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Practically achievable WLTC loss improvements for the Si/SiC hybrid switch approach in a 400 V automotive traction inverter application – A retrofitting case study

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Valeo

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Co-funded by the European Union

FRANCE 2030

25/09/2025

01

VALEO POWER

United for innovation, we power the future of mobility and beyond

POWER

ELECTRIFICATIO N ACCELERATION

BRAIN

ADAS ACCELERATION

LIGHT

LIGHTING EVERYWHERE

SERVICE

INTERIOR EXPERIENCE REINVENTION

Valeo

POWERTRAIN & THERMAL SYSTEM FUSION FOR COST & EFFICIENCY

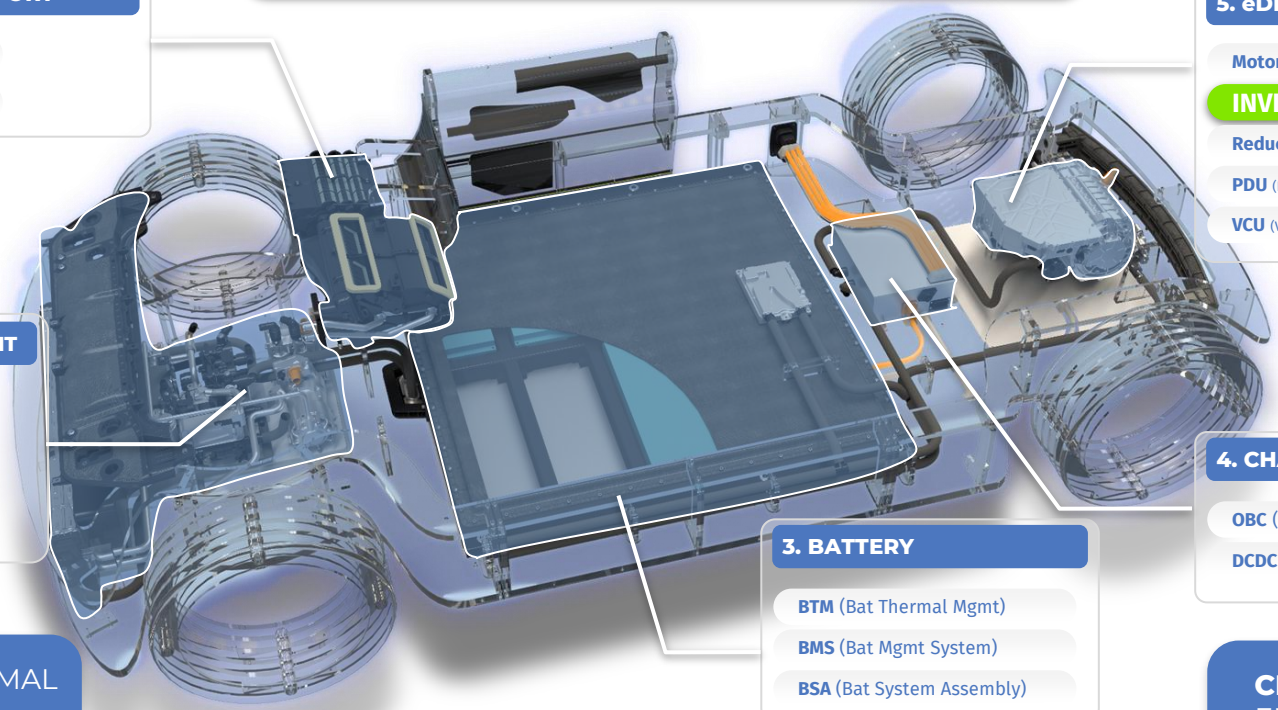
Drive & Thermal System Control / Software anSWer

2. CABIN COMFORT

- HVAC Module
- Air Heater

1. THERMAL MANAGEMENT

- Smart Heat Pump
- EDC
- HV Heaters
- Front Cooling Module



5. eDRIVE

- Motor
- **INVERTER**
- Reducer / Gear box
- PDU (Power Drive Unit)
- VCU (Vehicle Control Unit)

4. CHARGING

- OBC (On Board Charger)
- DCDC Converter

3. BATTERY

- BTM (Bat Thermal Mgmt)
- BMS (Bat Mgmt System)
- BSA (Bat System Assembly)

RANGE by THERMAL & ELECTRICAL ENERGY EFFICIENCY

CHARGING EFFICIENCY, SPEED, SAFETY & LIFETIME

VALEO POWER DIVISION

FOOTPRINT

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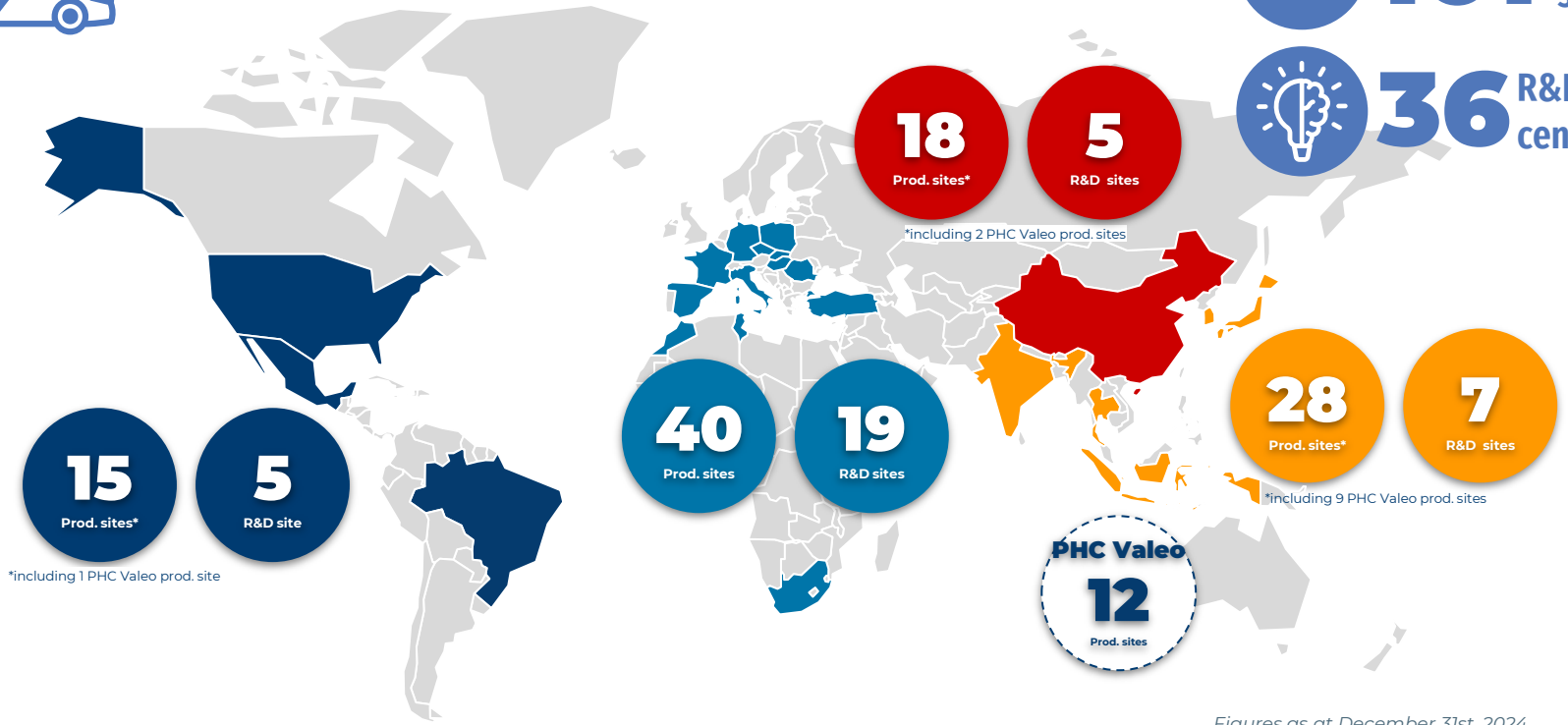
101 Prod. sites

36 R&D* centers



Figures as at December 31st, 2024

**R&D = Research & Development Centers*

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02

HYBRID SWITCH

Introduction & scope

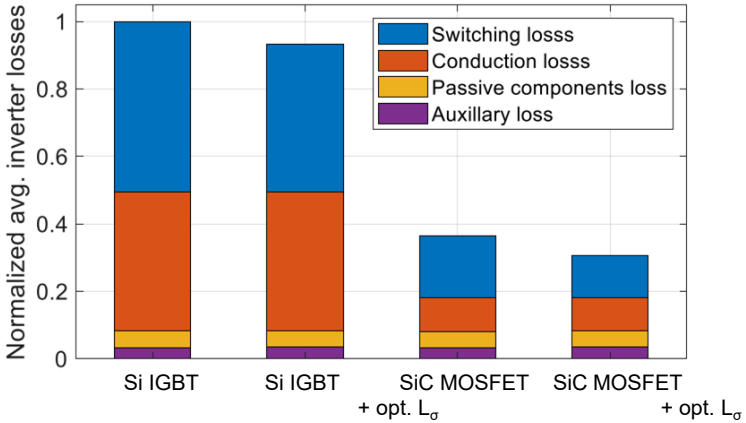
Introduction

State of the art

SiC as the new η GOLD STANDARD

Typically SiC MOSFETs reduce inverter losses by ~60 … 70 %

Exemplary WLTC inverter loss distribution for a c segment vehicle

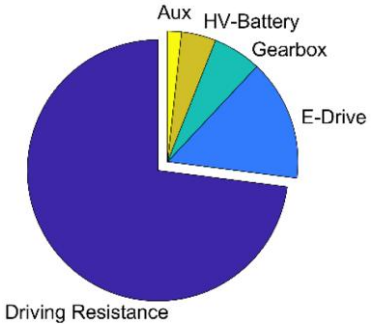


Source: A. Rambetius et al., *"Efficiency Trends for Electric Traction Drives"*, 32nd Aachen Colloquium Sustainable Mobility, 2023

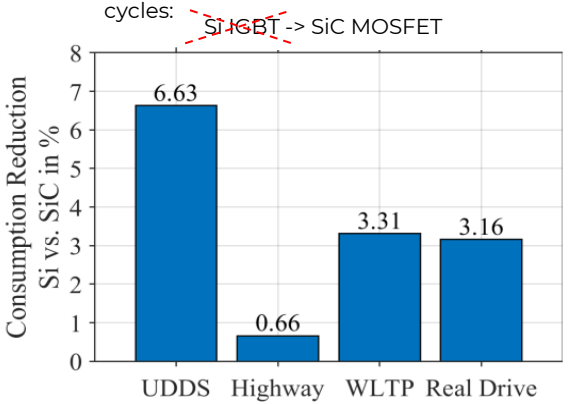
System BENEFITS

Even though impact of SiC upgrade on power electronics is huge, inverter losses are weighted with losses from other components

Exemplary WLTC drivetrain loss distribution for a c segment vehicle:



Exemplary WLTC vehicle consumption reduction of a d segment vehicle for different drive cycles:

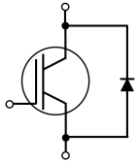


Source: A. Nisch et al., *"Simulation and Measurement-Based Analysis of Efficiency Improvement of SiC MOSFETs in a Series-Production Ready 300 kW / 400 V Automotive Traction Inverter"*, 22nd European Conference on Power Electronics and Applications, 2020

Scope

Si/SiC hybrid switch retrofitting

Si IGBT & FWD



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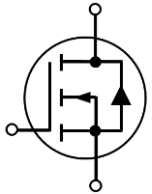
SiC MOSFET



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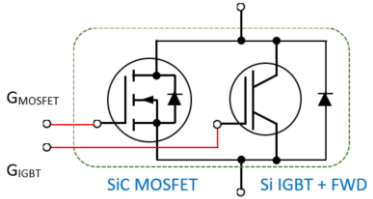
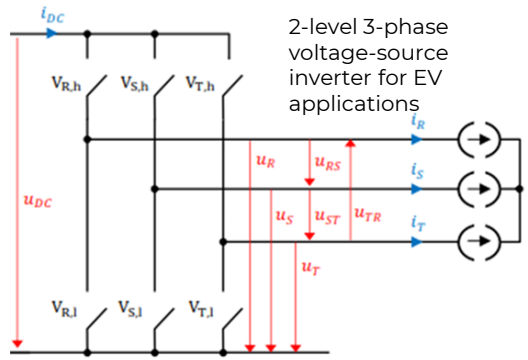
Si/SiC HYBRID SWITCH





2-level 3-phase voltage-source inverter for EV applications

Bipolar devices

- \+ high ampacity
- \- slow/lossy switching
- \- stored charges
- \- part-load voltage drop
- \+ EMI-friendly

Area/cost ratio

- \+ cost-effective
- \- large footprint

Unipolar device

- \- medium ampacity
- \+ fast/efficient switching
- \+ negligible charges
- \+ resistive voltage drop
- \- pronounced ringing

Area/cost ratio

- \- pricey
- \+ small footprint

Practically achievable PERFORMANCE?

- Retrofit implementation in series-production automotive traction inverter 400 V / 150 kW
- Realistic switching speeds
- WLTC usage
- Thermal equilibrium
- Benchmarking vs. full Si and full SiC

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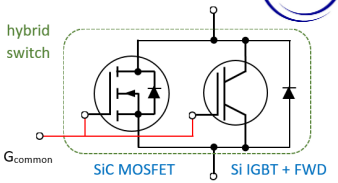
03

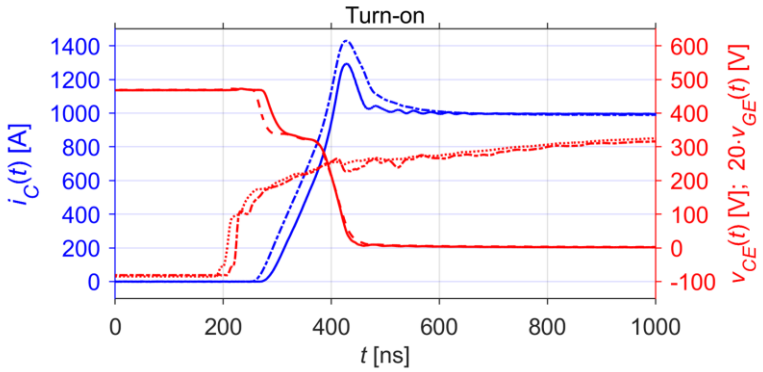
HYBRID SWITCH

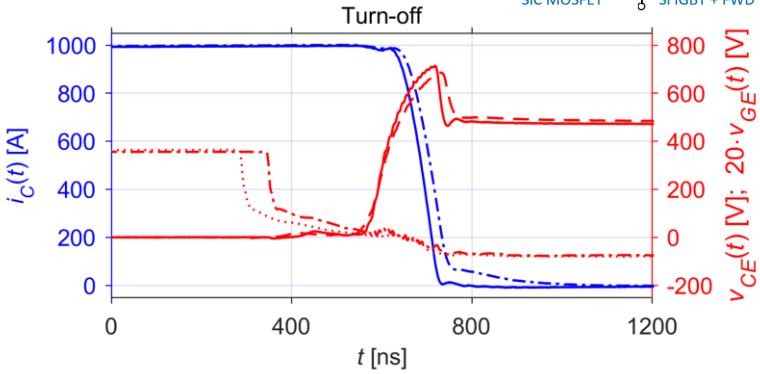
Characterization & simulation

Dynamic characterization

Switching performance common gate

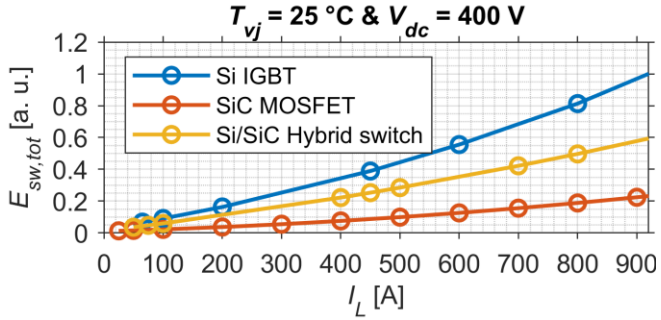






Double-pulse test conditions:

V_{dc} = 470 V
I_L = 1000 A
T_{vj} = 25 °C (RT)
T_{vj} = 175 °C (HT)

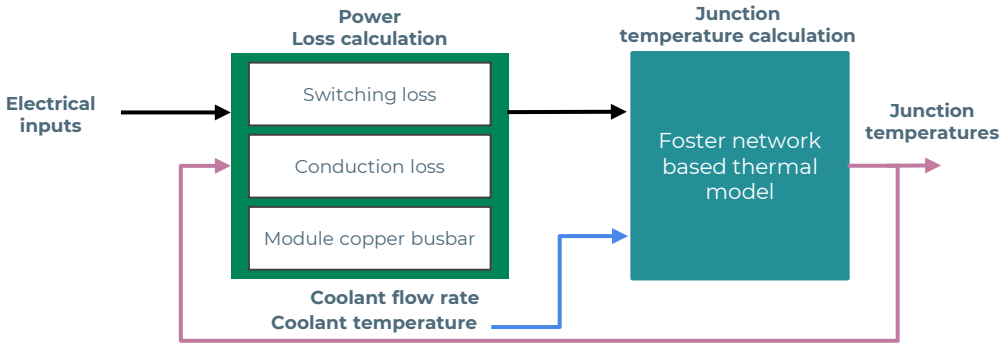


Switching performance COMMON gate ctrl

- Clean switching waveforms
- Coverage of full dynamic load range
- Very good harmony btw. dyn characteristics of different devices mandatory
- Switching loss reduction < 50 % vs. full SiC

Simulation model

Power module model description

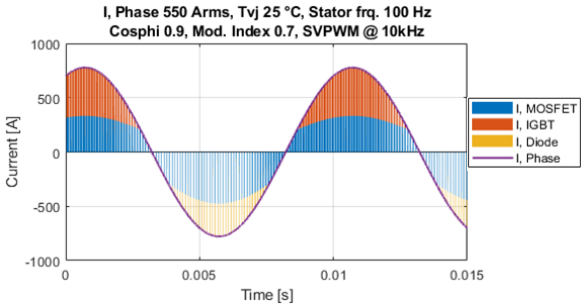


Advanced model for hybrid switch is needed for simulation of:

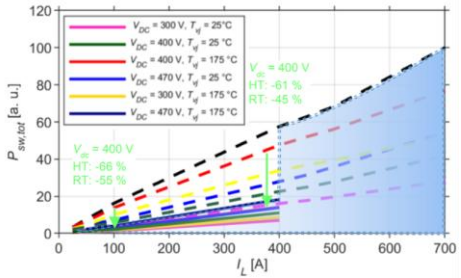
- Semiconductor power loss
- Individual junction temperature

Power loss calculation

Current sharing

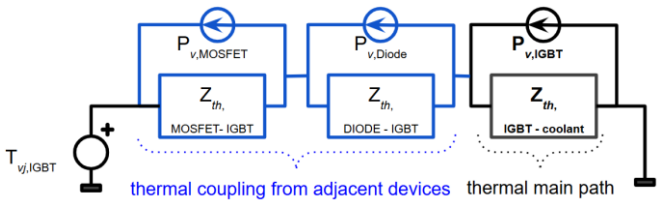


Switching energy



Junction temperature calculation

Thermal network

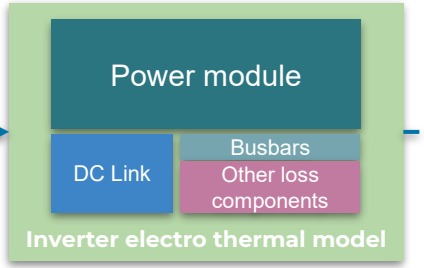


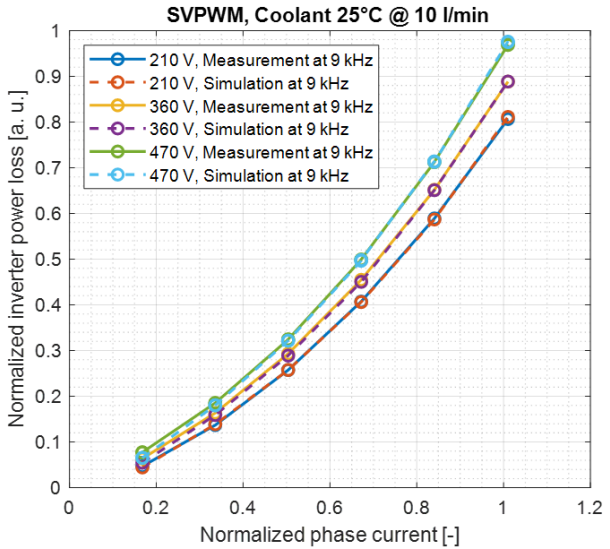
Note : Exemplary representation of the IGBT thermal network

Simulation model

Model validation

- DC voltage
- Phase current
- Coolant temperature
- Switching frequency





The comparison reveals excellent agreement between measurements and simulations.

WLTC simulation

Class C/D vehicle

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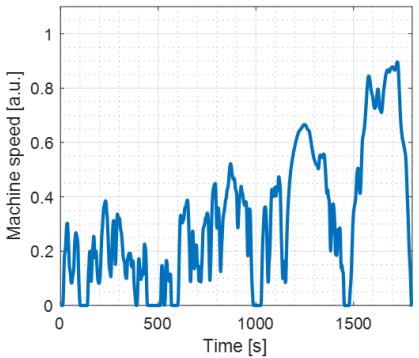
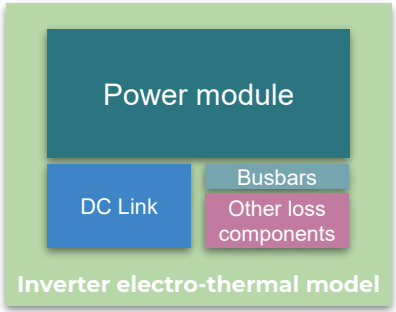
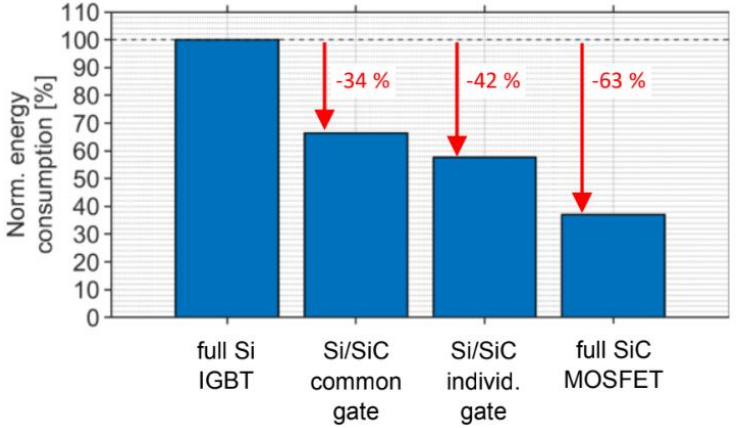
WLTC profile for class C/D vehicle



Simulation



WLTC Simulation results



Si/SiC hybrid switch brings about 54% of overall reduction in energy consumption achievable with SiC MOSFET power module with common gate control.

Boundary conditions

DC voltage : 360 V
Modulation : SVPWM @ 10 kHz
Coolant temperature : 65 °C
Coolant flow : 8 l/min

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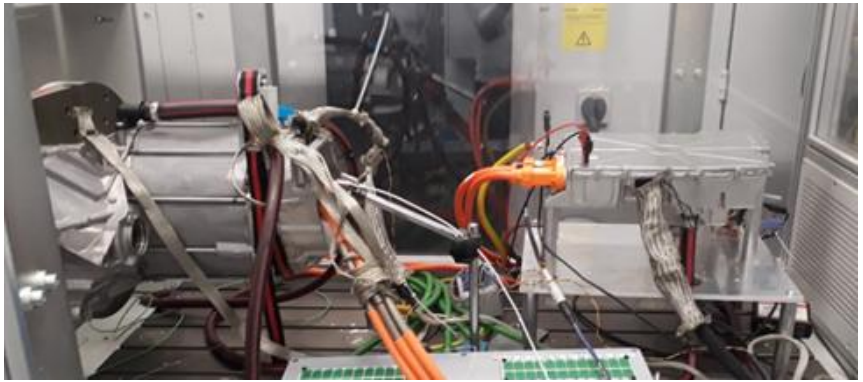
04

HYBRID SWITCH

Test bench measurements

Motor test bench measurement

Measurement set up

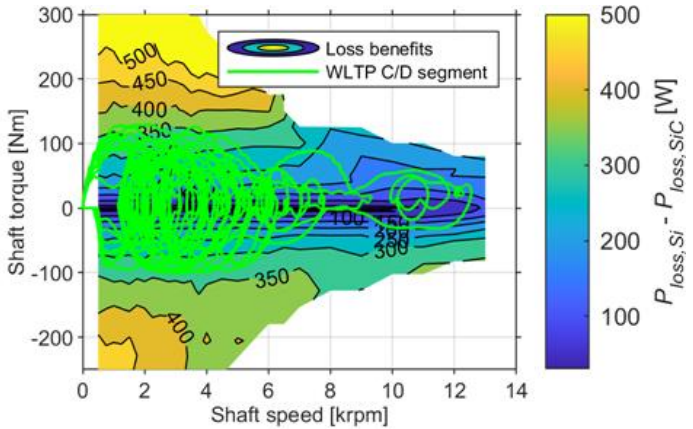


Si IGBT and Si/SiC hybrid inverter on motor test bench

Identical measurement setup, thermal conditions for inverter and motor were maintained to achieve a fair comparison.

WLTC measurements

- Constant torque speed maps with defined stator and rotor temperatures were measured
- A multitude of consecutive WLTC cycles were measured with defined thermal starting conditions

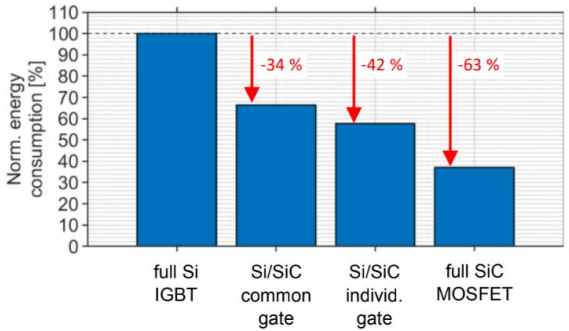


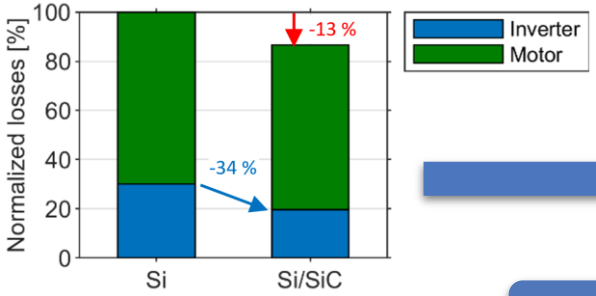
Motor test bench measurement

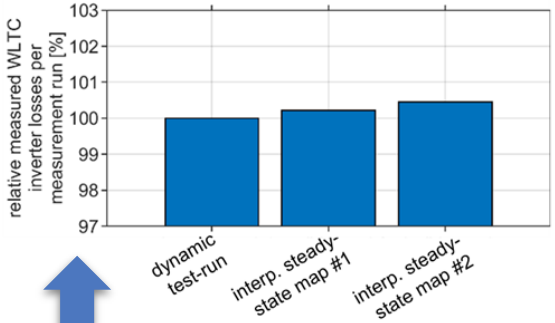
Measurement results

Excellent CORRELATION with simulation results

The measurement results show identical loss improvement of -34 % on inverter level







REPRODUCIBILITY

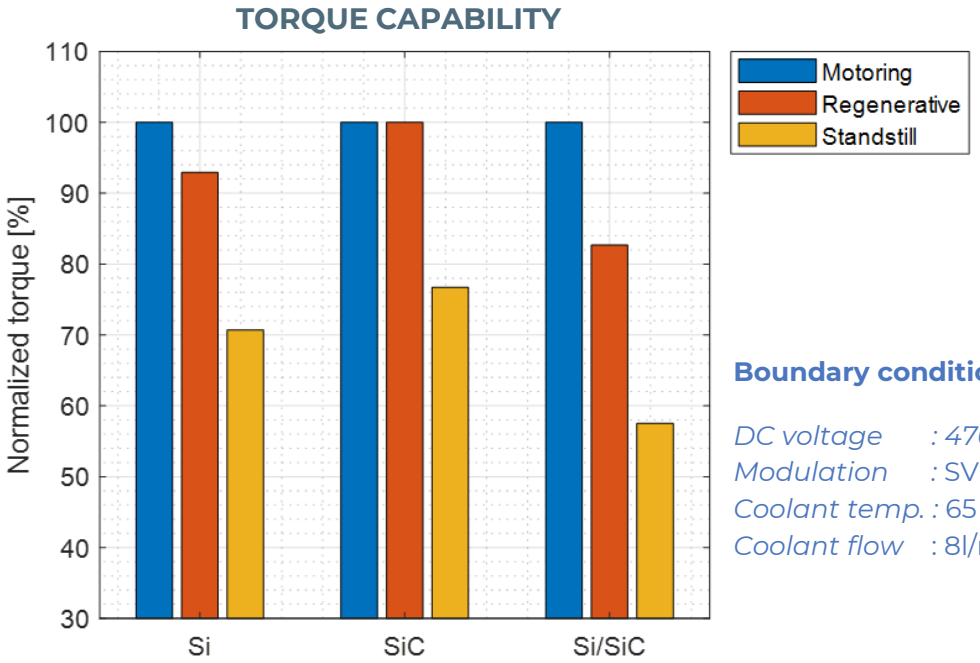
High reproducibility ensures reliable and comparable test results, which is crucial for accurate performance validation.

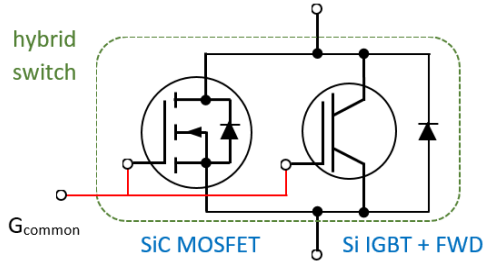
05

HYBRID SWITCH

Performance & conclusion

Performance outlook





Boundary conditions

DC voltage : *470 V*
Modulation : SVPWM
Coolant temp. : 65 °C
Coolant flow : 8l/min

Operation *mode*	Performance limited by
Motoring mode	Si IGBT
Regenerative mode	Si Diode
Stand still	Si Diode

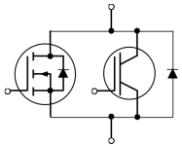
Increasing the die area to satisfy the application's regenerative torque requirements is a tradeoff between torque capability and efficiency.

Summary

The hybrid switch: from theory to proven performance

HARMONY

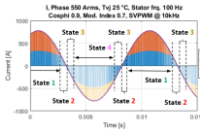
Hybrid switch requires most careful selection of dynamic and static characteristics



- Hard parallel operation feasible
- SiC content significantly reducing switching and part-load conduction losses
- Further efficiency gains with individual gate control

PREDICTION

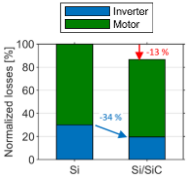
Hybrid switch requires advanced modelling due to complex electrical & thermal interaction



- Model validated through extensive test-runs
- Side-by-side eDrive test results fully align with predicted improvements
- 34 % reduction in inverter losses confirmed on real-world set-up

IMPACT

Hybrid switch with compelling efficiency boost compared to full Si-IGBT



- Retrofitting offers ⅛ reduction of eDrive losses
- “In-between solution” compared to full SiC for WLTC efficiency
- Achievable regen braking and standstill performance require special attention

Enriched with hybrid switch technology, VALEO's comprehensive inverter portfolio offers customers an optimal cost-performance ratio and future-proof integration.

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FOR SMARTER MOBILITY