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R&D Gaps and Business Opportunities

Sandia National Laboratories: Power Electronics Technologies and Energy Conversion Workshop

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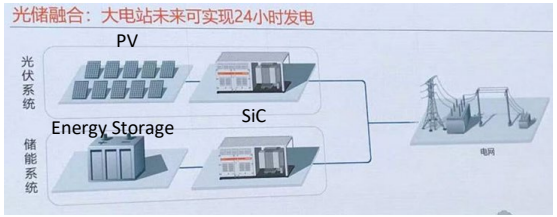
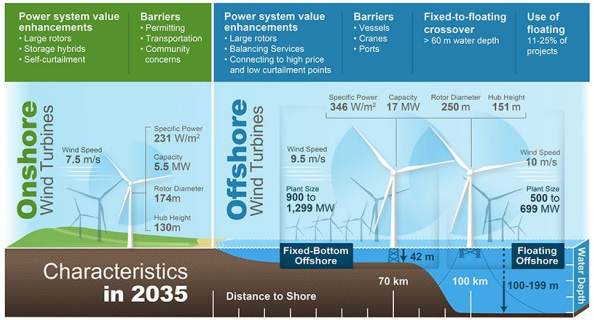
Product Definition / Marketing

WHY SIC IN RENEWABLE SPACE?

- Worldwide energy consumption only increasing over time
- Governments across the world introducing mandates to reduce carbon footprint
- Solar power, Wind power and Energy storage key to reach goals set





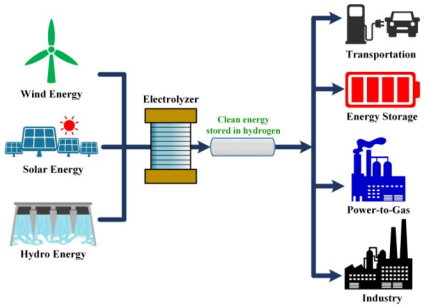
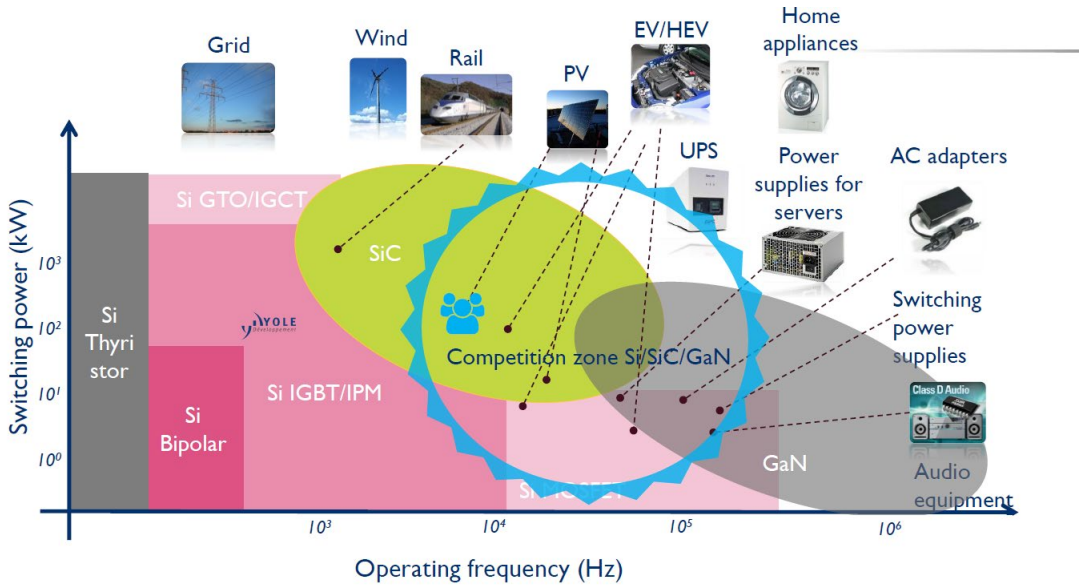


Figure 1. Overview of applications based on water electrolysis process supplied by renewable energy sources.

For mass adoption need a solution with high efficiency, performance and low cost, SiC enables these

Advantages of Medium Voltage SiC Power Modules

- Reduced volume/weight → **Reduced BOM / Lower cost**
- High-speed switching → **Lower Loss / Higher Efficiency**
- Higher voltage (> 2.0kV) → **Less levels / Simplified system**
- Higher frequency → **Smaller magnetics and filter capacitors**
- Excellent Thermal Conductivity → **Higher current / less cooling**



Commercially available, qualified medium voltage (1.7 kV – 15 kV) SiC power modules are needed to revolutionize next generation grid applications

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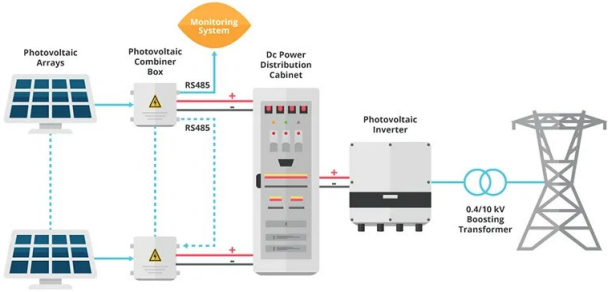
[1]. Yole Development, 2023.

BENEFITS OF USING SIC MODULES WITH 1500V BUS

- Processing power at higher voltages where current and conduction losses are lower this translates to
  - Higher system efficiency
  - Lower cost of cables and installation
  - Increases power generation
- Low voltage directive (2014/35/EU) is applicable to systems up to 1500V. Beyond 1500V the installation requirements are non-trivial and the safety precautions that need to be adhered to are cost prohibitive
- Based on a study by GTM research a 10MW solar plant shows a potential deployment savings of $400k by moving from 1kV to 1.5kV bus. Additional savings in efficiency gain leading to power savings (3% to 4% increase in efficiency) is not included in this analysis

Typical PV arrangement



Potential deployment savings –10 MW solar plant

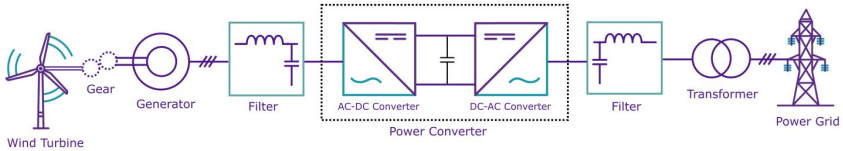
Component	Component Count	Unit Cost	System Cost (per W)
PV Modules	Same	↑ +1~2%	↑ +$0.02
Cables, Conduits, Trenching	↓ -40~45%	Same	↓ -$0.03
Combiner Boxes	↓ -33%	↑ +10~20%	↓ -$0.005
PV Inverters	↓ -40%	↑ +80~100%	↑ +$0.01
Ac Subsystem	↓ Reduced	↓ -10~15%	↓ -$0.005
Direct Labor	*N/A*		↓ -$0.03

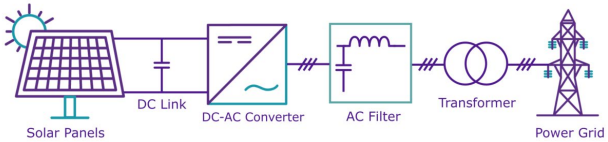
Analysis is for solar plant similar savings expected for wind power

HOW WOLFSPEED IS ENABLING RENEWABLE CUSTOMERS

Customer need….

- Increased power density
- Increased switching freq
- Longer Lifetime
- Support 1500V DC bus
- Lower TCO
- Low FIT rate (Cosmic ray)

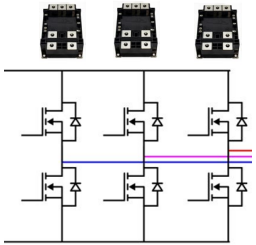




LM module offers

- High Power Density
- Improved dynamic performance
- WS Gen4 SiC technology with soft body diode
- Optimized power Loop Inductance: <10 nH
- Simple mechanical integration / TIM and screw
- Lower Junction temperature operation
- <110 FIT/module at 25C, 1000m at 1500V DC bus

Typical Topology: 2-Level



Supports 1500V up to ~1.5 to 2MW

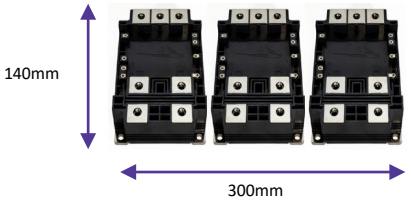
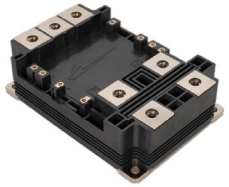
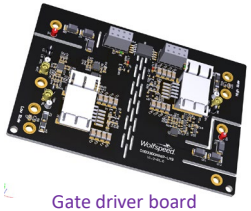


Image source: https://www.renewableenergyworld.com/solar/10-notable-battery-storage-projects-that-went-live-in-2021/#gref

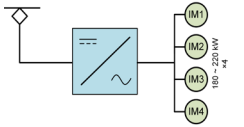
3.3kV All-SiC MOSFET MODULE FOR MV MOTOR DRIVES



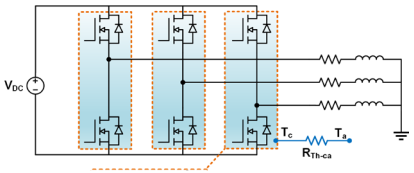
3.3 kV LM3 All-SiC MOSFET Module



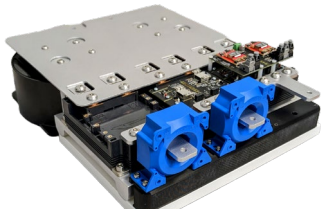
Gate driver board



VVVF drive for railway application



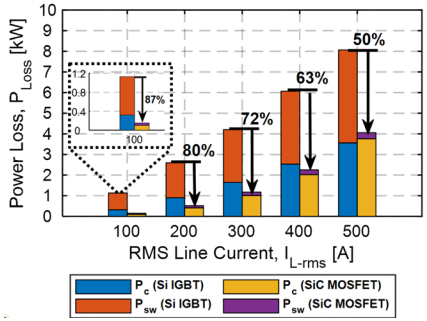
Three phase test bench for performance evaluation



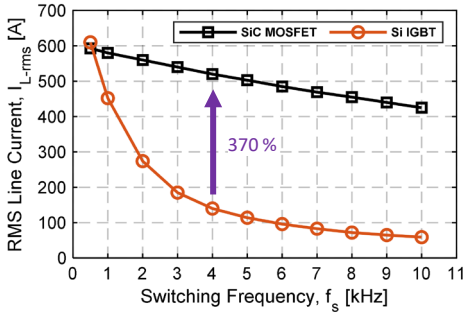
Hardware prototype of 3-phase 2-level inverter for MV motor drives

Parameter	Value
DC voltage	1500 V
Switching frequency	0.25 – 10 kHz
Modulation	0.9
Power factor	0.9
Fundamental frequency	60 Hz
$R_{th\text{-}jc}$	32 K/kW (SiC)
$R_{th\text{-}jc}$	9.55 K/kW (IGBT)
$R_{th\text{-}ca}$	15 K/kW per half-bridge
Ambient temperature	45 °C

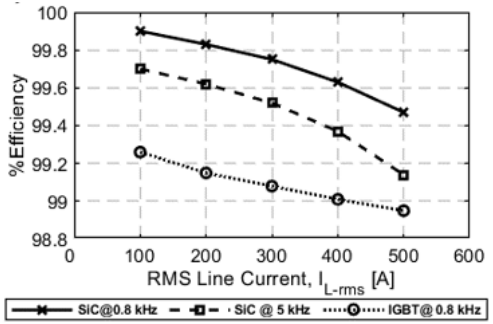
Operating condition for performance evaluation



Comparison of power loss distribution in SiC MOSFET and silicon IGBT-based power converters



Maximum output current in SiC MOSFET and silicon IGBT-based power converters; $T_{VJ(peak)}$ = 150 °C



Efficiency of 3.3 kV All-SiC MOSFET-based and silicon IGBT-based converters

Benefits of Wolfspeed 3.3 kV All-SiC MOSFET

- The 3.3 kV All-SiC MOSFET module can deliver higher output rms current at the same junction temperature and switching frequency compared to silicon IGBT
- The module can operate at higher switching frequency with lower junction temperature and higher efficiency than the IGBT counterpart
- The module has higher power density, less harmonics and higher efficiency

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WOLFSPEED 3300 V THREE- PHASE INVERTER

Performance Comparison with 3300 V silicon IGBT-based inverter*

Parameters	3300 V, 600 A Si-IGBT Module	3300 V, 600 A, 2.7 mΩ SiC MOSFET LM3 Module (Wolfspeed)	Improvement
DC Input Voltage (V)	1500	1500	
AC Output Voltage RMS (L-L)	1200	1200	
Motor Frequency (Hz)	50	50	
Motor Power Factor	0.88	0.88	
Inverter Switching Frequency (Hz)	4000	4000	
Switching dv/dt (V/ns)	~ 1	6.5	
Peak Junction Temperature (°C)	125	150	+ 20 %
Output Power (kW)	216	880	+ 307 %
Inverter Volume (liter)	11	11	
Inverter Power Density (kW/liter)	19.6	80.0	+ 307 %

- 3300 V SiC MOSFET-based inverter results in 307 % improvement in power density at 4 kHz switching

* Electrothermal simulation Results

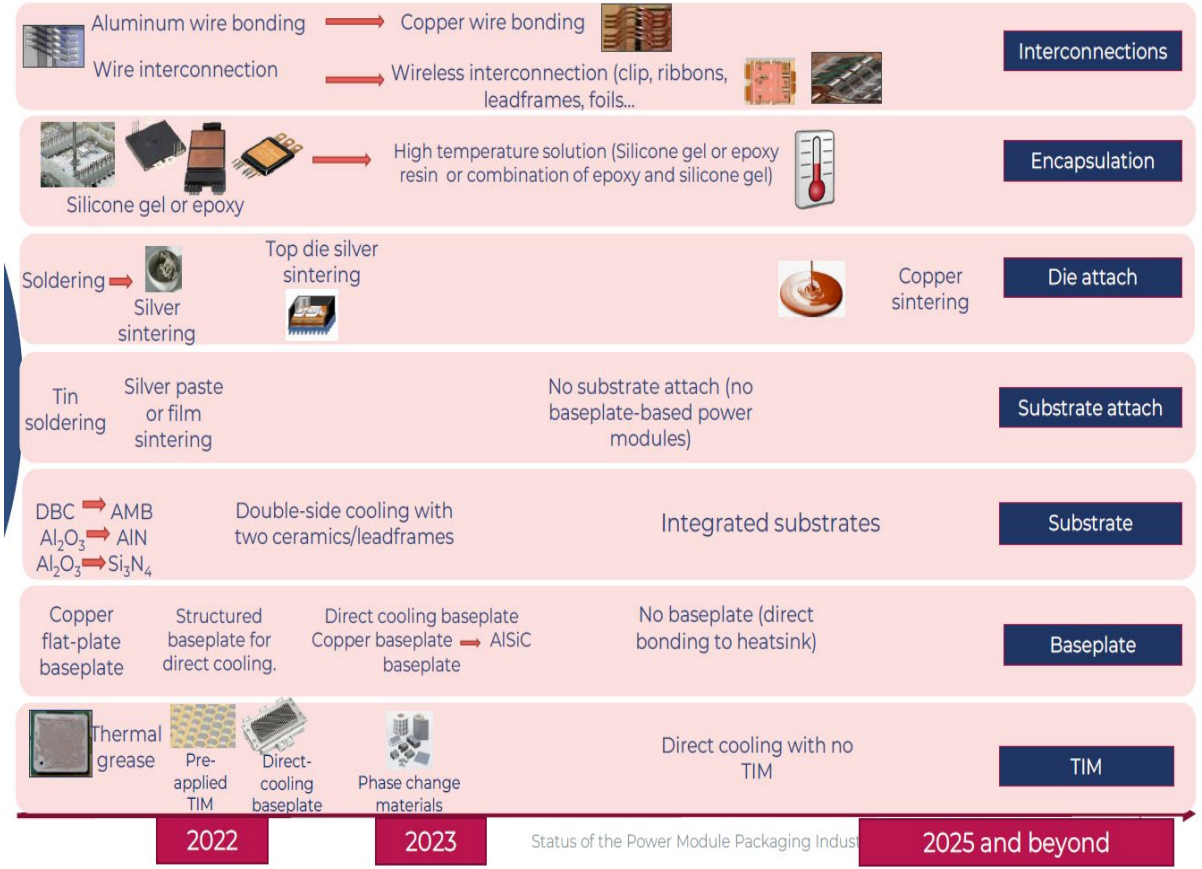
Medium Voltage Power Module Needs

Advanced materials

- Power substrate technologies → lower thermal resistance and higher dielectric strength
- Silicone gel encapsulation materials → higher dielectric strength, less susceptibility to partial discharge, and higher temperature, more moisture resistant
- Coatings → higher dielectric strength, less susceptibility to partial discharge, and higher temperature, more moisture resistant

Others

- Need for magnetics to handle high currents and high voltages



[1]. Yole Development, 2023.