Fraunhofer IISB

FRAUNHOFER INSTITUTE FOR INTEGRATED SYSTEMS AND DEVICE TECHNOLOGY IISB

# ENERGY ELECTRONICS




## Our Energy Electronics Expert Teams

### Application

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- Product  related engineering
- Impartial design reviews
- Lifetime optimized systems
- System failure analysis

### Energy Systems

**Head: Dirk Malipaard**

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- Power electronics for electric grids
- Megawatt power electronics
- System modeling and design
- Power device and system characterization

### Battery Systems

**Head: Dr. Vincent Lorentz**

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- Hardware and software for electrical energy storages
- Modeling of electrical energy storages

### DC Micro Grids

**Act. Head: Bernd  Wunder**

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- Power electronics for local DC grids
- Energy management and control
- Safety concepts and components

Fraunhofer
IISB

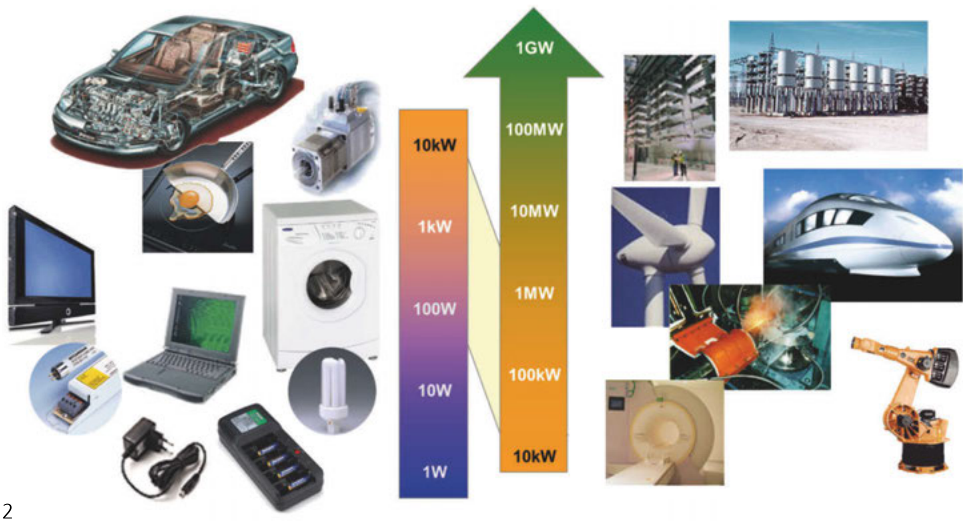
# The Power Electronics Innovators

Our mission is to advance power electronics into new ranges of performance and to help our customers in opening new fields of applications. Finding creative and customized solutions - if necessary offside from beaten tracks - is our incentive.

Fraunhofer IISB offers the whole R&D chain, from base materials over semiconductor processes and components, power modules up to power electronic systems for the main application fields mobility and energy.

Highly qualified teams of engineers and technicians work in a number of excellently equipped power electronics laboratories with access to a wide range of simulation and design tools, modern measuring, testing and analysis equipment, as well as cutting-edge assembly and joining technologies. The fact that we apply latest components, materials, and methods goes without saying. Regular expert seminars on selected power electronics topics are part of our professional training offer.

For an overview on all activities of our power electronics competence center please also refer to the brochures on vehicle power electronics, devices, modules, and reliability (available from our homepage www.iisb.fraunhofer.de).

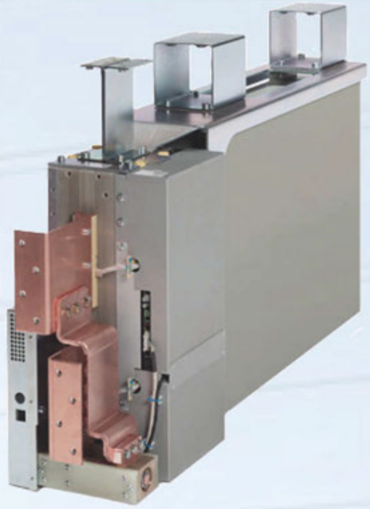


3 Source: Siemens

# Megawatt Power Electronics for Electric Energy Transmission

The ongoing transformation of the public energy supply to a self-sufficient system based on renewable energy sources will speed up significantly in the coming years. This process is directly associated to an increased use of power electronic systems, affecting the whole energy supply chain from generation over transport and distribution up to the consumers. Advanced power electronic systems are the key to higher transmission efficiency and stability of the whole grid.

Since 2005, Fraunhofer IISB successfully concluded numerous research projects with the focus on power electronics for advanced electrical energy networks. This includes basic research work as well as industrial development projects with the objective of developing and qualifying components ready for series production. Main goal is to increase the efficiency, availability, and lifetime of the systems at reduced overall system costs.



4) Basic switching cell (3.3 kV / 1500 A) of a modular multi-level converter ■ Fraunhofer IISB design running in series production

## Our Focus

- High-power, high-voltage solutions for HVDC links, static VAR compensators, and active filters
- Active frontends for grid-compatible power electronic systems
- Safety, monitoring, and protection elements for high-voltage grids (e.g., DC breakers, crow-bars, current sensors)
- System designs for very high lifetime and availability requirements

## Our Offer

We offer a wide range of design support for industrial customers with a special focus on:

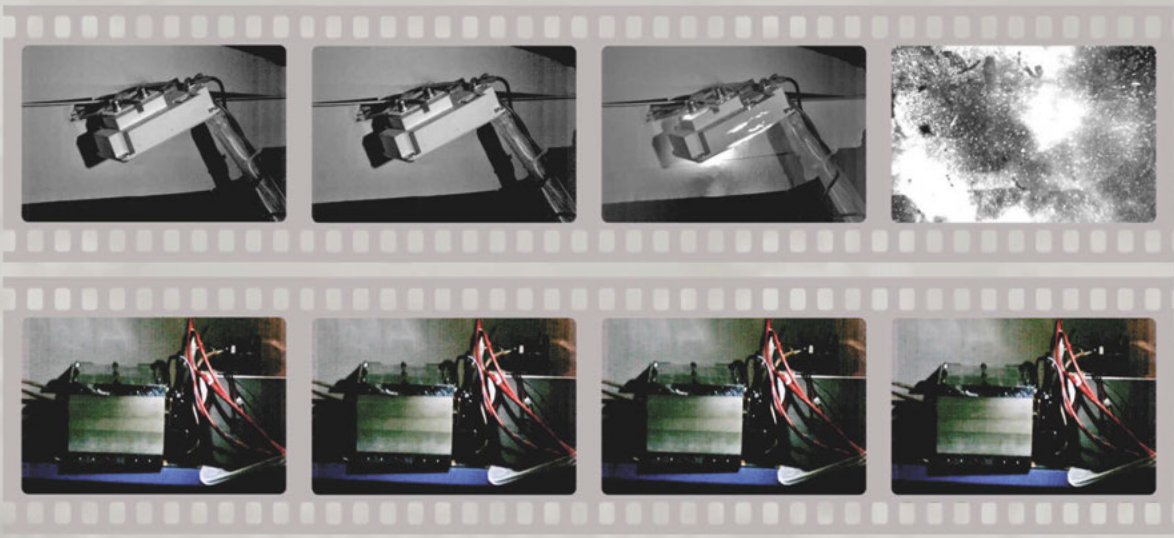
- Topology and system analysis
- System design and prototype development
- Failure analyses and design reviews
- Component and system characterization

5) Modular multi-level converter with 66 submodules for static var compensation (SVC) in a medium voltage power grid (Source: Siemens)

### Topology and System Analysis

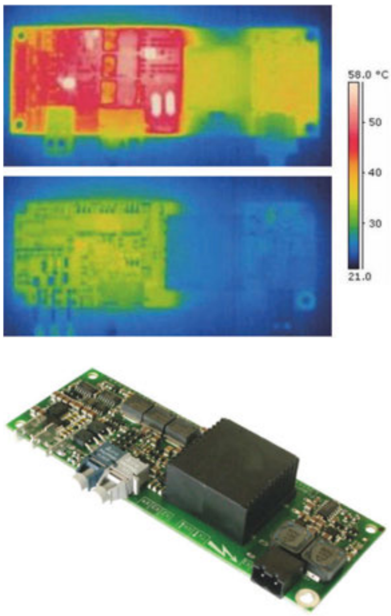
Based on years of experience in the design of power electronic systems in all power ranges, the Fraunhofer IISB offers support in:

- Compilation of specification, evaluation of applicable standards
- Analytical and numerical circuit and system simulations (using Mathcad™, Matlab™ / Simulink, Plecs, or Spice)
- Benchmarking of different topologies





6) Experimental investigation of hazardous events with a high-speed camera.
Top frame: 1.7 kV IGBT module without enclosure - debris damage converter system;
Bottom frame: Hazard proof IISB solution - debris fully captured




7) HV IGBT driver
Top: IR thermography of initial customer situation ■ Bottom: IR thermography and photo of matched Fraunhofer IISB design

### System Design and Prototype Development

To meet the high and often contradictory requirements regarding reliability, availability, efficiency, power density, and system-costs an integrated system design incorporating mechanical, electrical, and thermal design aspects is essential.

Prototypes are mandatory for a qualified engineering assessment of the performance in an early phase of the design process, too. We offer a complete prototyping process chain from 3D construction to assembly of first small batch series. This includes designs close to series production based on available industrial components as well as proof-of-concept studies involving experimental parts and assembly technologies. In cooperation with our in-house technology experts, we can offer prototyping services starting at bare-die level.

### Failure Analyses and Design Reviews

We perform design reviews in all stages of development. This includes a general view, e.g., assessment of potential sources of failure at system, circuit, and production level. We offer analysis of field rejections and review of possible breakdown scenarios based on decades of experience in power electronics system design.

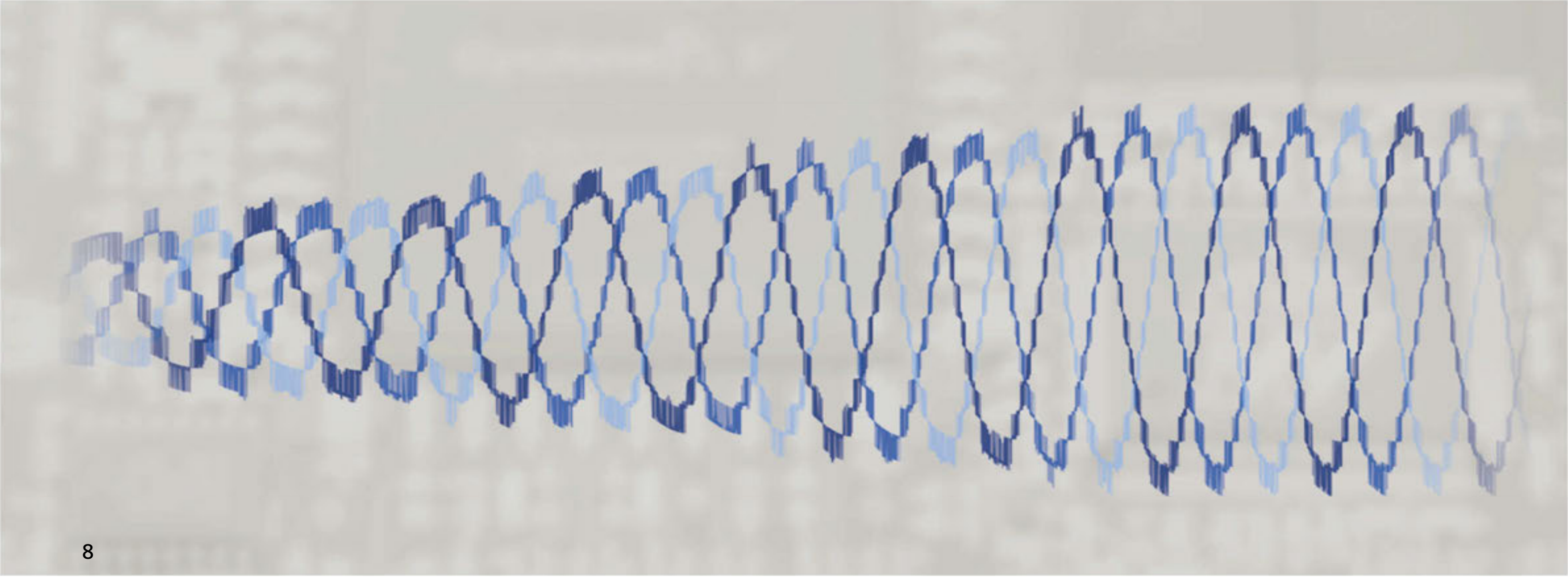
### Component and System Characterization

We can provide many years of experience in reliable characterization measurements for industrial customers. Our test capabilities comprise, among others:

- Analysis of high-energy failure scenarios (with high-speed camera system and current sensors up to 800 kA)
- Thermal characterization ($Z_{th}$, lock-in thermography, thermostats and climate chambers from -60°C up to 300°C)
- Lifetime and reliability tests (active and passive temperature cycling, HALT, electrical stress, vibration)
- Partial discharge measurements (IEC 60270)
- Static and dynamic characterization of power semiconductors (semi-automatic test benches for fine-meshed and reproducible characterization of the switching behavior throughout the entire operating range (up to 6500 V and 6 kA))

## Project Examples

- Design of a switching cell for modular multilevel converters (3.3 kV / 1500 A); complete project cycle from concept phase to series production launch (Fig. 4)
- Development of constructive solutions to limit the impact of fatal error cases (Fig. 6)
- Development of a HV IGBT driver that fulfils exceptional lifetime and reliability specifications, immune against extreme electromagnetic fields (Fig. 7)
- Development of explosion-proof safe auxiliary power supplies



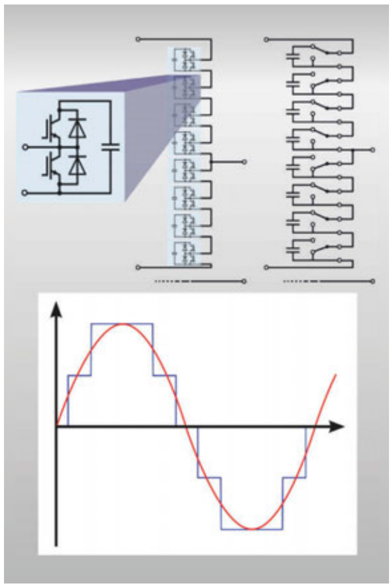


# Multi-Level Converters

With the rapid increase of power electronic systems in electrical energy grid applications multi-level topologies gain in importance. These converters allow overcoming the specific weak points of high-blocking voltage semiconductors with respect to their static and dynamic properties. Multi-level systems are therefore the key technology for efficient and cost-effective power electronic systems in high- and medium-voltage applications. Multi-level systems provide also better EMC performance, which allows the reduction of system size and costs. The low line perturbations of these systems and a general "grid-compatible" behaviour become more important with increasing dominance of power electronic systems in the electrical energy grid.

Based on these specific characteristics, multi-level converters are used in many areas of electrical energy conversion. The term "multi-level" comprises various converter topologies. Depending on the specific application, different power electronic topologies represent the optimal solution.

Today, in the electrical energy grid, the well-known three-level NPC inverters are widely used for small and medium power solar inverters and a new family based on the modular multi-level (MMC/M2C) principle has found its way into high-power and high-voltage transmission systems (HVDC, SVC). Besides grid tied systems, many other applications can be covered by multi-level converters, for example high-performance drives for industrial, railway, or naval systems.

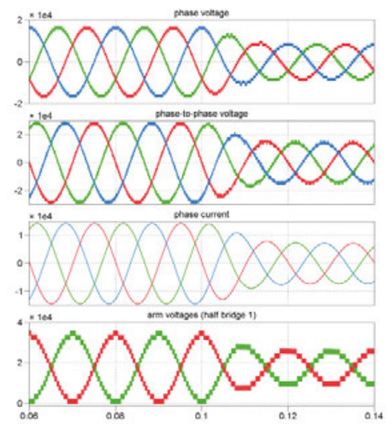


9) Basic principle of a modular multi-level converter (M2C)

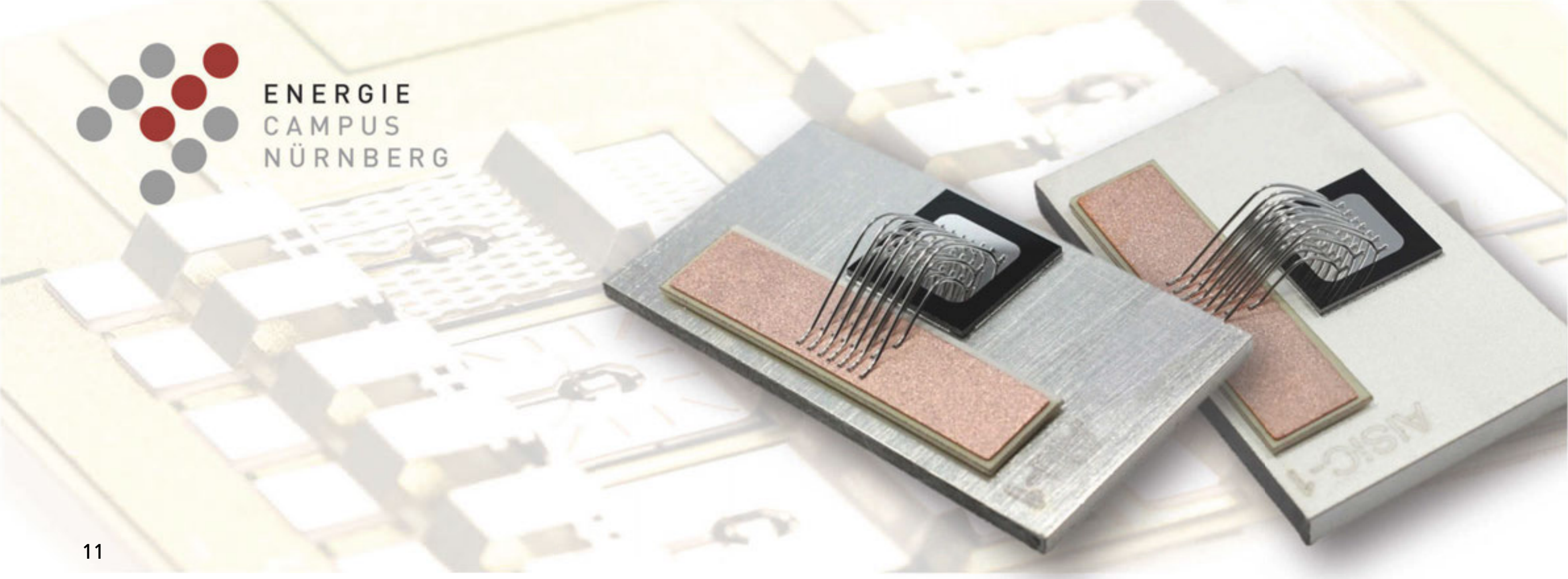
## Focus Applications and Current Projects

At Fraunhofer IISB, we develop multi-level systems optimized especially for customer specific applications in all power and voltage ranges. Teams of engineers with many years of industrial background and experience from numerous projects enable us to offer support in a wide area of power electronics-related problems with a special focus on:

- System evaluation and topology benchmarking
- Customer-specific designs, including construction, assembly, and characterization of prototypes
- Technical benchmarking of systems to evaluate the current market situation for new customer product definitions
- Design of optimized power modules for multi-level converters
- Rapid prototyping for the benchmarking of new technology approaches close to the target application
- High-power converters for medium- and low-voltage drive applications

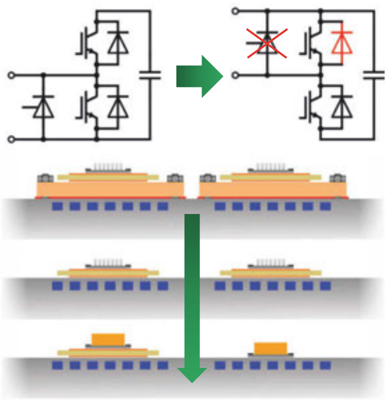



10) Numerical circuit simulation of a modular multi-level converter

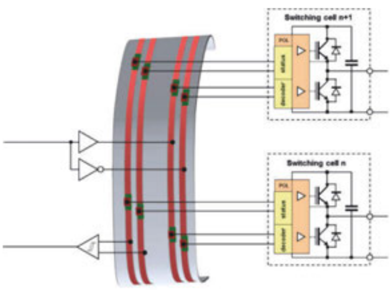




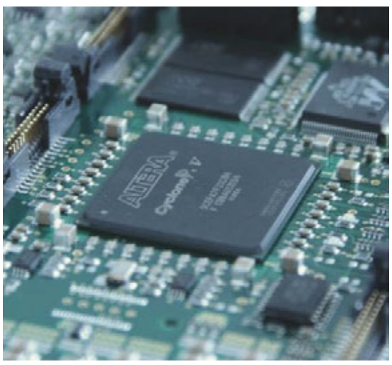
11) Direct baseplate bonded power semiconductors for superior thermal performance and overload capability



12) Novel design concepts for optimized M2C switching cells




13) Innovative, cost effective control bus solutions for multi-level converters



14) Highly functional control electronics for multi-level converters

## Power Modules for Multi-level Converters

State-of-the-art multi-level converter systems make use of power semiconductors in industrial standard-packages with isolated baseplates. For applications in the energy grid a system lifetime of 40 years and more has to be guaranteed – a real challenge against the background that power electronics at all exists for only about 35 years.

Compared to traditional two-level topologies, multi-level systems have special requirements regarding the power modules. On the other hand, several of these topologies provide additional degrees of freedom.

In order to optimize the complete converter system Fraunhofer IISB is developing and qualifying new specific power modules. These power modules are required to utilize the full potential of modern power semiconductors in multi-level systems. By using specially adopted joining technologies the system lifetime is increased compared to state-of-the-art modules. New application-specific power module concepts allow the integration of protection mechanisms to improve the converter behavior and availability in case of system or device failures.

## Control of Multi-level Converters

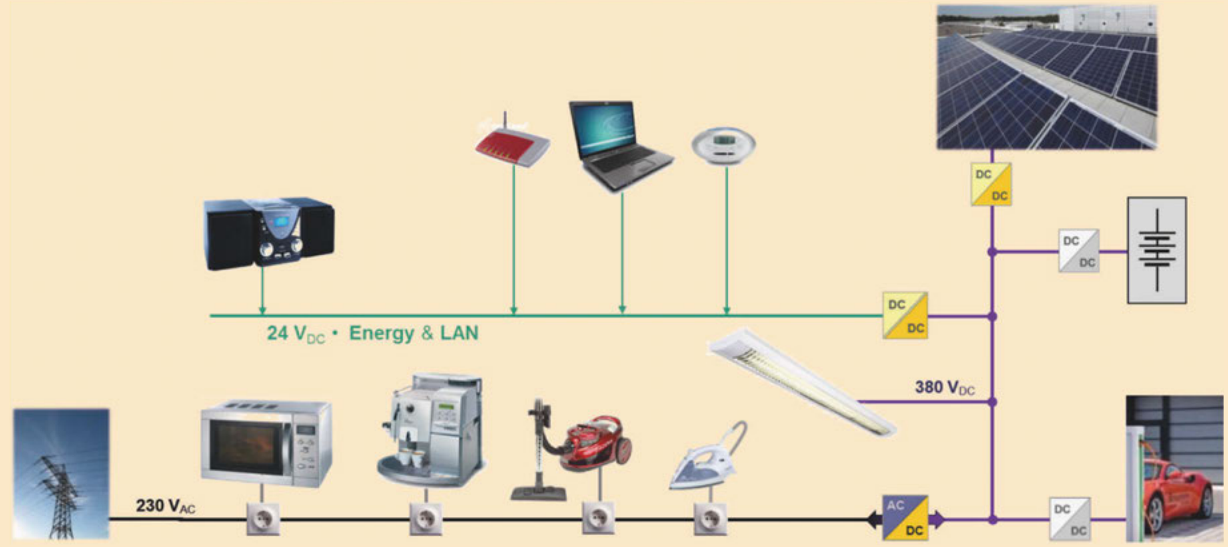
One drawback of multi-level topology concepts is the increased number of semiconductor switches to be controlled. Especially for systems with small and medium power, the control effort can represent a significant proportion of the total system cost. Fraunhofer IISB is developing optimized control and communication systems as key elements for cost-efficient multi-level systems. The work is focused on:

- Innovative communication concepts for cell based multi-level systems
- Development of control boards and decentralized control solutions
- Optimized IGBT and MOSFET drivers with special functions for multi-level control

## Customer-specific System Designs

We offer a wide range of design support for highly demanding customer applications:

- System design and optimization considering multi-level concepts
- Improvement or redesign of existing electronics systems with respect to efficiency, reliability, and/or cost
- High-power static frequency converters for medium- and low-voltage applications
- Cost optimized system solutions for small and high-volume production
- Design for manufacturing and high reliability

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# Local DC and Hybrid Grids

The massive expansion of renewable energy sources will involve a wealth of change in electrical energy supply. An important aspect arises out of the transition from a centralized to a highly decentralized supply system.

For reducing system cost and achieving highest efficiency in providing electric energy, DC based systems and grids will play key roles in future. This is due to the intrinsic DC characteristic of the main elements, like photovoltaic generators and electrical energy storages, and the elimination of many inefficient DC-to-AC and AC-to-DC conversion steps in the case of direct supply of the large number of electronic loads.

## Our Focus

- Highly efficient and cost-effective DC/DC converters
- Innovative solutions for DC connectors, switches, and protection elements
- Control strategies for converter-based DC-grids incl. grid stability analysis
- Characterisation and testing of all kind of DC-Grid components up to 1500 VDC
- Integration into smart building concepts for modern lifestyle applications
- Active AC frontends

## Application Center for Highly Efficient Power Supply Solutions and DC Grid Technologies

The Fraunhofer IISB office and lab building is already equipped with a DC grid system. We steadily increase and optimize this DC application platform to achieve a maximum in efficiency, functionality, and user comfort.

All necessary key components are developed at Fraunhofer IISB together with our industrial partners. Examples are a battery storage system, different DC/DC and AC/DC converters, a DC Grid Manager for controlling the energy flow, and several safety components for typical DC grids in 380 VDC or ±380 VDC configurations. A proprietary DC fast charging solution allows the cost effective realization of e-car charging stations.

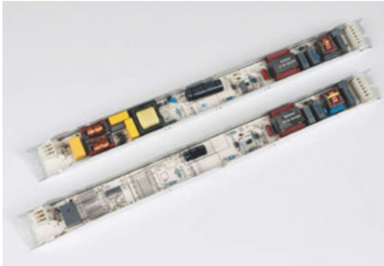
This unique platform is open also for our industrial partners and offers:

- Application-oriented testing of DC micro and nano grid components
- Data acquisition under realistic operational conditions
- Optimization of the energy flow between different sources, loads, and energy storage devices; evaluation of control strategies
- Education and advanced trainings in the field of next generation power supply and local grid technologies

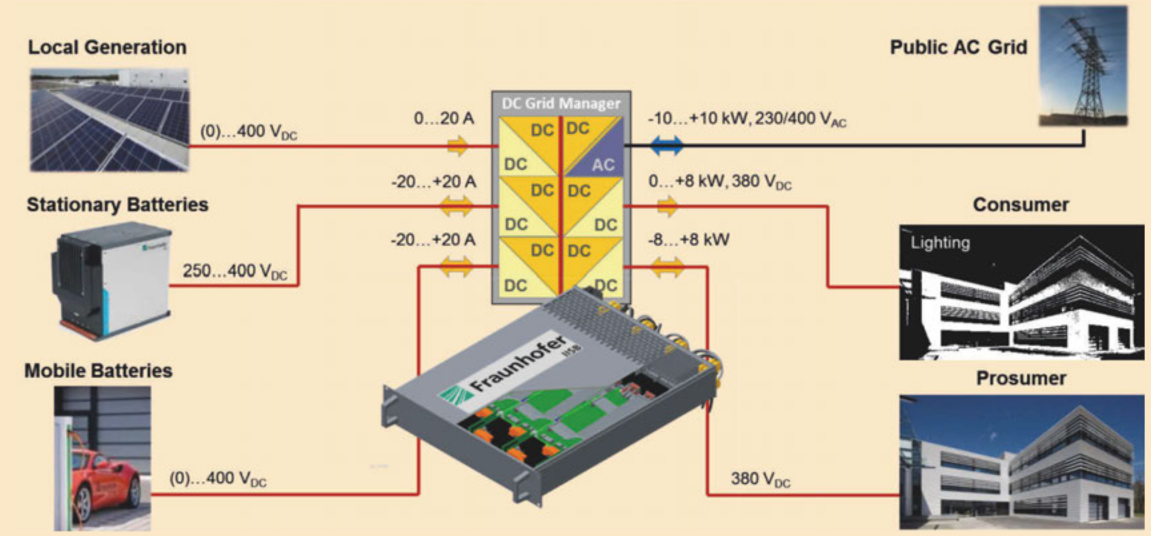
15) The illustration shows how different DC-based micro and nano grids can cooperate for improved energy efficient, functionality, and system cost reduction

16) Bidirectional isolating DC/AC bridge (3.7 kW) with two DC/DC channels for MPP tracking of PV strings (3.7 kW) and one bidirectional DC/DC channel (7.4 kW) for the management of a stationary battery

17) HV-DC switch board for office light control: six channels each 380 V / 1 A for 6x 50 W fluorescent lamps (DIN rail mounting); suitable for capacitive inrush



18) DC fed lamp ballasts (bottom) allow a great cost and size reduction compared to their AC versions (top) – same applies for LED drivers

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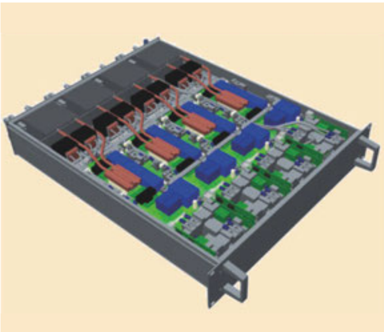
19) The universal DC grid manager – a system solution from Fraunhofer IISB



20) Rack mounted (19") multiport DC/DC converter (8 bidirectional channels each with 20 A; max. voltage 430 V, efficiency 99%); CAN interface

21) Innovative LV-DC socket and connector solutions: arc free, application specific output voltage, zero stand-by power

22) Drive inverter for direct motor attachment with an innovative cooling solution based on thermally enhanced polymers.

# Grid Components and Appliances

The realization of the sophisticated EC efficiency targets is a challenge especially in the case of AC supplied appliances. With a DC grid approach the power supply of most applications can be implemented with much easier circuit topologies, higher efficiency, a lower number of components, and considerable lower costs.

The illustrations (15) and (19) show how an energy efficient cooperation between diverse applications can be realized in a DC based micro grid. The backbone, e.g. within a building, is formed by a "high voltage" DC grid, supplied from renewable sources and/or the public AC grid. Examples of our priorities and current projects:

## Customized Converters

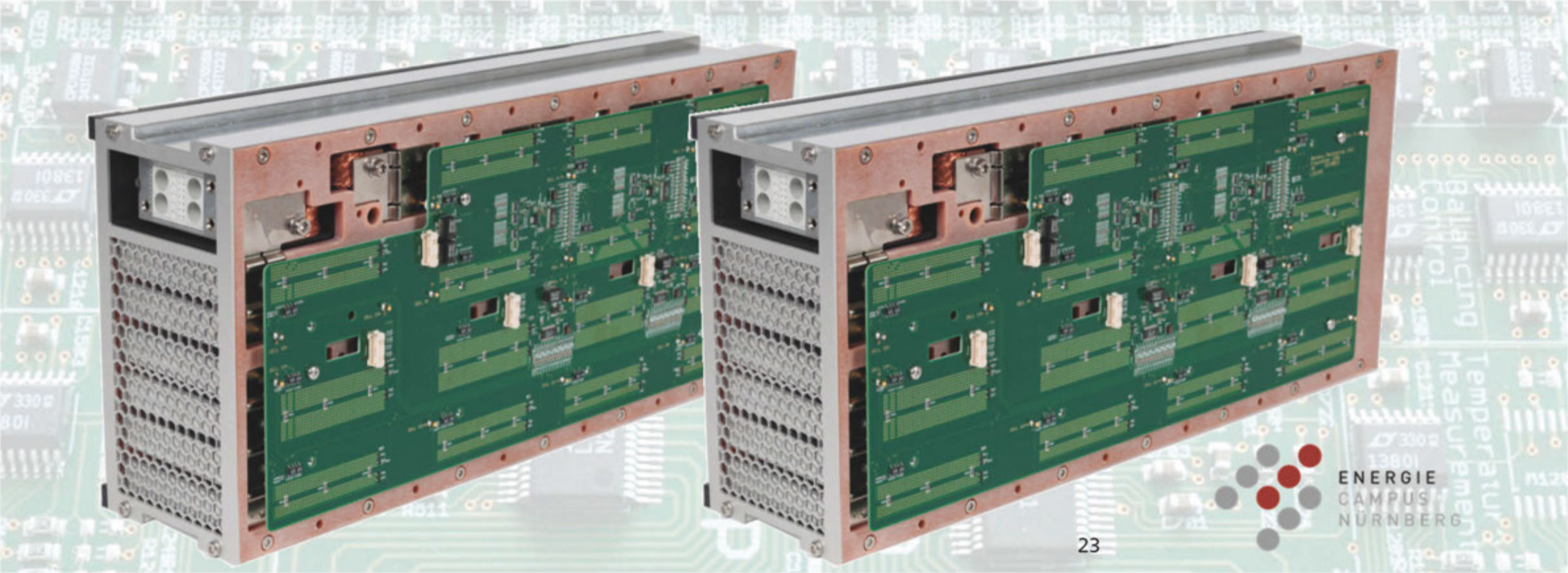
- DC/DC converters for all kind of energy management tasks
- For single and bipolar DC grids (e.g., +/-380 V three wire grid)
- Up to 200 kW per power channel
- Standard max. voltages 430 V and 850 V (higher voltages on request)
- Low DC link capacitance versions for lowest fault energies
- User configurable sink/source operation with current a/o voltage control, individual current limiting and short circuit characteristics, higher level control functions like MPP tracking or battery charging.
- High control dynamics for fast error-control and special safety and protection functions (e.g., arc-blanking)
- Innovative droop control allows smart grid functionalities without an overlaid high-speed data link between the grid components
- Isolating bidirectional AC/DC converters for the coupling of AC and DC grids

## LV-DC Power Socket with Variable Voltage

- Automatic detection of the right application voltage (5-24 V)
- Only one plug for all applications (mobile phone, notebook, monitor, etc.)
- Up to 100 W, efficiency up to 98%
- Less volume and costs
- Eliminates the chaos of numerous AC-adapters

## Inverter Drives for Low-cost Applications

- Cost optimized system designs
- Mechatronic system integration
- Inverters for DC a/o AC supply




23) Air-cooled battery module for 19” cabinets (35 V, 320 A, 1.4 kWh, LTO cells)

# Battery Systems

Advanced and innovative solutions for electrical energy storage systems. Our focus is on full-custom cost-efficient electric energy storage and management system solutions for mobile and stationary applications. The activities range from development of embedded energy management software up to the design of complex high-power energy storage systems for electrically propelled vehicles (e.g., automobiles, bikes, motorcycles and other types of road vehicles, aircrafts, ships, and submarine vehicles) and for smart grid applications in combination with renewable energies (e.g., in private household and industrial utilization).

### Battery System Design

- Definition of the overall system requirements (e.g., energy and power capability, interfaces)
- Selection of the best-suited cells based on our internal database
- Modeling of the electrical, mechanical, and thermal parameters of the cells for the specified system

### Battery Mechanical Design

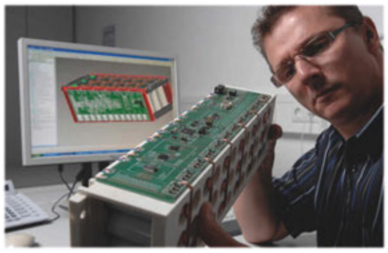
- Definition of the mechanical requirements
- Definition of the battery cell assembly method (e.g., laser welding, ultrasonic welding, clinching, screwing)
- Design of the battery modules with their power and signal connections
- Design of the battery pack overall assembly

### Battery Thermal Design

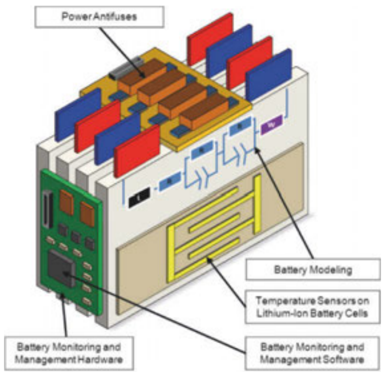
- Definition of the thermal requirements including cooling and heating functions
- Thermal design of the battery system by means of coupled electro-thermal simulations based on customized advanced FEM methods with powerful MOR (model-order-reduction) algorithms for system level analysis (combination with CFD also possible)
- Definition of the thermal management components depending on the type of cooling and heating methods specified (i.e., liquid or air)

### Battery Electrical Design

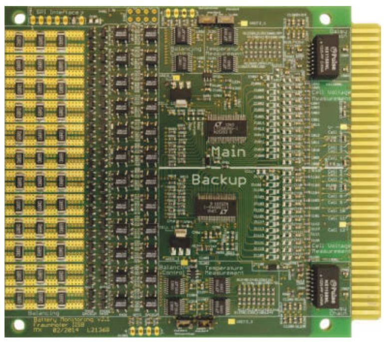
- Definition of the electrical requirements including safety aspects
- Design of the battery cell monitoring hardware
- Design of the battery management system (BMS) hardware based on the requirements to the analog and digital I/O
- Design of the battery junction box (BJB) hardware including, amongst others, power and pre-charge contactors, pre-charge resistors, fuses, current sensors, galvanic isolation fault monitoring
- Cell voltage equalization design



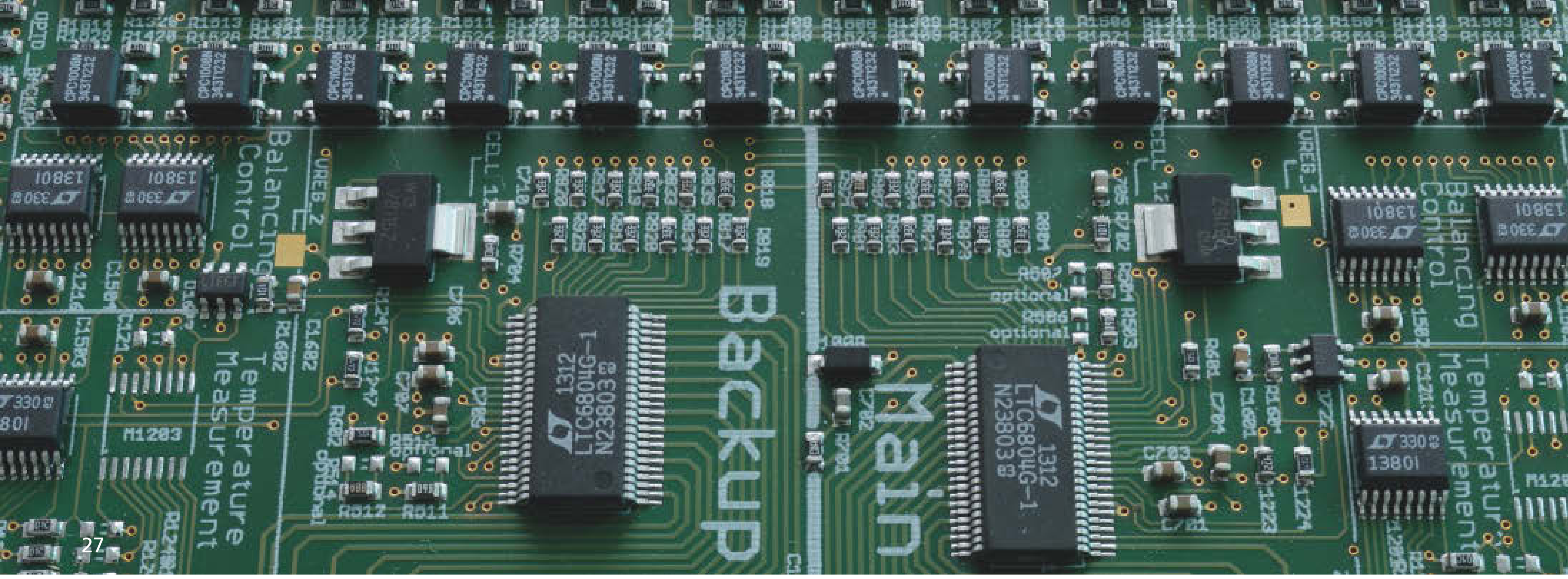
24) Full-custom battery system design, including mechanical, thermal and electrical engineering




25) Research and development topics in the fields of battery system design, sensor and actuator developments for battery systems at Fraunhofer IISB




26) High-end daisy chainable universal battery monitoring electronics with full redundancy for safety-critical high-availability applications offering up to ±1.2mV accurate cell voltage measurement, NTC-based or sensorless temperature measurement, active or passive balancing with balancing status monitoring

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## Battery Management Software Development

- Development and adaption of the battery management system (BMS) software (application level) by means of a continuous workflow based on industry standard tools
- Standardized AutoSAR 4.0-based software architecture that was customized for development flexibility and specific BMS needs
- Development of advanced algorithms for battery state estimation: state-of-charge (SOC) estimation based on Kalman filters (e.g., EKF, AEKF, UKF), state-of-health (SOH) and state-of-life (SOL), state-of-function (SOF), sensorless temperature measurement, charging strategies
- Modular design for fast adaption to specific customer demands and special features
- Development and adaption of the testing software for the functional tests of the complete battery system

## Battery System Integration

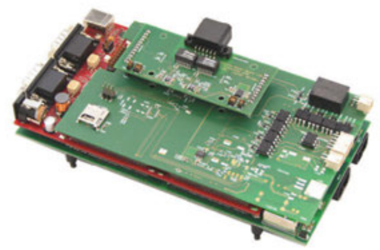
- Component fabrication and assembly (e.g., package manufacturing, bus bars manufacturing, bus bars welding)
- System assembly and integration
- Final tests and characterization

## Battery Modeling

- Electro-thermal modeling of batteries and supercapacitors on cell and system level with in-house-developed efficient computation solutions based on model-order-reduction (MOR) and parametric-MOR methods
- Electro-chemical modeling of battery cells for robust and accurate battery state estimation algorithms; generation of compact battery cell models for their implementation on the BMS microcontroller platform
- Powerful model parameter optimization algorithms for global offline optimization and for local in-system online optimization over the complete system lifetime

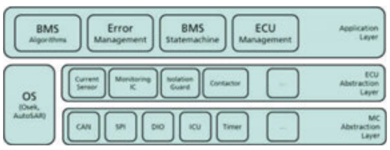
## Battery Testing

- Electro-chemical impedance spectroscopy (EIS) up to 1 MHz and up to 30 A
- Charging and discharging test on battery cell level between -1 V and 8 V and up to 440 A continuous current
- Testing of real or standardized driving cycles on cell, module and system level up to ±1000 V, ±1000 A, 500 kW

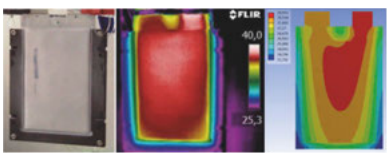


28) Highly modular battery management system (BMS) for mobile and stationary applications. Photo shows the safety and monitoring control boards with their analog and digital interfaces

29) Full-custom high-performance battery cabinet (480 V, 320 A, 20 kWh, 100 kW continuous charge and discharge) based on lithium-titanate (LTO) prismatic battery cells able to operate at temperatures between -30°C and 55°C.

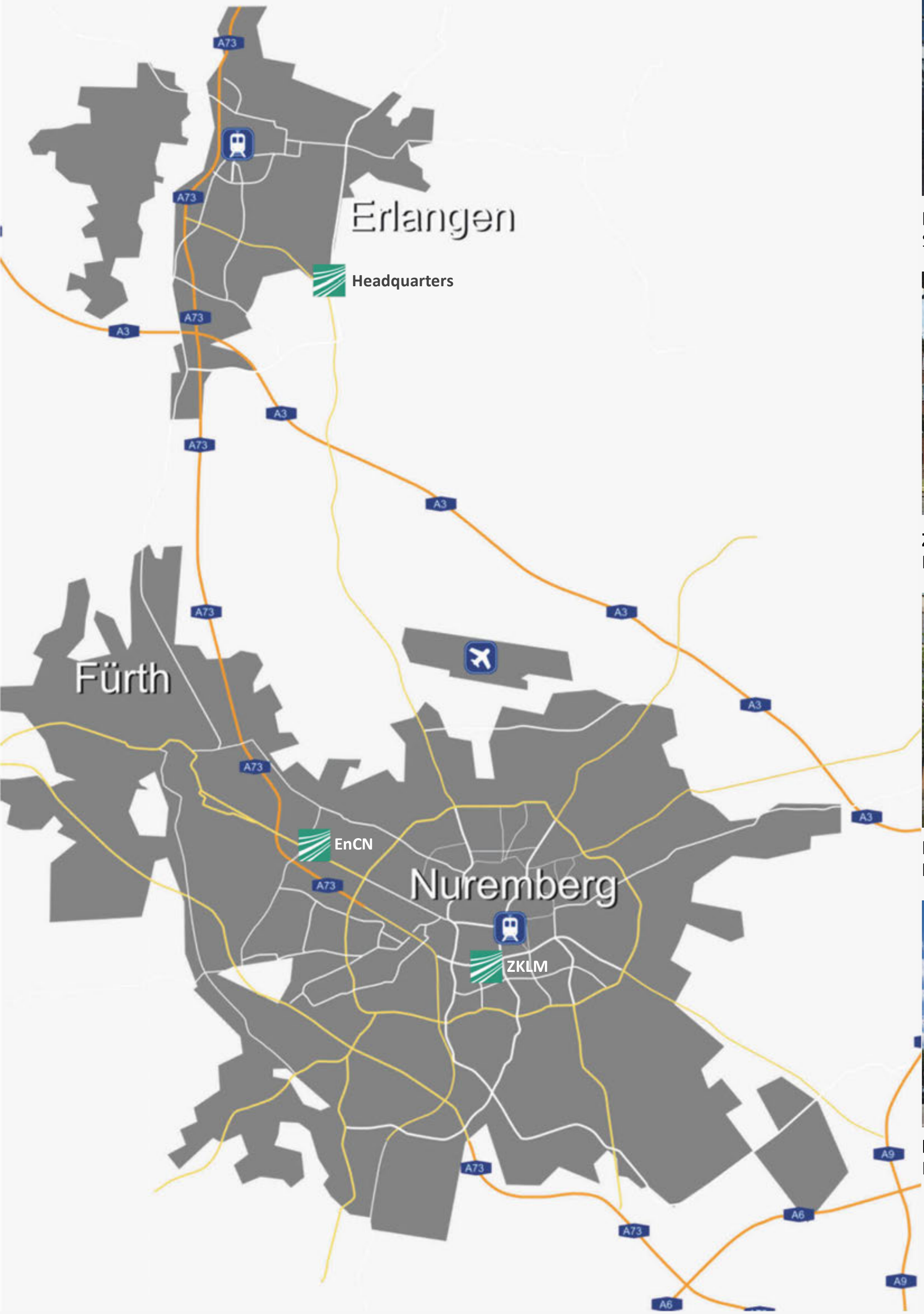



30) Software engineering for the battery management system (BMS), including battery state computation algorithms (SOC, SOH, SOL, SOF) and safety




31) Highly-accurate coupled electro-thermal modelling, simulation and characterization of battery cells and complete systems

# Your Way to Our Centers of Excellence

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