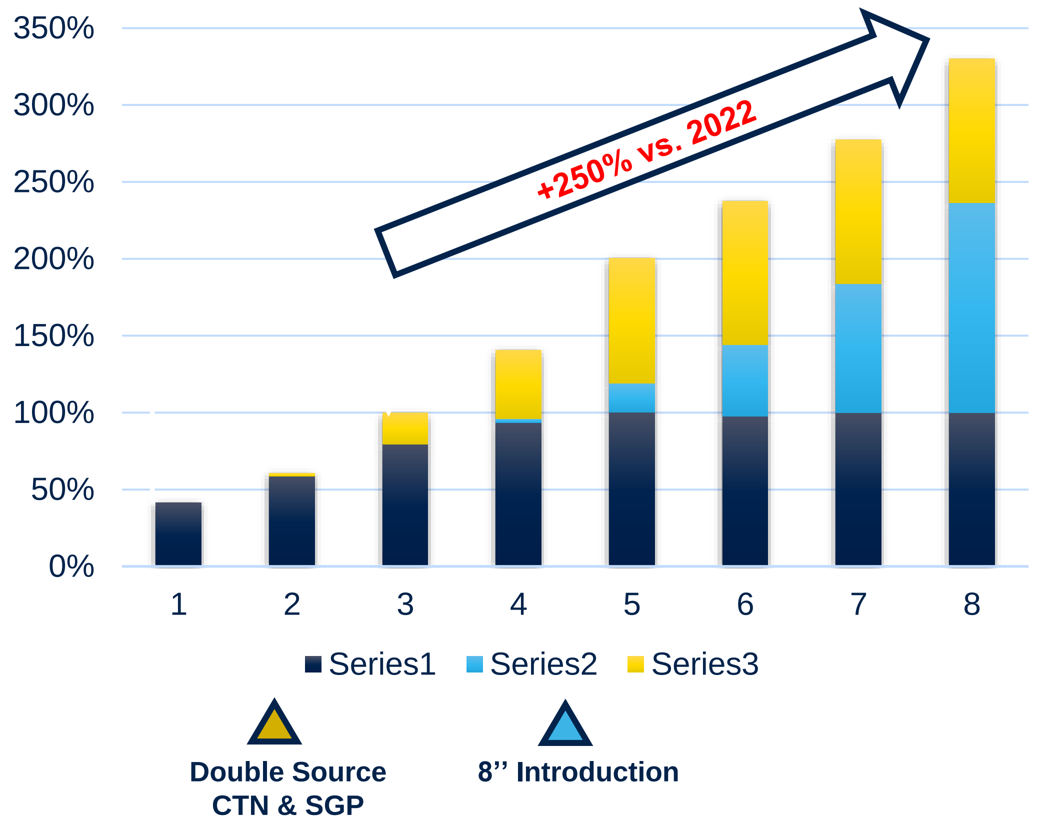
- Front-end FABs: **Catania** (Italy) and **Ang Mo Kio** (Singapore)
- Back-end FABs: **Shenzhen** (China) and **Bouskoura** (Morocco)

Substrate manufacturing

- ST SiC* 150 mm small volumes production in **Norrköping** (Sweden); 200 mm prototypes with good quality and yield
- New full integrated fab under construction in **Catania,** ready by 2024 and targeting > 40% of substrate internal needs by 2025

** Norstel AB renamed as ST SiC AB in 2020*

SiC normalized capacity evolution (2022)



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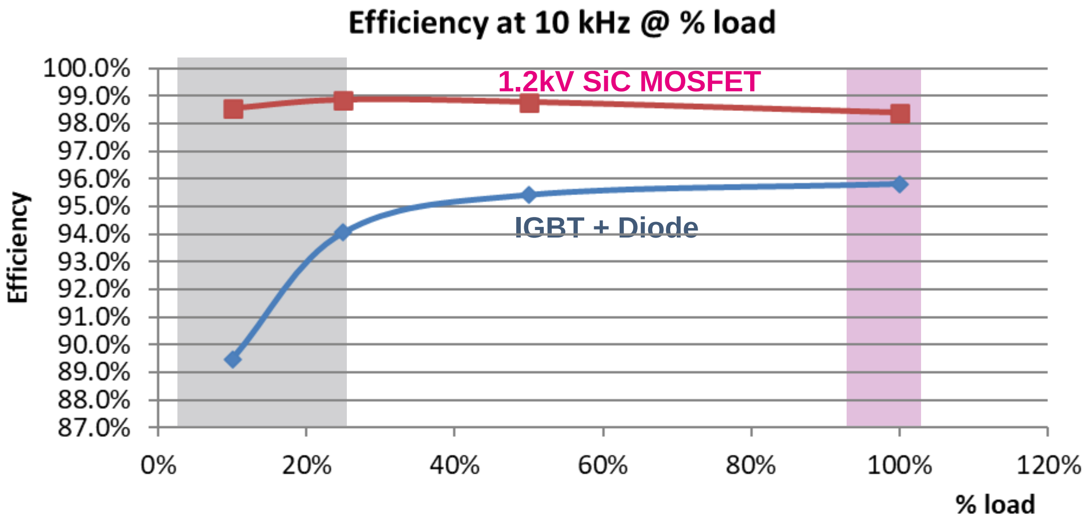
Example of SiC MOSFET impact on high power inverter

1200V SiC MOSFET vs. IGBT: 210 kW inverter @ 10 kHz

Typ. power losses per switch @ 350 A_{rms} peak power		IGBT + Diode		1.2kV SiC MOSFET
	total chip area (mm^2)	600	x5	120
	conduction losses (W)	300		307
	switching losses (W)	564	x4	143
	total losses (W)	864	x2	450
	Junction Temp (°C)	134.8		132.4



SiC adoption

- Better power density
- Better efficiency
- Reduced cooling system

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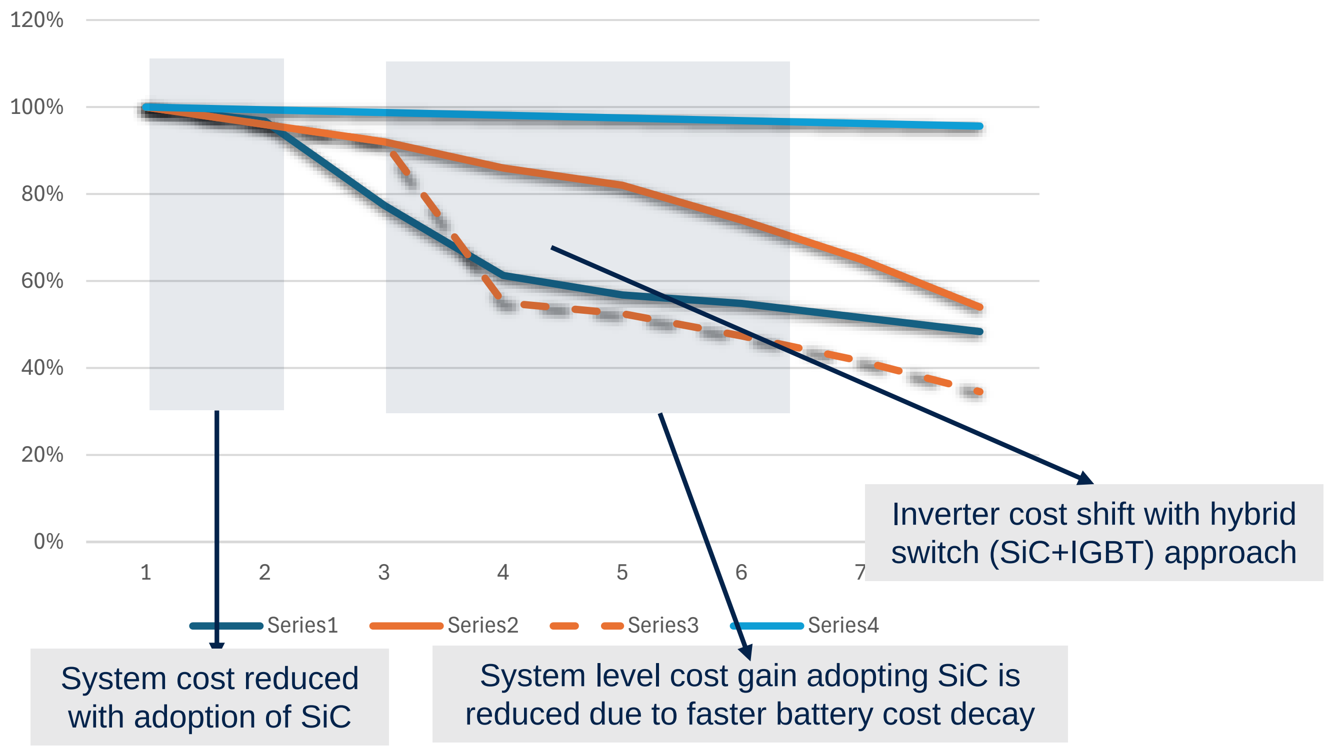
From SiC to hybrid technology

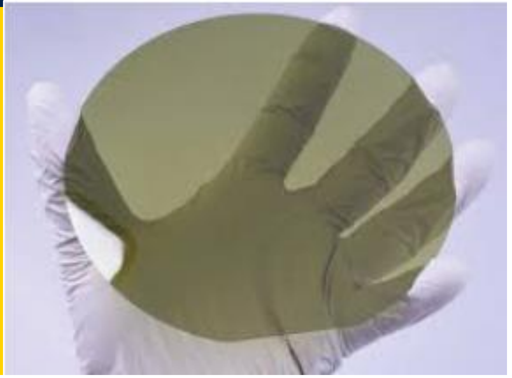
Evolution of SiC technology cost vs battery cost

Normalized cost evolution



SiC

- Medium-long term FAB allocation
- Yields improvement
- Die size shrinking
- Internal raw wafers
- Migration to 8" substrates



Battery

Projections based on several publications focusing on utility-scale battery systems

Cost Projections for Utility-Scale Battery Storage: 2023 Update (nrel.gov)

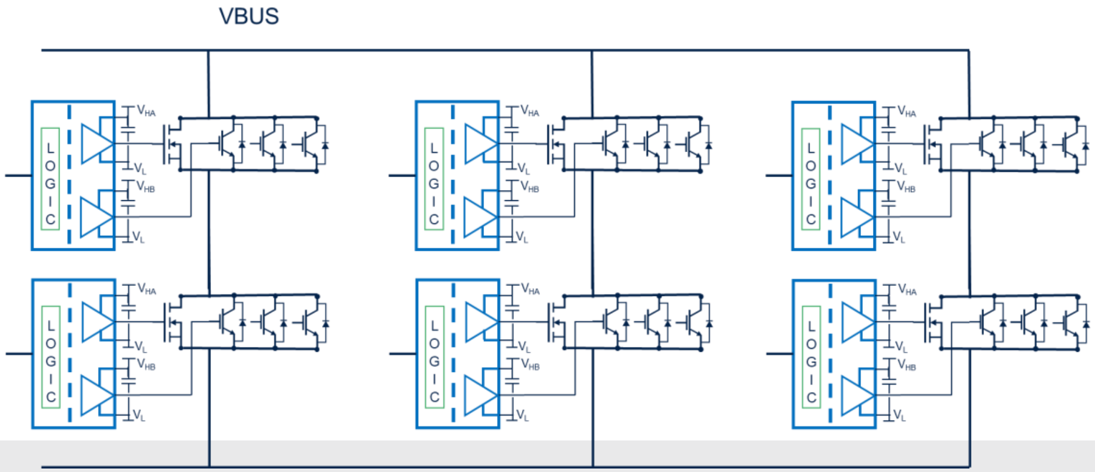
https://www.goldmansachs.com/intelligence/pages/electric-vehicle-battery-prices-falling.html

Hybrid switch inverter

Hybrid switch 4:1 (IGBTs + SiC)

Inverter test conditions

VBUS	850	V
Vout (line to Line)	480	Vac-rms
Vout(line to neutral)	277	Vac-rms
Vout(line to neutral)	392	Vac-pk
Pout (active)	30,000	W
Power Factor	0.80	
phy	0.64	rad
Pout per phase	10000	W
Iout rms	45.11	A
Iout pk	63.79	A
Fs	10,000	Hz



Selected devices:

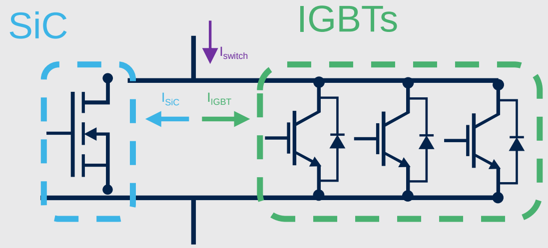
- **STGW40M120DF3** Trench gate field-stop IGBT, M series 1200 V, 40 A
- **SCT070W120G3** Silicon carbide Power MOSFET 1200 V, 63 mΩ typ., 30 A in an HiP247 package

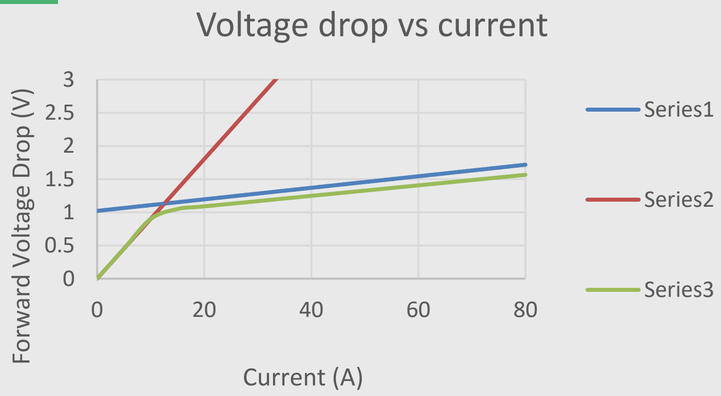
Selection criterium

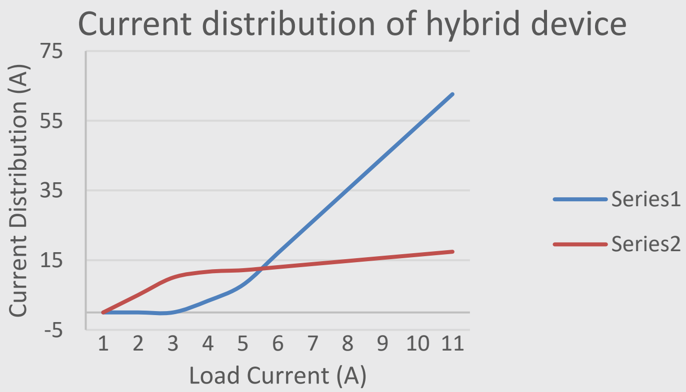
- Device with similar current rating
- SiC MOSFET able to withstand full current repetitive pulses for limited time

Hybrid switch: Forward and reverse conduction

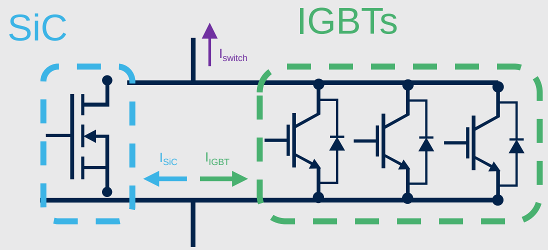
Forward conduction losses

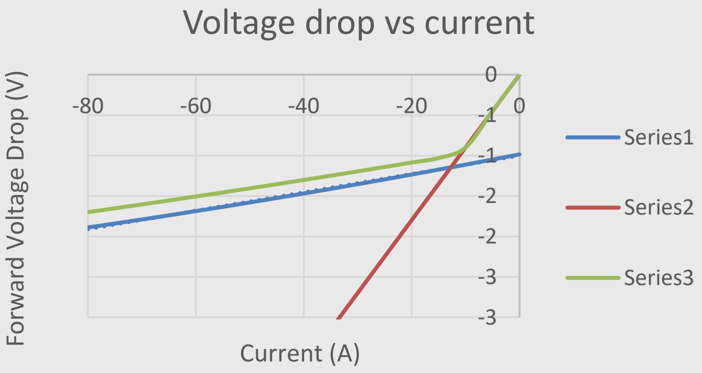


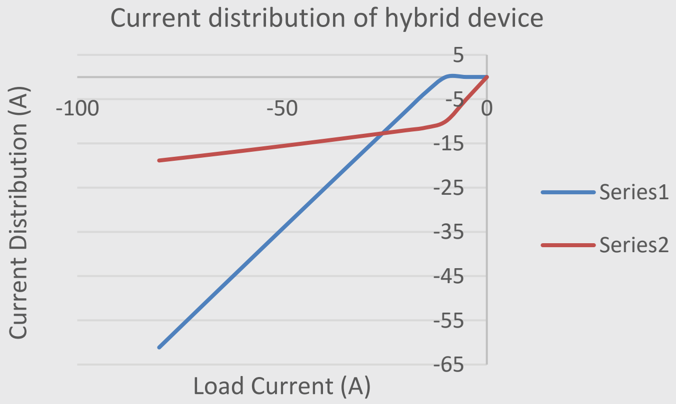




Reverse conduction losses (freewheeling)







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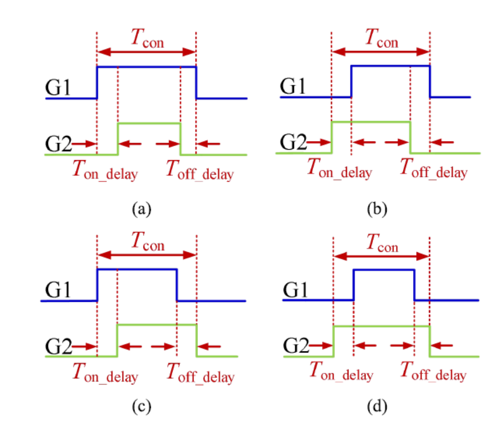
Hybrid switch:
Gate driving and switching operation

Switching losses



Turn-ON

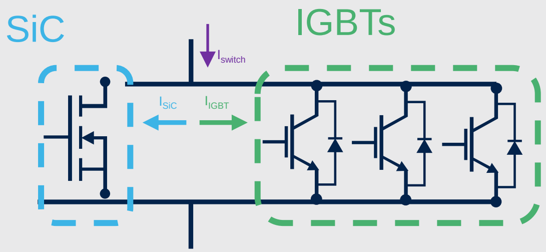
A. (a) and (c) SiC MOSFET undertakes all forward current for a short time, and the IGBT achieves ZVS turn-on
   1. Ton_delay > Ton_MOS
   2. Ton_delay < Ton_MOS

B. (b) and (d) IGBTs undertakes all forward current for a short time, and the SiC achieves ZVS turn-on
   1. Ton_delay > Ton_IGBT
   2. Ton_delay < Ton_IGBT

Turn-OFF

A. (a) and (b) SiC MOSFET undertakes all forward current for a short time, and the IGBT achieves ZVS turn-off
   1. Toff_delay > Toff_IGBT
   2. Toff_delay < Toff_IGBT

B. (c) and (d) IGBTs undertakes all forward current for a short time, and the SiC achieves ZVS turn-off
   1. Toff_delay > Toff_MOS
   2. Toff_delay < Toff_MOS



- IGBT gate is turned On first and Ton_delay is set to synchronize commutations and avoid excessive current unbalance during the commutation
- SiC is turned off later and Toff_delay is set to minimize turn-off losses (IGBT commuting in ZVS).

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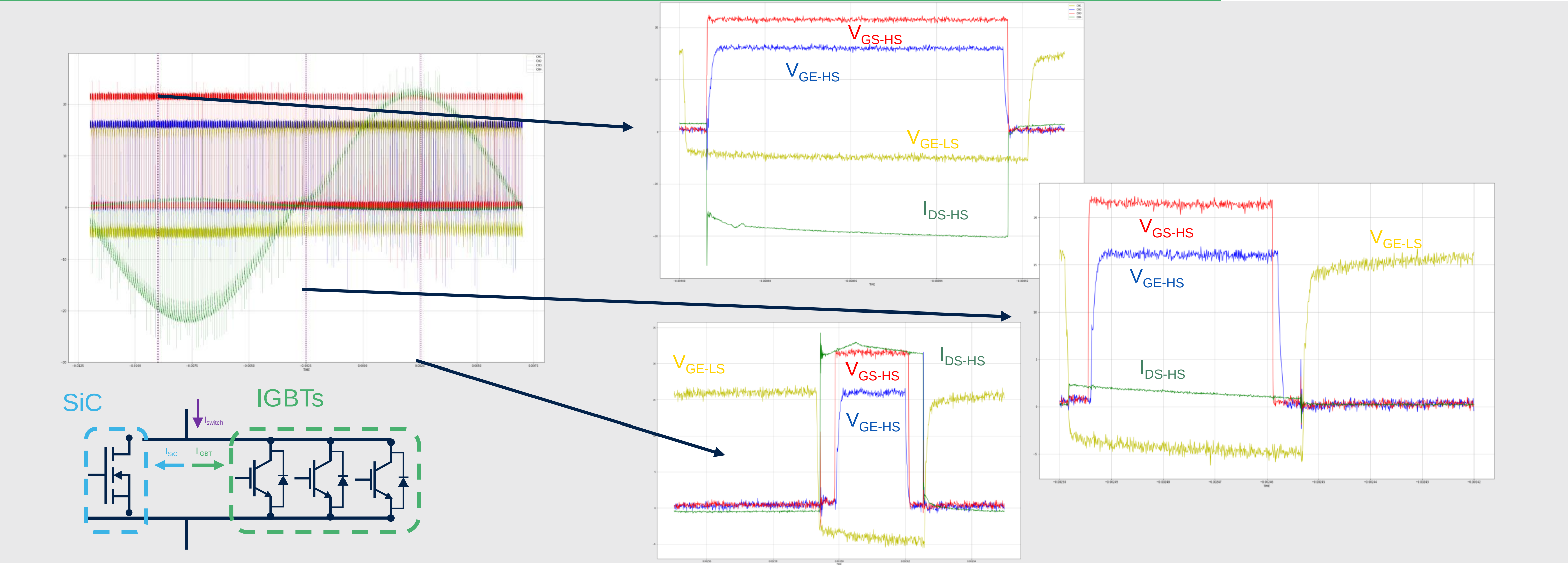
Hybrid switch:
Gate driving and switching operation

Working waveforms

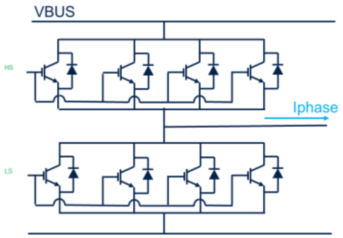


Switch technologies vs hybrid switch in 30kW Inverter

1200V SiC MOSFET vs. IGBT vs hybrid: 30 kW inverter @ 10 kHz, 850V input

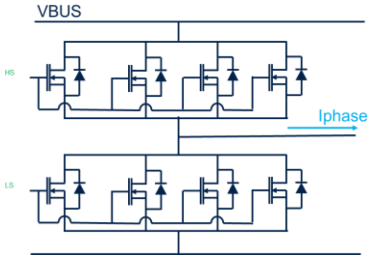
IGBT inverter

STGW40M120DF3
(4 in parallel)



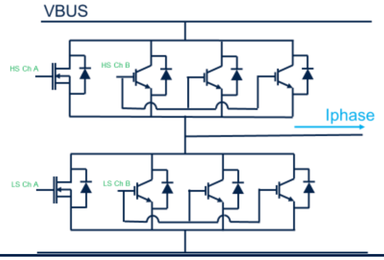
SiC inverter

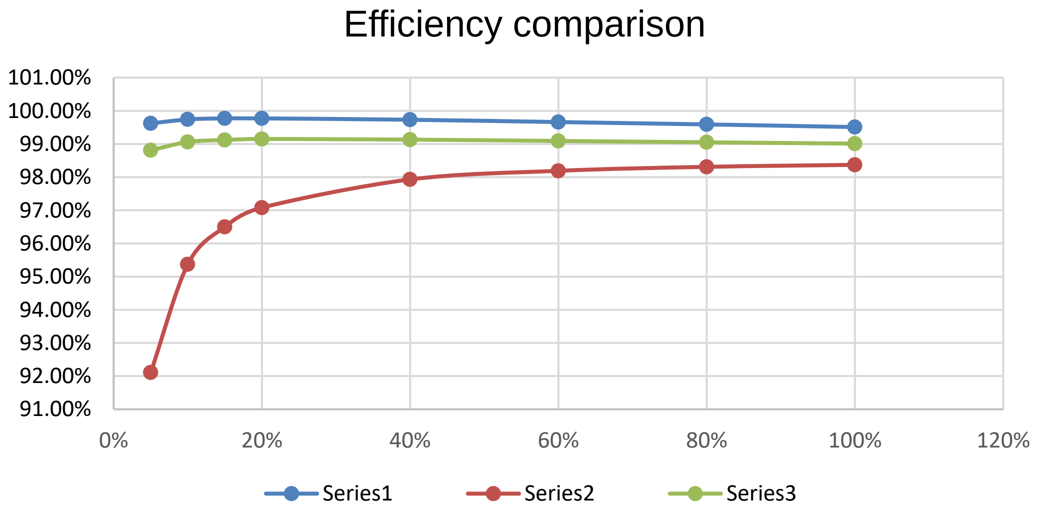
SCT070W120G3
(4 in parallel)



Hybrid (SiC+IGBT) inverter

STGW40M120DF3
SCT070W120G3
(3 IGBTs+1 SiC in parallel)





Inverter specification		
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Vout (line to Line)	480	Vac-rms
Vout(line to neutral)	277	Vac-rms
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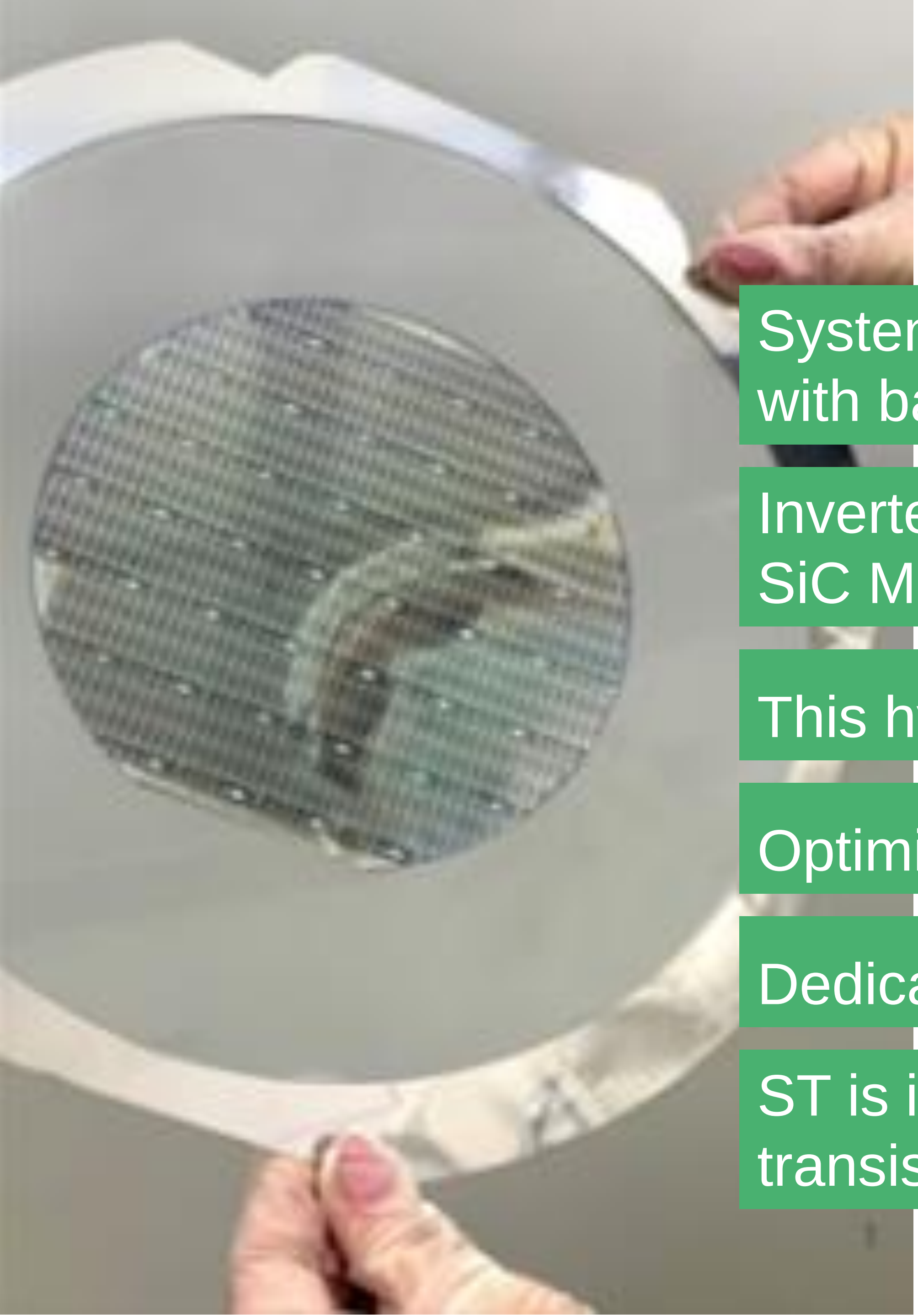
Pout (active)	30,000	W
Power Factor	0.80	
phy	0.64	rad
Pout per phase	10000	W
Iout rms	45.11	A
Iout pk	63.79	A
Fs	10,000	Hz

- Hybrid switch configuration considfred is 1:4 ratio (1 SiC + 3 IGBTs)
- Efficiency gain of full SiC Inverter and hybrid switch inverters vs IGBT inverter is from low load to medium load, generating advantages in power systems that operate most of the time below 40% load
- Hybrid switch inverter shows similar efficiency curve compared to SiC. Here efficiency is ponly 0.5% lower than SiC



Summary

- System cost benefits of SiC based inverters are evolving with battery technologies
- Inverters benefit from a mix of next generation IGBTs and SiC MOSFETs
- This hybrid switch optimizes inverter performance and cost
- Optimized cost might enable new applications for SiC
- Dedicated gate driver is required for Hybrid Switch
- ST is innovating at all levels in gate drivers and power transistors to lead this new trend in inverter design

Our technology starts with You

Find out more at www.st.com

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