New Power Electronic Devices and Technologies for the Energy Sector

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The ECPE Network

- The Industry-driven Research Network for Power Electronics.
- Association with more than 170 members all over the Europe.
- The European Technology and Innovation Platform for PE.

- Precompetitive Joint Research in Power Electronic Systems
  - ECPE Projects with focus on automotive and industrial PE systems, renewable energy and electric grids
  - EC or national funded research projects
- Education and Advanced Training
  - Expert workshops and tutorials for engineers from industry
  - ECPE online course ´Power Electronics´
- Public Relations & Lobbying for Power Electronics

The ECPE Network: 81 Industrial Members

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The ECPE Network: 92 Competence Centers

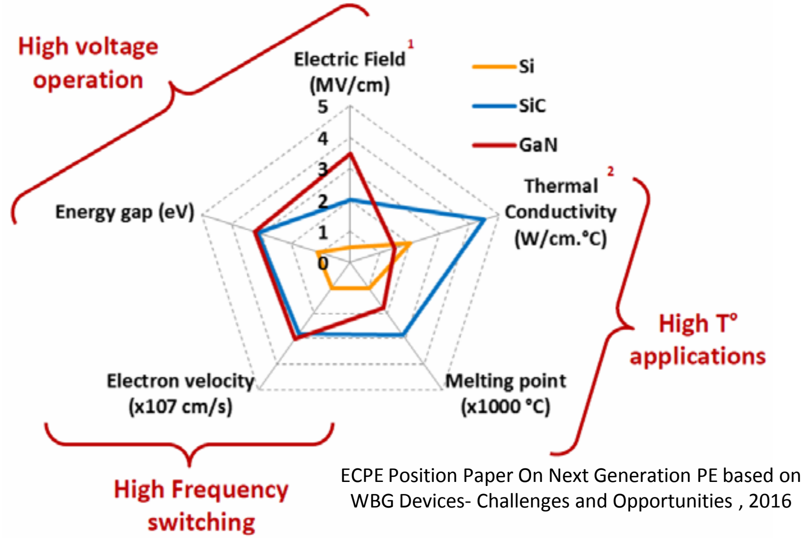
ECPE Competence Centre

Outline

- Potentials of WBG Devices
  - o Overview
- HV DC Transmission
  - o MMC for VSC-HVDC
  - o New MMC Topologies for VSC in MTT-HVDC
  - o HDCV Breakers
- More reliable, cost-effective PE systems
  - o Condition and Health Monitoring
- Conclusions

Potentials of WBG Devices

- High breakdown field strengths
  - Lower conduction losses
  - Higher current density
  - Smaller devices
- Fast switching, range of nano-seconds
  - Lower switching losses
  - Higher switching frequencies
  - Smaller and cheaper passives
- Higher operation temperatures
  - Less cooling effort
  - Smaller devices



ECPE Position Paper On Next Generation PE based on WBG Devices- Challenges and Opportunities , 2016

Dan Kinzer, Navitas Semiconductors, Welcome to the Post-Silicone World, PCIM, 2016

Potentials of WBG Devices: Overview

Power Electronics for PV systems

- SiC and GaN devices improve the efficiency
- System costs benefits: passives, heat sink
- Low power applications (solar microinverters)
  - GaN devices with high switching frequency
- High power applications (solar string inverters)
  - Si IGBTs → 1.2 kV SiC JFETs

Power Electronics for HVDC Transmission

- Low switching frequency
- Eventual benefits of WBG devices not so obvious

→ **Focus of this presentation**

Generation 1 (2012)
SiC JFETs, 48 kHz pulse frequency
18l - 18,4 kg (15kW)
conventional packaging

Generation 2 (2015)
SiC MOSFETs, 250 kHz pulse frequency
2,4l - 4 kg (15kW)
embedded power modules

ECPE Joint Research Programme 2015, Very fast switching & simple topology inverter for grid feeding applications, (SiC), E. Hoene, Fraunhofer Institute for Reliability and Microintegration IZM; germany

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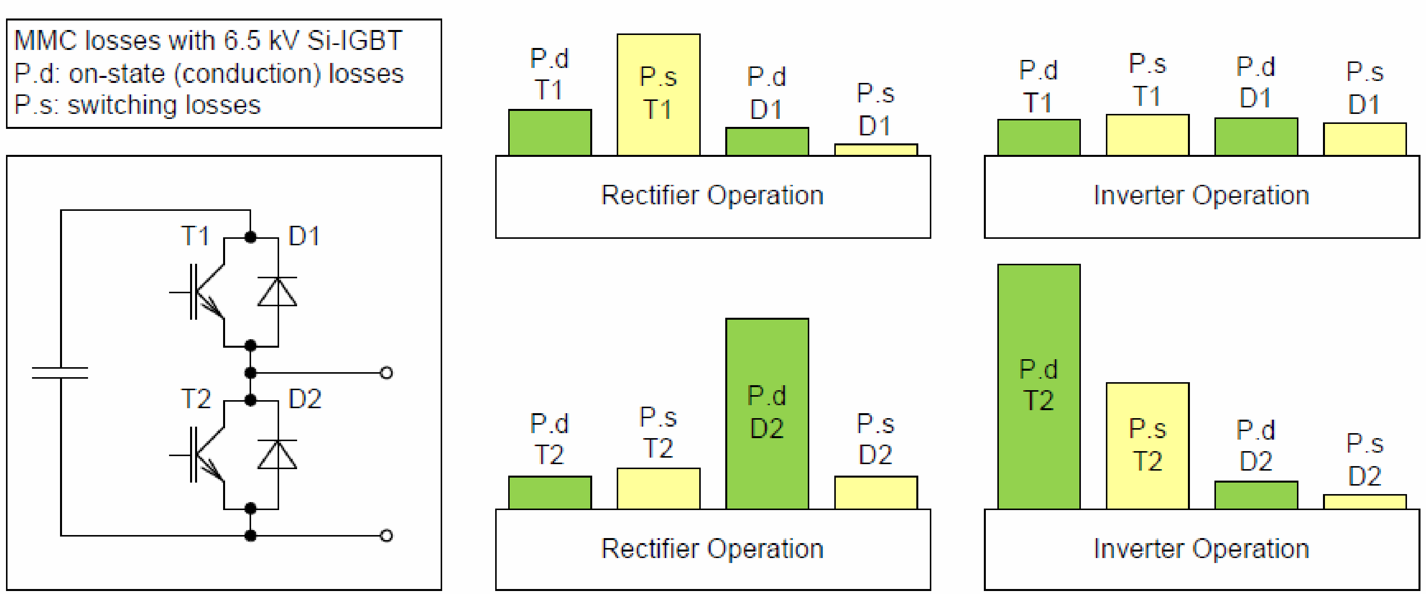
HV DC Transmission

- **Conversion**: Voltage Source Converters
  - Two-level converters
  - Three-level converters
  - Multi-level converters
    - Modular Multi-Level Converters (MMC)
    - Alternate Arm Converters (AAC)
- **Protection** : HVDC Circuit Breakers
  - Hybrid Circuit Breaker (HCBs)
  - Solid-State Circuit Breakers (SSCBs)

MMC for VSC-HVDC

HVDC VSC equipped with 3.3 kV, 4.5 kV or 6.5 kV Si-IGBTs are the backbone of high power, long distance electrical energy transmission. A major design criterion = efficiency.

Loss distribution in a MMC submodule for HVDC



ECPE Joint Research Programme 2017: VHV SiC IGBTs and Diodes: Potential and Challenges for HV Converters; Prof. Kaminski, University of Bremen and Prof. Eckel, University of Rostock

MMC for VSC-HVDC

Application	power loss	operating hours per year	energy loss per year	lifetime resp. time for return of invest	energy loss during lifecycle	energy costs	**costs of power losses per IGBT module**
	[kW]		[kWh]	[a]	[MWh]	[€/MWh]	**[k€]**
HVDC Grid connection	3	8500	25500	20	510	39	**20**
HVDC Grid connection	3	8500	25500	8	204	39	**8**
Offshore Wind Power HVDC Connection	3	4000	12000	20	240	139	**33**
Offshore Wind Power HVDC Connection	3	4000	12000	8	96	139	**13**

Penalty for the losses of one Si-IGBT module is more than a factor ten higher than the production costs of the module.

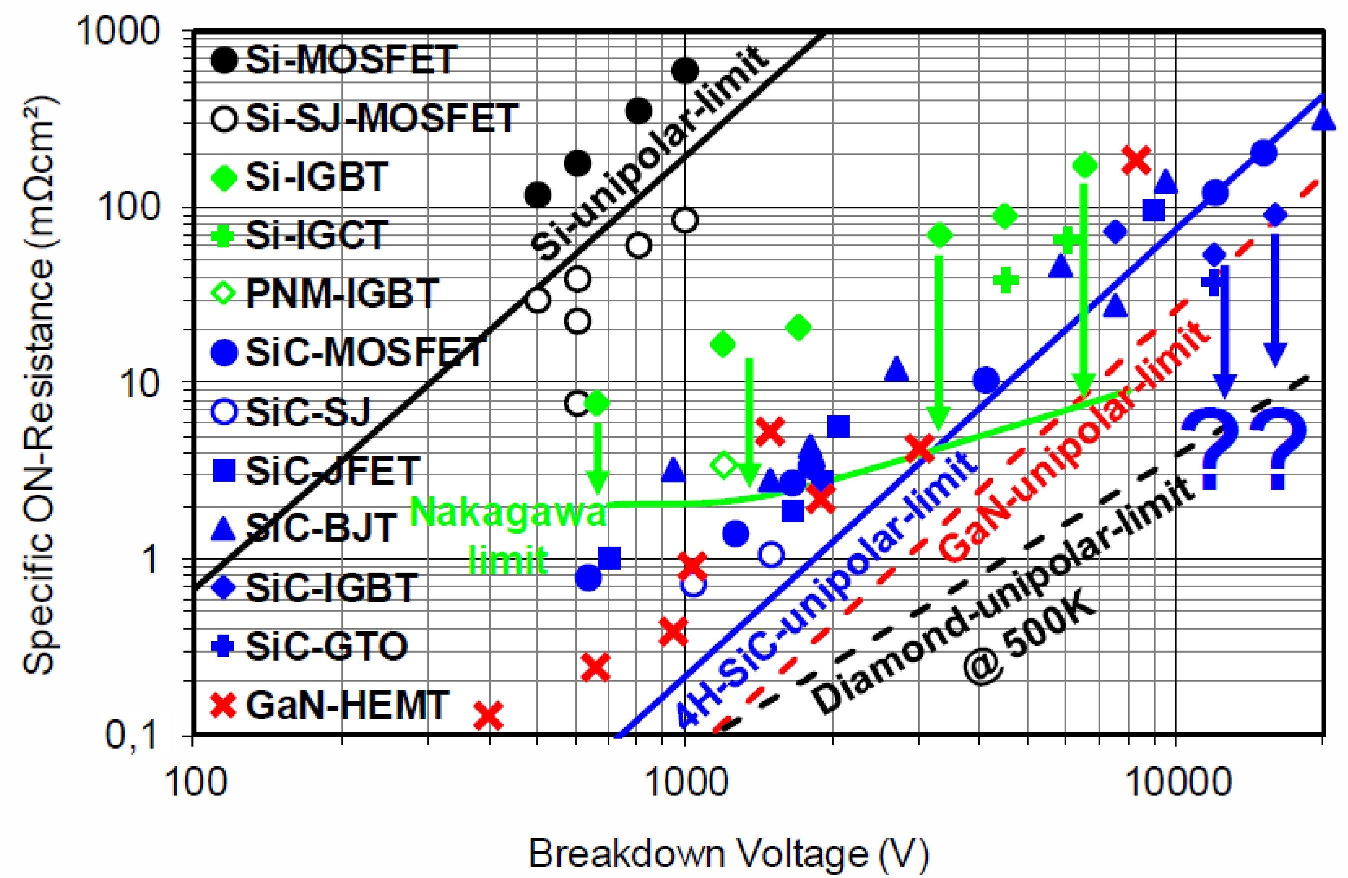
→ An increase in semicond. costs is justified by significantly lowered losses.

VHV bipolar SiC-IGBTs and SiC-diodes (10 kV – 20 kV) would allow replacement of the 2 - 3 in series connected Si-IGBT modules by one SiC-IGBT module.

→ The loss reduction by more than factor 2 could be achieved.

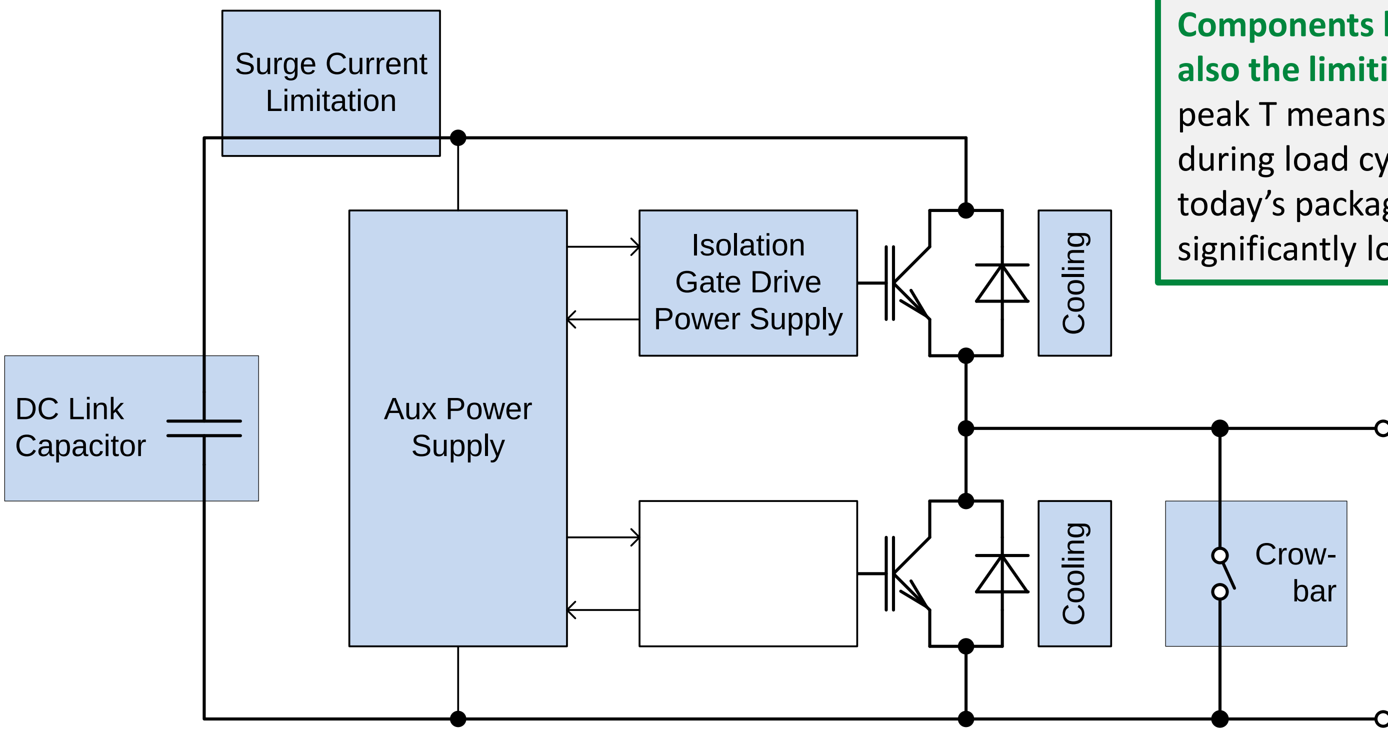
MMC for VSC-HVDC

A **SiC-IGBT optimised** by considering application specific trade offs between on state loss, switching loss and blocking voltage is needed.



MMC for VSC-HVDC

Critical system aspects and other critical aspects for VHV to be investigated regarding MMC with DC-link voltages 10 kV -20 kV

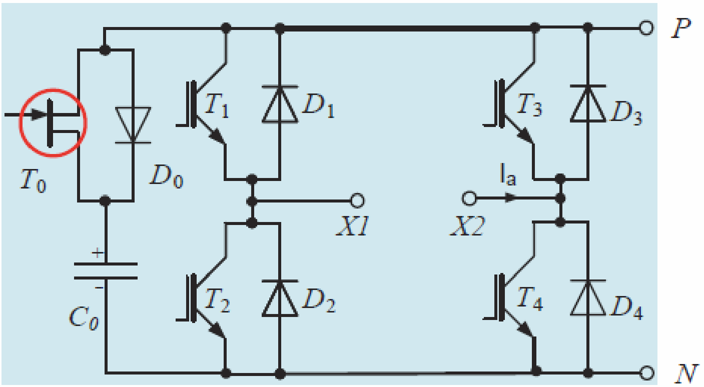


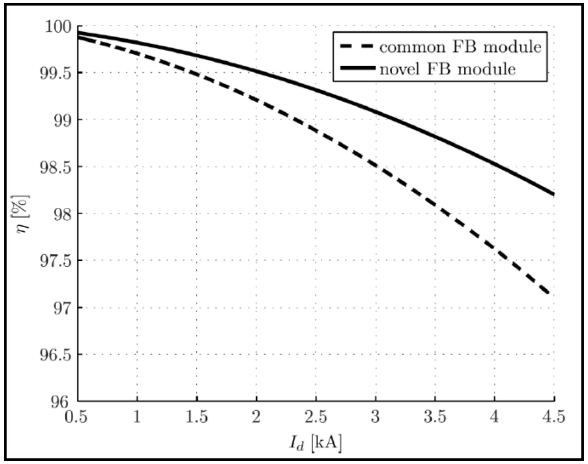
Components level packaging is also the limiting factor. Higher peak T means higher T swings during load cycling and using today's packages leads to the significantly lower lifetime.

ECPE Joint Research Programme 2017: VHV SiC IGBTs and Diodes: Potential and Challenges for HV Converters: Prof. Kaminski, University of Bremen and Prof. Eckel, University of Rostock

New MMC Topologies for VSC-HVDC

- Example of FB topology with combination of Si and SiC semicond.
- Introduction of controllable DC-capacitor – realized by a reverse conducting SiC-FET
- On state AND switching losses can be reduced. Reduction of total power loss up to 40 % (6.5 kV-IGBT)
- Reduced size of capacitors
- Further improvement possible with optimisation of semiconductor devices
- Other possible topologies (FB+HB)

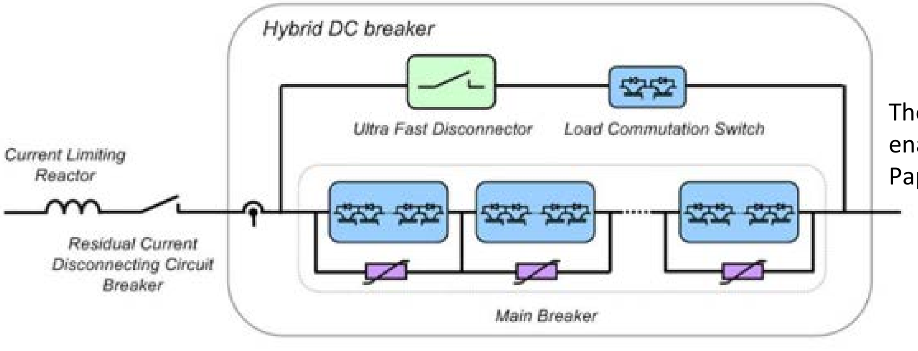




ECPE CLINT Project (BMBF-Fördermaßnahme) 2016: SiC-Development for Multilevel-Topologies, R. Marquardt, Uni of Bundeswehr

HVDC Breakers

- Short circuits at the DC-side when using conventional VSC. An electronic DC-current limiting can be realised in MMC by:
  - o Submodules with FB functionality
  - o Electronic or Hybrid DC-Breakers at the DC-side of the converter
- Criteria for DC-Breakers: on-state voltage, robustness, speed



The Hybrid HVDC Breaker, An innovation breakthrough enabling reliable HVDC grids, ABB Grid Systems, Technical Paper, 2012

- Implementing WBG semiconductor devices:
  - o SiC bipolar or even SiC Nakagawa IGBT could be an option for VHV
  - o The rest of the circuit unchanged

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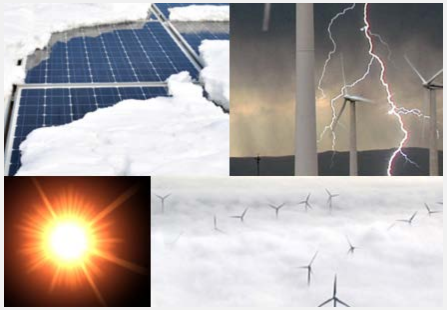
More reliable, cost-effective PE systems

- Long operation hours under harsh environments.
- Power semiconductor modules are the major failure source in the products (1).
- The general objective: to improve the safety, the longevity, and the life-cycle cost of PE devices.



The enabling technology is (also) **Condition and Health Monitoring** (2) which implies:

- Estimate State-of-Health
- Estimate End-of-Life
- Optimised maintenance actions and possibility for max. usage before failure
- Active stress management
- Safer handling of severe events

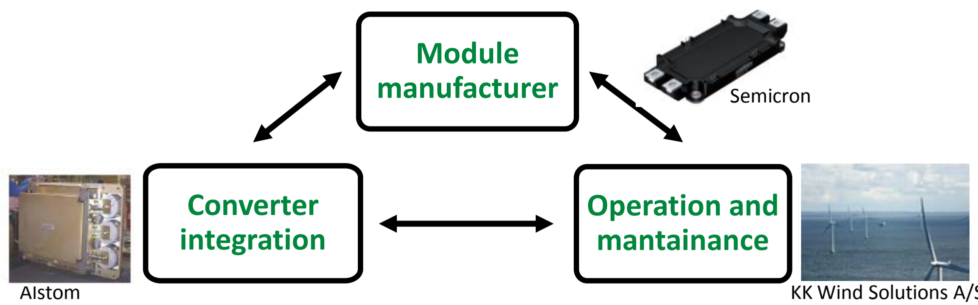
(1) ECPE Joint Research Programme 2016, Investigation of reliability issues in power electronics, P. Zacharias - Uni Kassel, M. Lissere - Uni Kiel

(2) ECPE Workshop: Condition and Health Monitoring in Power Electronics, Aalborg, Denmark, July 2017

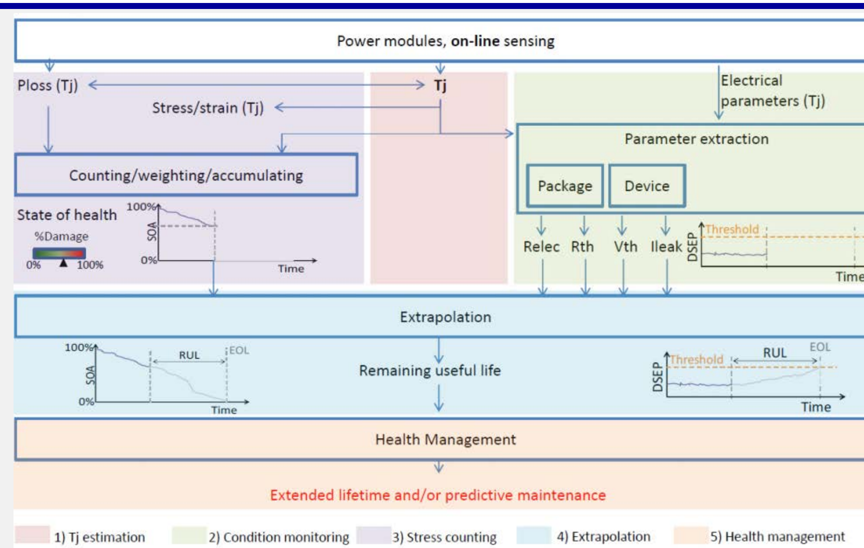
More reliable, cost-effective PE systems

The need for C&H M for power semicond. modules is perceptible but:

Business case realization requires communication - involvement of different partners!



Scientific and engineering challenges still fail to provide a low-cost and reliable field prognostic.



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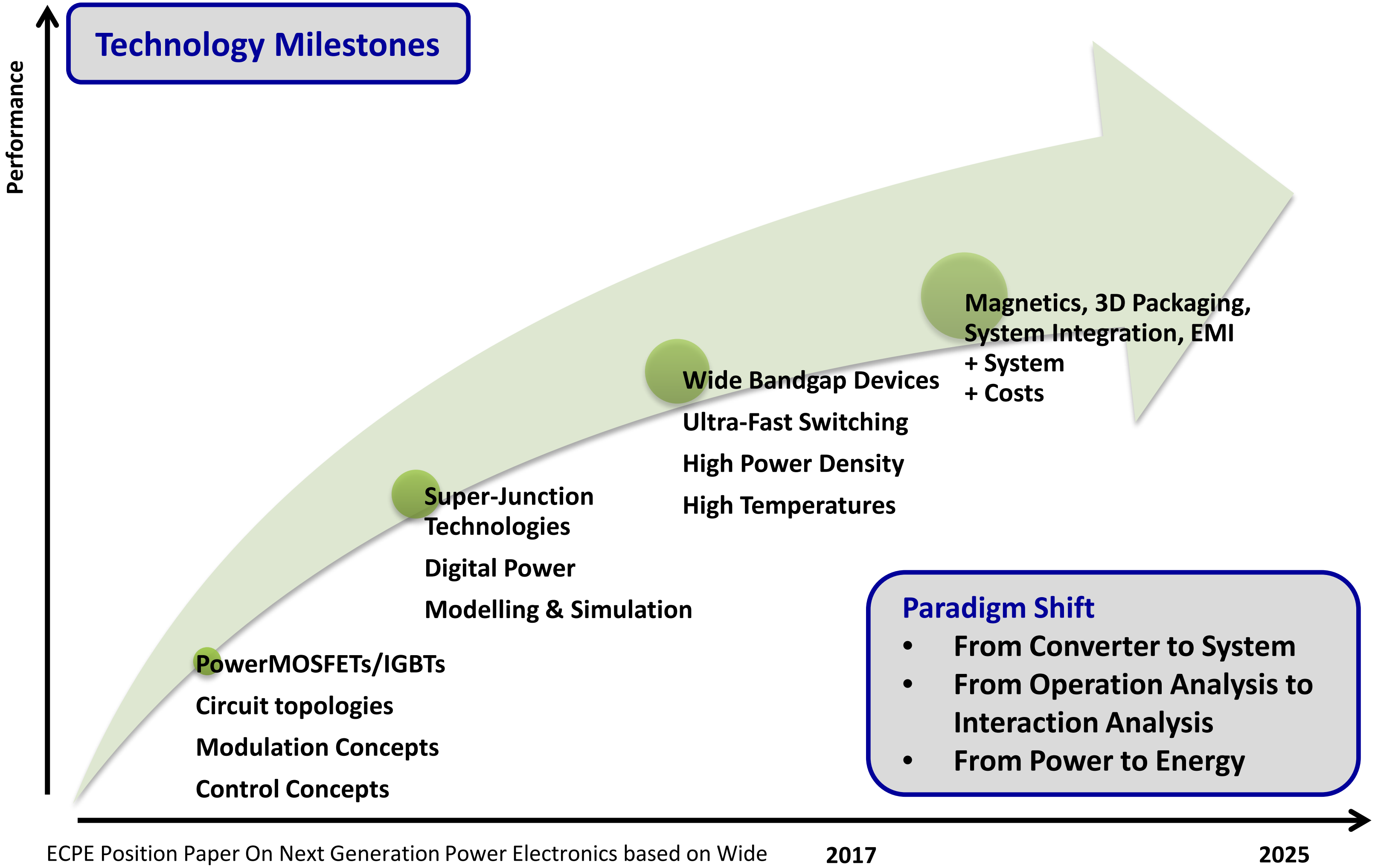
Conclusions

- The power semicond. device is the key driver/enabler in PE systems.
- WBG devices opportunities are numerous.

- WBG devices in DC/DC converters:
  - SiC and GaN improve efficiency
  - The passives can be smaller, lighter and cheaper
  - System advantages achievable
- WBG devices in HVDC MTT grids:
  - Optimised SiC semiconductor devices for MMC VSC
  - Combining Si- and SiC-devices in the novel MMC topologies

- All elements of the solution have to be optimised together addressing respective objectives of individual application!

Conclusions



ECPE Position Paper On Next Generation Power Electronics based on Wide Bandgap Devices - Challenges and Opportunities for Europe, 2016