ISSUE 1 | JUNE 2024

PCIM MAGAZINE

EVENT EDITION

Your power electronics magazine for industry news, hot topics and insights

TALKING ON DATA CENTERS WITH KEYNOTE SPEAKER DEBOY
Page 6-7

SPOTLIGHT ON SUSTAINABILITY, E-MOBILITY AND ENERGY STORAGE
Page 12-17, 20-25

UNIVERSITY RESEARCH INSIGHTS
Page 28-32

Messe Frankfurt Group

mesago

pcim

Editorial

As we know, the world of electronics is a complex and fascinating one, full of possibilities. Often hidden from the spotlight, it still has an enormous impact on our daily lives and affects almost every facet of modern society. From energy efficiency and renewable energies to electromobility – power electronics is considered a key technology of the future. This potential is accompanied by growing and changing demands in this field. At the same time, solutions need to be designed more efficiently and reliably.

In this first issue of the PCIM Magazine, we are delighted to share practical insights into some of the pioneering developments and trends from industry and academia that are shaping our future.

In his introduction, Prof. Dr. Leo Lorenz, General Conference Director of the PCIM Europe Advisory Board, summarizes the main areas of development for power electronics in 2024 (p. 5).

As a key technology, power electronics further play an essential role for electromobility and energy storage. In addition, the development of powerful and efficient power electronics systems for electric vehicles is a decisive step on the way to a more sustainable future. Therefore, one focus of this issue is on the topic of power electronics for electromobility and energy storage (p. 19-25). The articles on power electronics for sustainability, climate change and energy transition (p. 12-17) underline the status of power electronics as a key technology for sustainability and provide an insight into its practical implementation. In an interview with Dr. Gerald Debroy, keynote speaker at the PCIM Europe conference 2024, the challenges created by the extreme power demand by latest processor generations as being used to train large models for artificial intelligence and for other use cases in hyperscale datacenters are being highlighted (p. 6-7).

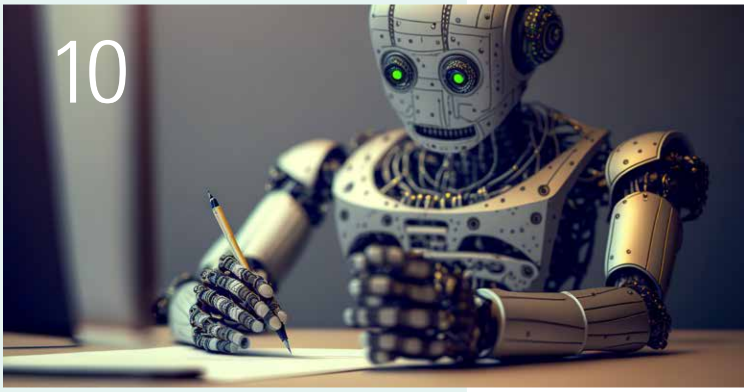
The Event Edition 2024 of the PCIM Magazine complements the holistic presentation of power electronics at the PCIM Europe Exhibition and Conference. Do look forward to this year's event, which will once again be packed with exciting personal encounters and discussions.

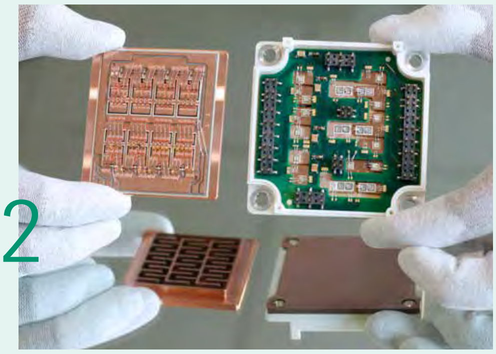
We hope you enjoy reading and discovering all that the first issue of the PCIM Magazine has to offer. The next issue will be published this fall and we look forward to compiling it with exciting contributions from the industry.

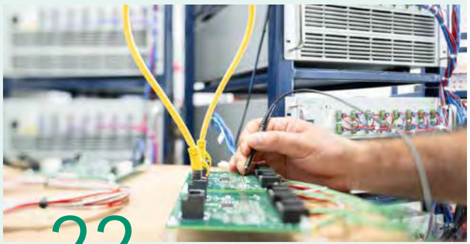
Regards
Lisette Hausser
Vice President PCIM Europe

View digital issue

Contents







Five key areas for power electronics in 2024

Prof. Dr. Leo Lorenz, President, ECPE European Center for Power Electronics e.V., General Conference Director PCIM Conference

At the PCIM Europe 2024, we'll be highlighting five key areas of development spanning the entire power electronics value chain. This year's event features a wide range of presentations, outstanding innovations, and keynotes focusing on the following topics: components, new materials for packaging and interfacing technologies geared to improving reliability and extending lifetimes, various fields of application, artificial intelligence (AI) and digital twins, and system design for sustainability.

When it comes to components, the trend is toward smaller chips with higher power densities and ultrafast switching speeds. Here, the goal is not only increased chip ruggedness at elevated operating temperature ratings; a more significant aim is to deliver outstanding reliability in order to achieve the desired application-specific lifetime. Material science is pivotal to mastering these challenges – with innovative new materials that deliver the necessary thermal management, isolation properties, and matching coefficients of thermal expansion. At the PCIM Europe 2024, innovations in this area will include new ceramics and chip passivation materials, as well as new chip bonding technologies, such as advanced soldering or sintering technologies.

In packaging and interfacing technology, the spotlight is on smart, scalable, power electronic building blocks, or power embedding, which aims to achieve a single, shared platform for power modules that will meet application-specific requirements. Encompassing power chips, integrated sensors, and digital control of power devices, this platform should be scalable in terms of current and voltage ratings. Here, too, module design and material science are key to tackling heat transfer and managing all the parasitics inside the power block. We'll have several papers about scalable power electronic building blocks, with a focus on establishing new standards and modularization. And we'll show a new approach to designing power modules for the tiny, ultrafast switching WBG (wide bandgap) devices that addresses the many associated challenges.

This year's PCIM Europe highlights the following fields of application: the mobility sector, the energy sector, and data centres. In all three fields, there's a need for more compact power converters operating at high efficiency ratings, not least for mobile applications. As with components, increased power densities can pose tough thermal-management challenges – especially in the fastest-growing application area, data centres. Greater efficiency will be key to meeting these demands and ensuring that power converters are reliable and have long useful lifetimes in their widely differing applications and operating environments. We'll be showing some impressive innovations in the various fields of application – with a particular focus on electromobility.

Interest in AI and its practical applications has grown rapidly in recent years. So, it's hardly surprising that the technology is becoming increasingly important in power electronics. Deploying AI and digital twins promises shorter development time and faster time-to-market, plus more reliable converter products. During ongoing operations, AI and digital twins will play a central part in predictive maintenance – for example, by helping determine how components are aging. Here, there's a need for industry standards to gauge the reliability of the vast volumes of data involved. What's more, we need to think about how the digital world relates to the real world so that we can translate insights from the former to the latter.

One of this year's keynotes focuses on AI, and we'll see a good example of how AI is applied in the real-world production of a power converter. We'll also see the benefits that AI has to offer across the entire product lifecycle – from the initial idea for a new converter, to product development and production, right through to decommissioning.

One of the most important topics for the future is sustainability. Not only are zero carbon emissions a must; we must also significantly reduce the amount of electronic waste, which has risen by 80% in the past decade alone. This will call for a fundamental rethink and a move to a circular economy. Achieving this will entail considering ways of repairing converters and recycling all materials so that we can reuse them. One extremely important factor here will be acquiring the dataset needed to accurately calculate the carbon footprint of components and systems. We also have several papers about design for sustainability, focusing on carbon footprint and lifecycle assessment, with special emphasis on the dataset needed to calculate this footprint and on cost of ownership.

We hope you enjoy reading the first edition of the PCIM Magazine.

Sincerely,

Prof. Dr. Leo Lorenz

Image: EmmaStock – Adobe Stock

Challenges and solutions for powering the latest processor generations in hyperscale data centers

An interview with the PCIM Europe keynote speaker Dr. Gerald Deboy, Fellow, Infineon Technologies Austria AG, Villach, Austria

As AI models increase in size and complexity, training them is requiring more power per motherboard and per rack. At the same time, parallel processing by GPUs and TPUs – with 500 cores and more – means high operating currents, and very steep transient loads. In short, the rise of AI data centres is as much a challenge for the power supply system as it is for processing power. Tackling this will be the topic for Dr. Gerald Deboy in his keynote speech at this year's PCIM Europe.

Gerald Deboy got his M.Sc. and Ph.D. degrees in physics from the Technical University Munich, Germany. In 1994, he joined Infineon Technologies AG, Neubiberg, Germany, later moving to Infineon Technologies Austria AG, Villach, where he is Head of the Systems Innovation Group for Power Discretes and System Engineering, as Distinguished Engineer and since last year as Fellow. He has authored and coauthored over 130 papers in national and international journals, as well as contributing to student textbooks. He holds more than 100 international patents, and with David James Coe and Tatsuhiko Fujihira is the inventor of the superjunction principle, which revolutionised energy savings in high-voltage switching converters. Its use from laptops to EV charging stations has likely saved over 3.4 trillion kWh to date.

Dr. Deboy, what do you think of the current challenges in power distribution and conversion for hyperscale data centers?

The challenges start with keeping the power distribution losses down at the higher power requirements of newer motherboards, which are already typically at 6 to 8 kW. This is mandating a 48 V backplane, compared to the traditional 12 V ecosystems. This helps us to decrease losses 16-fold, but it results in needing a first stage of conversion to an intermediate bus, before converting again at the processor. At the same time, the higher transient requirements with much higher load currents of those processers, with 100s of cores, are driving the optimal intermediate bus voltage further down. To this end, at Infineon we are already providing hybrid, magnetically- and capacitively-coupled, switch converters, to transform to intermediate bus voltages at 6 or 8 V.

The 6 or 8 V levels do have the advantage of reducing switching losses, compared to 12 V. This enables higher switching frequencies, which further helps to better cope with the

Infineon dual-phase power modules, specifically designed to meet the needs of GPUs and TPUs, for vertical integration at the point of load, minimising distribution losses and providing high speed transition responses.

Training AI in hyperscale data centres presents new challenges not just for processing, but also the power supply to the rack, the motherboard, and the processor.

Image: Infineon Technologies Austria AG

faster transient load requirements, without having to resort to too many capacitors.

Furthermore, we need to cope with higher power levels in the server power supply units. To achieve the power density necessary – and we have already been able to achieve more than 300 W/in3 for isolating DC/DC stages operating on 400V – means using wide bandgap devices: typically silicon carbide in the AC/DC stage, and gallium nitride in the DC/DC power conversion stages.

What do you see as the challenges and opportunities for the power needs of the newest generations of graphic and tensor processing units?

Infineon's approach to powering the processor itself combines power stages with inductors, to create a voltage regulator module (VRM) that can be mounted on the rear of the processor, making it possible to provide the necessary power at the point of load. This vertical integration is important in minimizing the losses that the lateral distribution at these kinds of current – with transient loads up to 1000 A – would entail. It also enables the best possible use of the constrained motherboard area.

Because the real challenge is the current demand, trans-inductor coupled voltage regulators (TLVRs) are a good path forward, combining all of the output inductors of a multiphase buck converter into one system. If one phase fires, it increases the output in all the phases connected to the loop, enabling the fast transient response necessary.

It's worth noting that there has been a significant change in voltage levels here too. Most processors now have a silicon capacitor layer directly on the processor, typically removing the transient requirements beyond a 5 to 8 MHz bandwidth. This means the processor can operate in a lower voltage band: there is less need to have an overvoltage reserve to avoid breaching the undervoltage lockout limit of the processor. Being able to lower this band has the benefit of reducing the losses in the processor. Because these scale at the square of the voltage, going from, for example 0.8 to 0.7 V, reduces losses by a factor of 82 to 72, which is around a 25% saving. This is a useful additional budget that can be redeployed to overclock the processor.

What would you see as the next developments in the power supply of processors and for data centers?

Of course, the new possibilities in powering the processors has had to be reflected in processor and motherboard design. Instead of logic and power lines sitting on top of each other, the logic cell can now be separated on the top of the processor, with the power lines on the underside, where it can connect to the VRM.

The next challenge is the increasing of power ratings for the power supply units, from 3, to 5 and to 8 kW, and for racks where 40 kW is already typical, though this can extend beyond 100 kW. This is driving the need to migrate from single- to three-phase power supply units. And then further out, distributing plus and minus 400 VDC, instead of AC. But this is further out, as we are working through some complications. You need circuit breakers on several levels, to be able to isolate single failures. These are interesting challenges, and I am sure we will arrive at interesting solutions.

Dr. Gerald Deboy presents his keynote address on "Challenges and Solutions to Power Latest Processor Generations for Hyper Scale Datacenters" on 13 June 2024, 8:45 a.m., **stage Brüssel 1.**

Advances in Intelligent Motion: Electrical motors in industry and E-Mobility

O.Univ.Prof. Dipl.-Ing. Dr.techn. Manfred Schrödl, Director of the Institute for Energy Systems and Electrical Drives, Technical University, Vienna, Austria

Intelligent motion, with its challenges and opportunities, is among the focus tracks of this year's PCIM Europe conference. This includes current trends for the application of electrical motors in industry, driven by considerations like energy and resource efficiency, as well as sustainability. E-Mobility has additional needs to reduce volumes and tackle cooling issues. Balancing these challenges with investment and running costs are what shape the choice of materials and components, and the optimal control of drives covered in this track. We take a look at some of these issues here.

Focussing on intelligent motor efficiency

Some of the answers to the challenges facing electrical motors mean reevaluating the advantages of long-known technologies. Reluctance motors, for example, have been known for over 100 years. These either use no magnets, or have rotors that use inexpensive ferrites that are more readily available than the rare earth materials used in permanent magnet motors. Though they are not as compact or efficient as permanent magnet motors, reluctance motors are slightly smaller and significantly more efficient than induction motors, through slip-free, synchronous running. And because the rotors of reluctance motors aren't conducting current, they need less cooling. This makes them a good option for replacing induction motors in industrial applications.

Beyond the choice of motor, optimizing efficiency also needs to be tackled at a system level. An example would be running a pump at a constant speed, and using a valve to regulate the flow. An equivalent result could be achieved by controlling motor speed, where – although the control is more complicated –energy can be saved. A lot of factors have to be balanced, from investing more in efficient motors and elaborate control systems, to offsetting the lower running costs over the lifetime of the system.

Trade-offs in improving inverter efficiency

The efficiency of a system is also influenced by the switching losses in the inverter. Reducing these can be achieved by faster switching times. Silicon carbide or gallium nitride can reduce the losses (and the resulting heat) by an order of magnitude compared with silicon. The trade-off here is the affect that this can have on the reliability of the motor.

The voltage reflections at the motor terminal at quicker rise times can result in over-voltages that cause cascading channels of charge. Over time this damages the insulation of the motor. It also causes a capacitive effect in the motor windings – because of the affect the flow of charge has on the inductance between the terminals, and between the winding and the housing. Though this might only be for a few microseconds each cycle, it impacts the linearity of the voltage distribution in the winding, which over time damages the first winding in particular.

This is a new challenge when using these fast-switching semiconductors, which impacts the design of the system: to optimize the rise time to avoid damage, or by boosting the insulation of the motor to cope. While the increased cost of fast-switching inverters is probably an economic problem for industrial applications, the benefits can make a difference in E-Mobility solutions.

Flexibility for supply chain issues

Designing drives and systems today is also further complicated by supply chain issues. Apart from state control of access to (and the subsequent cost of) rare earth materials, or materials like cobalt that mostly come from politically unstable regions, there are the repercussions of transport disruptions – such as the effects of the Ever Given blockage of the Suez Canal in 2021. It can be worth building flexibility into solutions, whether this is by using commonly available ferrites in reluctance motors, or ensuring a system controller is not contingent on a processor that is only available from a single source.

This was at the root of the change in the European automotive industry after China restricted access to rare earth metals in the 2010s. Even though those material prices are now lower again, having developed classical synchronous machines with field windings, or induction machines with copper cages – in parallel to permanent magnet drives – means these companies can react to the changing parameters of global trade as necessary

Being able to recycle the materials – apart from the environmental benefit – can also contribute to resource independence. Volkswagen, for example, are planning recyclability of battery systems to reuse as input materials in following manufacturing generations.

Going sensorless

It might seem that everything to do with motor and system design is getting more complicated with increasing demands for efficiency and for flexibility to counter potential supply chain issues. But there are also trends that can simplify development. Improved mathematical modelling is making it easier to eliminate sensors from motors and drive systems. This is something that the TU Vienna has been working on for the last 30 years, and which has been used in product applications since 2010.

Depending on the needs of the application, the result doesn't only have the advantage of eliminating sensors, such as expensive tachometers or position encoders, it can also remove the need for test pulses. The outcome is motors that can be much quieter, as well as being more compact, and without having to solve for EMC in sensor cables. Without mechanically complicated instruments, robust control of sensorless motors has also been achieved, even in highly dynamic processes.

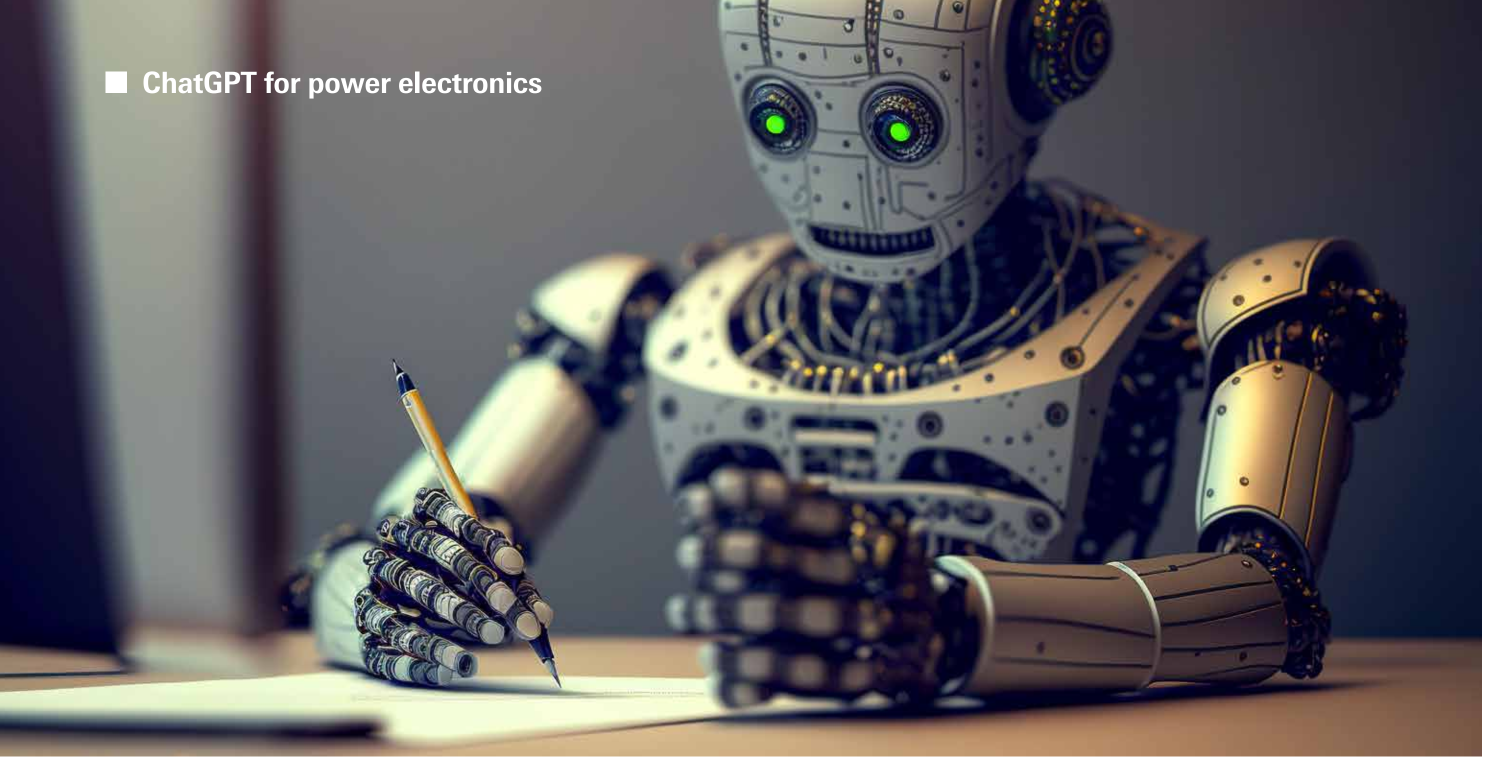
Perspectives in E-Mobility

Many of the other trends in E-Mobility are driven by changes in storage technologies, such as the shift from lithium-based to natrium-based technologies. Natrium-based batteries have the benefit of a cheaper, more widely available material, though development is still at an early stage and power densities are low. There are also ceramic-based, solid state batteries, which are inflammable, and thus can withstand higher currents for much faster charging. However, batteries remain the most expensive components in electric vehicles This makes the efficiency of the motors and inverters even more important. Every reduction in energy consumption reduces the battery size needed, keeping the cost of the whole system under control. This is what makes SiC and GaN inverters so interesting for EV applications.

Another motivation in E-Mobility is to reduce sizes, to minimise the compromises to overall vehicle packaging. One impact of such compactness is cooling difficulties, pointing the way to the greater use of liquid coolants. Though this increases complexity, it also creates the opportunity for better control of the excess motor and inverter heat, for example, to warm the battery in colder climates or conditions.

The challenges for intelligent motion, especially in combination with new power electronics devices, materials and production processes, continue to throw up interesting opportunities.

O.Univ.Prof. Dipl.-Ing. Dr.techn. Manfred Schrödl is chairing the session on "Advanced Control Techniques on Electrical Drives II" on 11 June 2024, 2:30 p.m. on **stage Athen;** and the poster presentations on "Advanced Converter Topologies" 13 June 2024, 11:15 a.m., **Hall 10.1.**



ChatGPT for the power electronics industry: Hit or miss?

OpenAI's ChatGPT has taken the world by storm in generating human-like responses in content creation, research, and even coding. At the PCIM News Platform – Power & Beyond, we looked at the potential impact of ChatGPT on the power electronics industry, and evaluated its value for engineers.

While ChatGPT cannot replace the expertise and skills of a professional, it can still assist engineers by taking on various, low-value tasks.

Create guidance/training for beginners

ChatGPT is a great tool to train beginners, hobbyists, and students in the power electronics industry. The software can summarize or research relevant content within minutes. However, the content does need checking for the best results.

Generate code

One of the best features of ChatGPT is that it can suggest code in various programming languages used in power electronics, such as C, Embedded C, C++, Python, and HDLs like Verilog, VHDL, etc. This can be useful to create even complex code, or to review existing code to find and fix errors.

Solve equations

ChatGPT can suggest steps and provide guidance for solving complex mathematical equations in power electronics. It can provide solutions for Boolean expressions, calculus, and popular signal-processing algorithms such as FFT (Fast Fourier Transform).

Enhance designs

ChatGPT can provide extensive support for designing electronic solutions and PCBs, such as to check design rules. It can also take direct inputs for real-life design problems with many values and instructions, or provide solutions for regulatory compliance in the power electronics industry.

Provide technical support to customers/clients

Many companies use ChatGPT as a bot to generate responses for customers/clients. Due to its human-like responses, ChatGPT is often better than pre-programmed responses.

The limitations to bear in mind

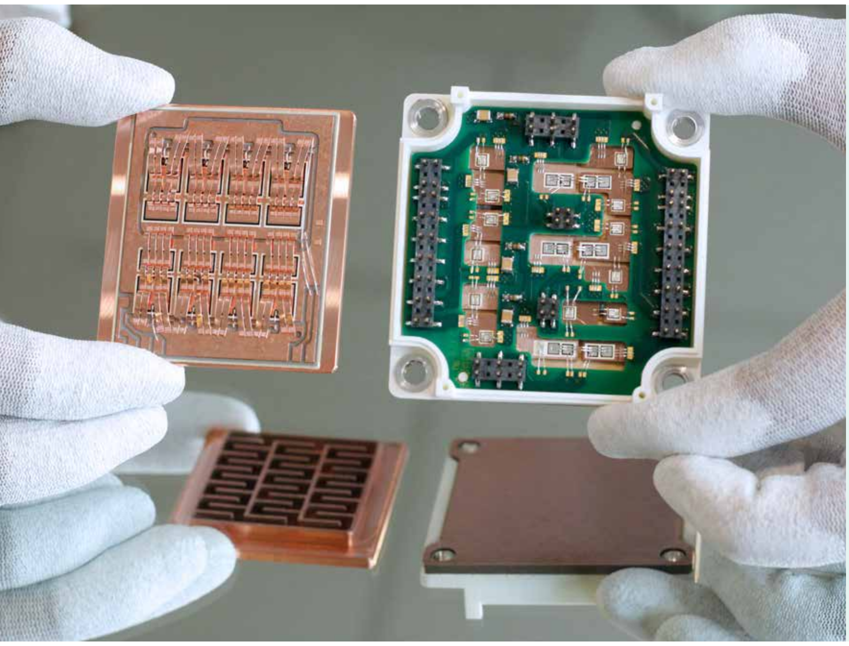
- ChatGPT cannot integrate with other software tools for designing and coding purposes. It can only suggest responses, which a human has to implement on the software/platform.
- ChatGPT responses are generic in nature. They are heavily dependent upon training material gathered from the Internet, and though they may appear coherent, they do not correlate or analyse advanced questions, like a human mind.
- ChatGPT cannot perform circuit simulations like an electronics engineer. The AI software can only provide information related to the software, components, and manufacturers.
- Certain problems are quite long and require multiple, interdependent steps, based on past conditions. ChatGPT often fails to provide responses based on previous input data.
- ChatGPT troubleshoots code, finds errors in text, and fact-checks information. But it has been known to provide incorrect information and generate non-existent reference links in its response to support the data.

Despite its limits, ChatGPT can assist electronics engineers with low-level research, fact-checking, coding, designing, and content creation.

Sustainability and Power Electronics

Prof. Dr.-Ing. Frank Osterwald, Managing Director of the Society for Energy and Climate Protection Schleswig-Holstein GmbH, Kiel, Germany, and member of the PCIM Europe Board of Directors

The German state of Schleswig-Holstein produces around twice as much renewable energy (from on- and offshore wind, solar and biogas) as it can use itself. This gives it a strong interest in driving a sustainability agenda; an agenda that is at the core of the work of the Society for Energy and Climate Protection Schleswig-Holstein (EKSH), a funding organization with stakeholders spanning the state, its universities, and the regional energy distribution grid operator. This helps it support education and research, enable transfers to industry and other stakeholders, promote the availability of renewable electric energy to attract industry, and guide and back energy transition projects from policy to the community.



On the left is the front and rear view of an inverter power amplifier, developed in intensive research at the FH-Kiel. Three of these can drive an 150 kW electric motor efficiently, getting more life and range from the battery. The rear shows the hydraulically optimized cooling channels, which together with the low-temperature, silver sintering technology provide cooling performance for efficient operation of the controlling semiconductors.

The motor control system on the right, also developed at the FH Kiel, uses a complex, stacked integration using energy-saving, organic copper-on-copper laminates (also known as the Kiel-PowerPlate), with the control board located in the second plane. This provides low-loss control for air-cooled industrial e-motors up to 20kW.

Image: Birthe Ritz, research engineer at the Team Eisele of Kiel University of Applied Sciences

The goal is not just for Schleswig-Holstein to be Germany's first climate-neutral industrial state, but also to provide thought leadership for the energy transition: The second PowerNet conference, organized by EKSH in February this year, aligned 600 people from across politics, administration, economy, science and municipalities to advance the energy transition in the region, and with its neighbours in Denmark. Always central to the discussion is the crucial role of power electronics, in mobility and transportation, grids, heating, and communication and digitalization.

E-Mobility: sustainability on a system level

The increased use of battery and hydrogen-powered vehicles, from cars, bikes, trucks, coaches and trains, to boats, ships, planes, and helicopters, all rely on power electronics. The projects supported by the EKSH range from electrolyzers and fuel cells for hydrogen energy, to wider sustainability issues (like battery control and re-use), and efficient charging – such as a two-year research initiative, with a local industry partner, on silicon-carbide-based charging stations (led by PCIM Europe advisory board member Marco Liserre).

Power electronics to form an even more flexible grid

Power electronics are also critical in enhancing the efficiency and intelligence of the power grid, thus facilitating a more sustainable and efficient energy landscape. This includes applications in smart transformers, high-voltage short-coupling devices, control systems, and energy storage solutions, as well as managing the charging and discharging of large battery plants.

One research focus at the University of Kiel, for example, is on smart transformers. The right solutions here could play a significant role in addressing the many extra transformer stations energy grids will need to accommodate increasing volumes of decentralized renewable sources. Comprehensive data from transformers can enhance grid control, to boost system-wide robustness. Smart transformers can also reduce the amount of copper required, by replacing it with semiconductors, which are not as scarce a resource as copper is likely to become in the future.

A related, EKSH funded project, at the West Coast University of Applied Sciences in Heide, is into MVDC short couplings, which will provide an even more flexible energy flow in the grid.

Power electronics for fossil-free heating
The smart grid is also implicated in the transition to fossil-free heating – a significant challenge for many, particularly in Germany and Schleswig-Holstein where oil and gas heating systems still dominate. The widespread adoption of heat pumps is one approach, which, of course, necessitates the efficient control of the compressors. Another approach involves expanding district heating systems and supplying them with fossil-free energy. Geothermal energy could be one way to generate both electricity and heat. For geothermal exploration to be effective, the many large pumps involved need to be controlled with advanced power electronics.

But there are other exciting opportunities. A winning project of the EKSH-Energy-Olympics that stands out was executed by the community cooperative in Bosbüll. The cooperative manages a wind and solar farm, and recently incorporated an electrolyzer to produce hydrogen with their excess energy. The electrolyzer's relatively low efficiency of around 30%, resulted in considerable heat losses. The cooperative leverages this excess heat to warm water (to 80°C), which is then distributed via a district heating system. This enhances the overall system efficiency to about 95%!

The three 'P's of sustainability: people – profit – planet
Achieving sustainable growth in the power electronics sector is paramount, due to its omnipresence in future technologies and applications. We need to ensure solutions that are sustainably produced, highly efficient, highly reliable, durable, as well as reusable and recyclable. This sustainability can be conceptualized in a triangle of three, interconnected dimensions: people, profit, and planet.

The energy transition requires the engagement of people across a range of professions, from legal to social specialists, and extending beyond the technical aspects of electronics, thermodynamics and materials science, to encompass the ability to communicate and collaborate across disciplines. For companies competing for skilled, multifaceted employees, sustainable operations can also be an important differentiator in attracting and retaining the right people, particularly if it is obvious as a guiding principle throughout the organization and value chain. Apart from energy use, this is also reflected in how scarce or limited resources are used, from water to rare earth elements, and metals that may be sourced through methods that infringe upon fundamental human rights. Tackling such challenges in power electronics through close cooperation between universities and industry can also help companies demonstrate a commitment to sustainability to students, whilst also paving a way for these people to transfer their talents to the company after their studies.

Profitable business growth is achievable through enhancing efficiency and sustainability, to reduce the consumption of energy and resources, and to minimize waste. One of the EKSH's scholarship recipients at Flensburg University of Applied Sciences, for example, is working on optimizing losses in electric machines by enhancing the control of eddy currents in their sheet metal packages. Increasing sustainability also should involve rethinking the use of composites, to simplify separation processes for recycling of materials and packaging. It culminates in identifying smart solutions that minimize resource consumption, or even by rendering certain aspects of the electrical energy system redundant. In this way, investments in sustainability can often lead to significant cost savings, thereby enabling increased profits, and creating opportunities for durable and long-lasting growth.

And not least, we cannot forget that "there is no planet B": Power electronics has a pivotal role to play in protecting our planet. Power electronics components and systems should be sustainable across their design and development, and throughout their product lifecycle. One of the EKSH-funded projects at Kiel University of Applied Sciences, which led to the startup Heimdalytics, involves an intelligent method for reusing battery packs from electric vehicles after they had undergone an electrical health check. And a sustainable lifecycle starts with producing power electronics using renewable energy sources. With this in mind, Schleswig-Holstein recently granted Northvolt a final decision to commence their battery cell production in the region.

Leading action (and thought) on sustainability
The EKSH engages actively with all dimensions of the people – profit – planet triangle. This starts with the funding of research projects and scholarships that pave the way to developing technologies and systems, along with well-trained personnel. And ultimately, creating solutions that are attractive for private and public sector companies to implement, which advance the energy transition, and contribute to the preservation of our planet.

The PCIM Europe provides an ideal platform for learning, idea exchange, and promoting the collaboration necessary to realize the energy transition fully – the qualities the EKSH is dedicated to fostering.

One of the recipients of EKSH funding, Kiel University of Applied Sciences, with Aylin Bicakci, a PCIM Europe Advisory Board member, will showcase their most recent project results and demonstrators at the PCIM Europe exhibition, and will also deliver presentations at the PCIM Europe conference, showing how making power electronics fully sustainable is challenging, yet achievable.

Prof. Dr.-Ing. Frank Osterwald is chairing the oral presentations on "Advanced Materials and Technologies" on 11 June 2024, 2:30 p.m., **stage Brüssel 2.**

To ease the chance of cooperation and to highlight the huge variety of researchers focusing on the energy transition, the EKSH launched a free researchers database, at https://energieforschung.sh/en/

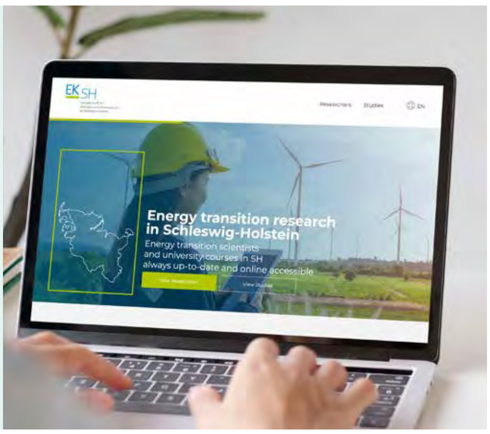


Image: mangpor2004 – Adobe Stock

Power electronics in the fight against climate change

Prof. Dr.-Ing. Thomas Basler, Power Electronics, Faculty of Electrical Engineering and Information Technology, Chemnitz University of Technology

The fight against climate change needs a strong growth of sources like wind turbines and photovoltaics. For example, reaching the official German target of 80% renewable energy by 2030 – though the target should be 100% by this date to avert climate disaster – means installing 8 GW of wind and 19 GW of solar a year. As part of this, power electronics is a key element for generation, for feeding energy into the public grid, and for transmission from the producing regions to where it is needed by industrial and private users – not least in the transition to high and medium voltage DC transmission and distribution – as well as to control the stability of those grids. At the same time, society is electrifying more, from heat pumps and electric vehicles to the exploding energy demands of the IT systems running AI.

The first step in meeting all our energy needs from renewable sources is in the saving of electrical energy. Power semiconductors are already contributing here, from LED lighting, to variable speed drives for pumps, motors, and industry. Advances in power electronics have achieved efficiencies which mean that, despite strong increases in electrified applications, overall electricity consumption did not increase. Some studies state a further potential saving of 22% of atmospheric emissions through the application of power electronics.

Improving price-performance points

Meeting the high demand on both sides of the supply and demand equation starts with improving the performance of the chips. Lower conduction and switching losses, – such as with the improved RDS(ON) of the second generation of trench gate SiC MOSFETs – helps increase the number of chips per wafer. This enables delivering more devices from the fabrication plants, and ultimately reduces price-performance points.

There are exciting developments in packaging, where new housings and materials are coming into play. And also new front-side interconnection technologies, such as for the front-side-only connection required for lateral GaN devices or clips. Foils and copper bond wires also offer interesting perspectives for getting the current out of even smaller chips. One trend is an increase in the variety of moulded discrete devices, such as small and larger half-bridge housings, or the many new solutions using top-side cooling. These use less material, are cheaper than the corresponding frame modules, and can be used in modular, self-designed parallel configurations (as is the case in Tesla EVs).

Other drivers come from increasing the range of applications for wide bandgap devices. For example, its low switching losses influenced the choice of SiC for achieving new levels of efficiency for solar inverters. But now we are seeing interesting possibilities for wind turbine applications, and traction applications where SiC MOSFETs in the 3.3 kV power module class could be used, significantly increasing efficiencies over today's IGBT solutions. The ever improving reliability is also important: In the case of traction applications these systems are in use all day over a 30- to 40-year lifespan. This, for example, has been achieved using sintering on the back of the chips, and copper-based interconnection technologies on the front.

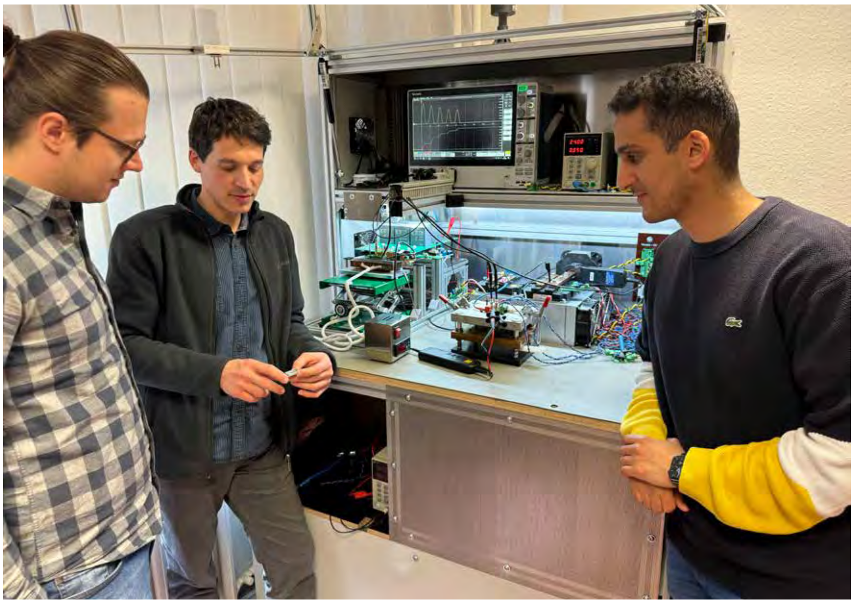
Challenges for testing

One of the biggest challenges is proving the reliability of the combinations of new chip, new packaging, and new interconnection technologies. Power cycling tests are most important, but this means improving the testing methodologies, or using innovative testing procedures, such as including new temperature-sensitive electrical parameters as part of the power cycling test of GaN HEMTs. New tests are also needed, particularly dielectric testing in the form of a gate switching stress test for SiC devices, to gauge the gate oxide stability. This was not a mode that needed to be qualified for silicon devices, but in the meantime, it is mentioned in the ECPE's AQG-324 testing standard for automotive power modules.

Often this is driven by the needs of the demanding applications, and not least by time pressure to get a solution to market. This has led to the theoretical understanding of SiC and GaN lagging behind Si-based counterparts, and the need to standardise tests for SiC and GaN to get reliable, comparable results.

Trade-off between effort and performance

Of course, new is not always better in all respects. The much smaller chip sizes and active thicknesses of SiC devices, for example, mean they reach very high temperatures and their failure limits much faster than IGBTs under short circuit conditions. And, despite all the hype around SiC and GaN, it is often silicon IGBTs that are available to meet the immediate demand for energy transition and electrification. Obviously, this will change as the capacity of SiC and GaN fabs increase in the coming years. IGBTs are also likely to remain dominant in high voltage and high current applications, like DC energy transmission. Or for applications where cost, rather than space and losses, are the main driver, such as in variable speed



Prof. Basler (centre) discusses the surge-current robustness of new SiC MOSFET chip technologies with two PhD students, at a test bench in the TU Chemnitz.

Image: Chemnitz University of Technology

drives in industry, or where costs are a big issue, such as in mass market EVs with moderate drive power.

There are also possibilities in hybrid technologies, combining silicon carbide to ensure low losses for light load conditions with the beneficial I-V curve of Si bipolar devices at higher currents. This is under discussion for EV applications. Further, there are already multi-level power modules on the market combining the advantages of IGBTs at positions with lower switching frequency and SiC MOSFETs for positions needing higher switching frequency.

Improving capacity and yield

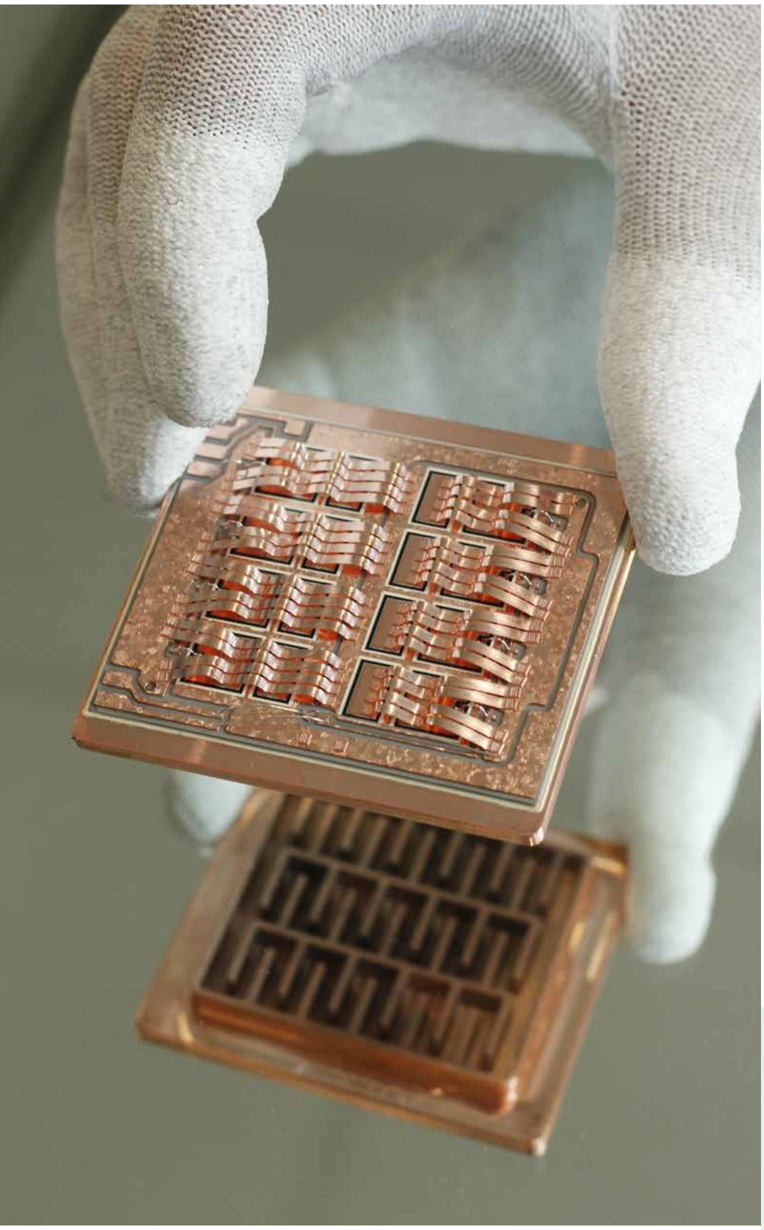
As noted, investment in new fabrication plants and increasing the yields per wafer are important in boosting the supply, to meet mushrooming global demand. In this respect, there are investments and advances in manufacturing silicon carbide, but, in the case of SiC, important work is also being done in splitting technologies to use the raw wafer for more than one processing run. A 1200 V class SiC chip only needs to be 10 µm thick, but ease of handling in the fab needs it to be 10- or 20-times as thick, and a raw 6" wafer is typically 350 µm. Nowadays, up to 60% of the wafer – which is the largest part of the cost of a SiC chip – ends up removed by backgrinding. A successful splitting technology would mean being able to use the raw material two or more times, and reducing device prices significantly.

The PCIM Europe 2024 – celebrating our success

There are a lot of new device and package concepts to learn about at this year's PCIM Europe conference, as well as solutions to explore at the exhibition. And there are many more current issues and problems to discuss.

The growing numbers attending PCIM Europe events shows the increasing engagement in our community. In wider society, while there is awareness of wind turbines and photovoltaic power, there is little awareness of the vital supporting role that power electronics plays in enabling everything: from LED lights to electric mobility, and from renewable generation to the grid. Even the AI hype would be unthinkable without power electronics for supplying the power to the servers. The general public doesn't (yet) know the importance and responsibility power electronics has in realising the potential of renewable energy and electrification in the fight against the upcoming climate disaster.

Prof. Dr.-Ing. Thomas Basler is chairing the oral presentation session on IGBT, on 12 June 2024, 2:30 p.m., **stage Brüssel 1.**



Power electronics and the energy transition

Prof. Dr.-Ing. Aylin Bicakci, Professor of Packaging and Bonding and JoiningTechnologies (BJT) of Mechatronics, Kiel University of Applied Sciences

Power electronics is of fundamental importance to the transition to sustainable energy. By controlling and converting electrical energy, it facilitates the efficient integration of renewable generation sources, optimizes energy consumption, and supports the stability of the grid (with greater than ever variability in supply and demand). There are technical challenges, but another real concern in ensuring power electronics can deliver on its full potential is that it takes the right people, with a combination of abilities, as well as creativity and motivation.

A module using SiC components for 150kW e-machine, but small enough to fit in the palm of a hand.

Image: Kiel University of Applied Sciences

Integration of renewable energies

Particularly noteworthy among the technical challenges, is the integration of renewable energies. Power electronics controls the variable power generation from solar and wind energy to match the needs of the grid. These sources are often remote, and power electronics enables the long-distance, high-voltage direct current (HVDC) transmission of this electricity with low losses, making sure it gets to consumption centres efficiently. As each conversion loses energy (in the form of heat), every increase in efficiency in each converter module means more renewable energy that can then be used sensibly.

The smooth integration of renewable energies into existing energy grids requires new approaches and innovations in power electronics. For module technology, the current focus is primarily on wide bandgap (WBG) semiconductor materials. These semiconductors – particularly silicon carbide (SiC) and gallium nitride (GaN) – offer higher efficiency, lower losses, and the ability to operate at higher temperatures, frequencies, and voltages than traditional silicon devices. This increases the efficiency of energy conversion, which is beneficial for example in renewable energy generation, and in electric vehicle (EV) charging stations.

These semiconductor technologies also offer a significantly higher power density. The modules can be smaller, which means they need less space, for example, when used in EVs. But it also means that the bonding and joining technologies (BJT) also need to be rethought and adapted. The thermal management of the modules is more complicated by the reduction in surface areas, and there are challenges of connecting the high powers within and at the interfaces to the module

Long-term significance and prospects

The increasing importance of power electronics and technical know-how for the energy transition makes it a critical field. A shortage of skilled professionals, in power electronics and related technical disciplines, affects the innovation and competitiveness of the energy sector in various ways. The research and development of new technologies, systems and processes require a high level of expertise and skills. A shortage of skilled workers could mean fewer innovative solutions to the challenges of the energy transition, which could ultimately slow down the speed and efficiency with which the energy industry is transitioning to renewables and sustainable practices.

At a time when there is already a decline in student numbers for technical subjects, attracting the next generation of engineers to work on these challenges requires a multi-layered approach. This needs to start with programs that get students excited about STEM subjects at school. Workshops, summer camps and competitions that make technology and science fun can inspire young people to study technology in the long term. It is in the interest of academia and industry to come together to increase the interest in STEM subjects, as well as in technical courses in further education. Prospective students need to be aware of the diversity and importance of technical professions, as well as the creativity associated with developing innovative solutions.

For power electronics in particular, the social and environmental impact of the work, as well as the diverse and global career opportunities in the sector are helpful in attracting motivated talent. A solid theoretical foundation remains essential – and we cannot pretend these are simple subjects. But first and foremost, education needs to be practical, with partnerships between universities, research institutions and industry to make the contribution and relevance of the power engineer obvious. Guest lectures by industry experts, and company tours that show technical knowledge being applied in real situations can be very influential. But better still are learning opportunities under the real conditions of projects carried out in partnerships. Apart from learning valuable practical skills, the result is genuine enthusiasm for many students: These are people who want to make a difference in the energy transition. The sooner they get to participate in the development of relevant solutions, the better!

With many of today's technological challenges being multifaceted, another important opportunity to attract potential students is in promoting interdisciplinarity. Universities can attract students who might not be primarily interested in a purely technical degree with courses that combine engineering with other disciplines, such as economics, or environmental and social sciences. Scholarships and financial incentives can also attract students who choose technical courses, both by reducing the financial burden and sending a strong signal of the social appreciation of these disciplines.

Prof. Dr.-Ing. Aylin Bicakci is taking part in the Encapsulation Materials session on 12 June 2024, 9:50 a.m., **stage Brüssel 2**, and in the poster session on Low Voltage Switches on 13 June 2024, 11:15 a.m., **Hall 10.1.**

Efficient converters and stable smart grids

High power converters contribute to optimal and stable electric grid operation through improving efficiency and providing information. We discussed the possibilities with Prof. Marco Liserre, Chair of Power Electronics, University of Kiel, in episode 6 of the PCIM Podcast – Sound on. Power on.

It starts with efficient components, developed efficiently

The efficiency of power converters, particularly in voltage categories to ~10 kV, begins with wide band gap devices, for example, in solid state transformers. But other contributions are made by modular technologies, that can be combined in series or in parallel also to reduce passive components. While parallelization used to rely on simple synchronization, interleaved modulation, apart from significantly reducing the need for inductances can be optimised for other factors, like the component lifetime.

Digital twins and power-hardware-in-the-loop facilitate the synchronised design of hardware and the corresponding control software. They also simplify testing, by supporting virtual environments where the rest of the system can be emulated. This not only takes more testing offline, it also enables the use of artificial intelligence to achieve higher levels of optimisation. This is an approach that the team in Kiel has been using, for example, to demonstrate multiport technology topologies for DC-DC converters as well as Modular Multilevel Converters with integrated junction temperature estimation for optimal services to the electric grid.

Supplying the right solution through understanding the demands

While improving converter efficiency is one side of readying the grid for the future, another important aspect is understanding the changing and growing variety of loads. The use of batteries is expanding from cars to also include heavier vehicles, as an alternative not only to fossil fuel, but also to hydrogen.

This means a spectrum of charging speed requirements, which in turn involves different technologies for charging stations. These could range from high-frequency solid-state transformers (reducing the use of metals, as well as size), to reducing the number of isolation stages, to increase overall efficiency. There are also new demands on the network, which is likely to shift to more distribution of low and medium voltage DC. This is where multiple active bridge technology, based on the use of multi-winding transformers, as well as Modular Multilevel Converters could be key.

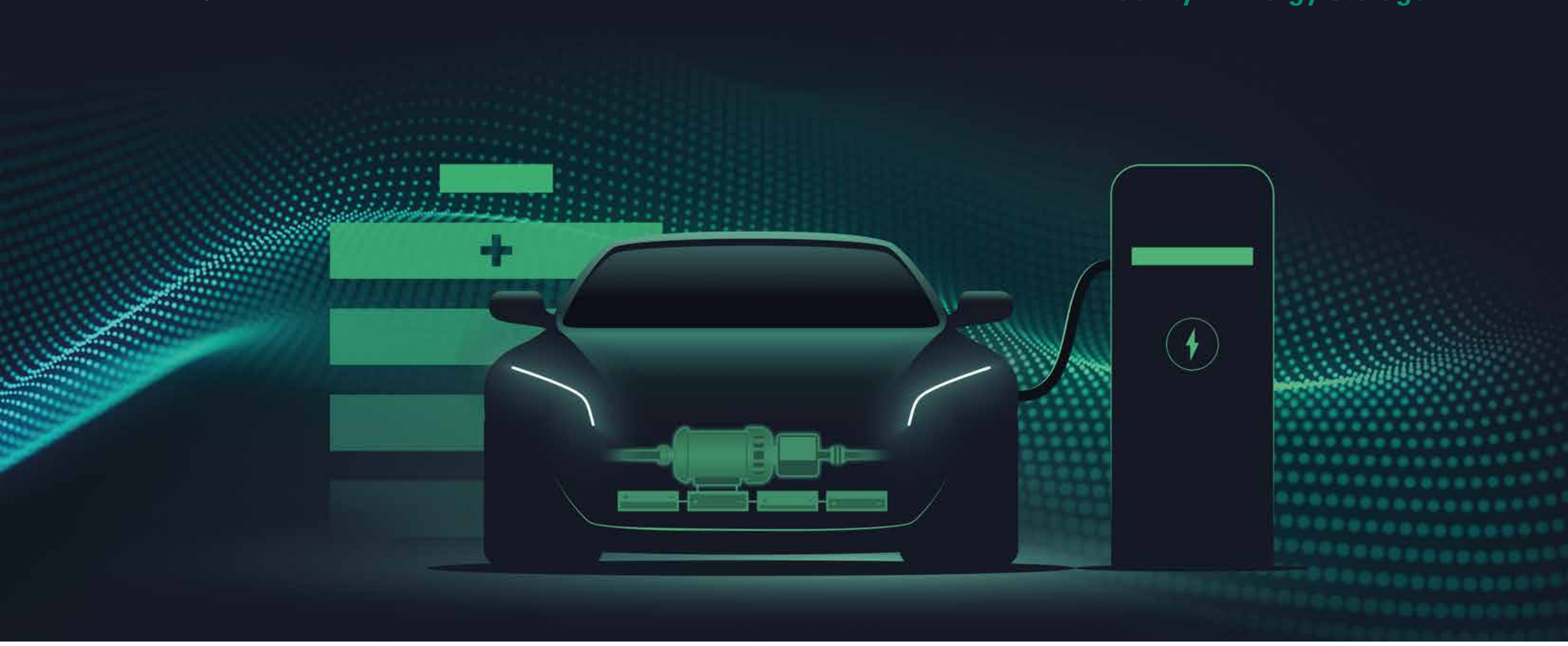
New opportunities through a more holistic perspective

As the charging stations and grid become more sophisticated, they also open the door to the emergence of a widened role for power converters. As a source of information they can interact, in a proactive, grid-forming way, to counteract potential disturbances, or even manage reactive power for grid stabilisation. Of course, this comes back to the current the power semiconductor devices can provide, making the thermal management the bottleneck. So, even when we look from the system level, the efficiency of the devices, is central, and the use of a digital twin can help ensure the best possible operation.

Of course, the increased complexity of a grid that is not just in following mode presents challenges for distribution system operators. But there is also an opportunity, as the power electronics converters provide an incredible source of data for system level optimization.

To keep up with developments in power electronics, subscribe to the PCIM Podcast at **pcim-europe.com/podcast.**

Image: Fraunhofer ISIT, Dahnan Spurling



Power electronics for E-Mobility & Energy Storage

Power electronics plays a crucial role in the fields of E-Mobility and Energy Storage, serving as the backbone that ensures efficiency, reliability, and performance. This drives the continuous development in this field. On the following pages, you'll discover power electronic products and solutions designed for E-Mobility and Energy Storage.

In addition, you can explore the products of numerous exhibitors as well as presentations at the E-Mobility & Energy Storage Stage at the PCIM Europe Exhibition 2024. The stage presentations will be available on pcim.digital.mesago.com until 31 July 2024 via your Messe-Login. This will allow you to explore the current capabilities of power electronics for these applications and gain insights into future advancements.

In the following you will find an overview of selected companies presenting products and services related to E-Mobility and Energy Storage at this year's event in Nuremberg.

Enjoy discovering the wide range of offerings for E-Mobility and Energy Storage.

Wolfspeed

HITACHI Inspire the Next

Hitachi Energy

KINWONG

Littelfuse

CeramTec THE CERAMIC EXPERTS

dSPACE

Heraeus Electronics

INDIUM CORPORATION

infineon

MERSEN

NOVOSENSE

NXP

SEMIKRON DANFOSS

EV charging systems from e-scooters to mining trucks

It seems like every month sees new applications for power electronics: from domestic, to industrial and e-mobility on land, sea or in the air. The rate of change impacts the electricity infrastructure too. The relatively relaxed world of "10% reserve capacity" in the grid has changed to one where dynamic grids need to react in milliseconds, as well as needing to accommodate DC alongside AC transmission.

There are many common challenges across the solutions developing to address these applications, most notably the need to operate reliably for many decades, despite difficult conditions in terms of vibration, temperature, and humidity. Another frequent issue is that when it comes to power semiconductor components – though increasingly established as key elements of many solutions – the standard products cannot always fit well to the requirements of particular applications.

The best-suited semiconductor technology, particularly for applications at or above 1.2 kV, divides between those where silicon, and those where silicon carbide makes most sense. Though the boundaries have yet to be finally set, SiC offers advantages in efficiency – which can be decisive for applications like e-mobility – but also in its higher possible junction temperatures. The latter is important as ambient temperatures increase, by leaving a larger delta before reaching the junction temperature, easing the design, not least of the thermal management.

Hitachi Energy offers one of the most diverse power semiconductor portfolios in the power range of 150 A up to 13500 A and 200 V up to 8500 V. All in all, as power engineers Hitachi Energy can support you with advanced, reliable and high-performance power semiconductors for your applications.

Power semiconductors: the silent heroes, forging the path forward to the brave new frontiers in power electronics applications.

Hitachi Energy Ltd. at the PCIM Europe 2024: Hall 9, stand 9-302.

Hitachi Energy extended its established LinPak family with SiC-based technology to deliver the highest current rating, for power conversion systems that are more efficient, smaller and need less cooling.

Image: Hitachi Energy

The benefits of SiC, from personal E-Mobility to earth-moving vehicles

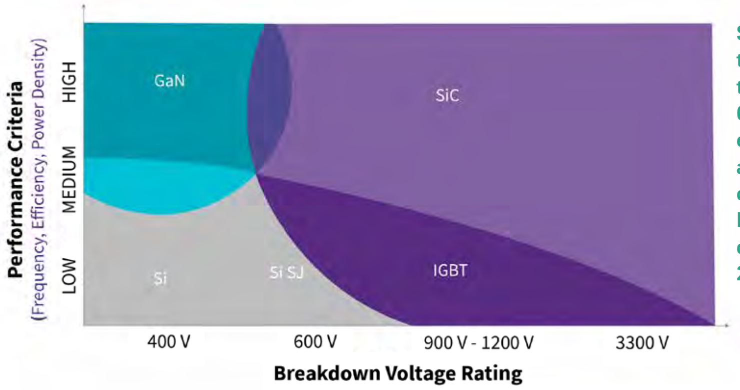
The value silicon carbide (SiC) brings to E-Mobility is clear. Most obvious is the performance, where, depending on the drive cycle, a SiC inverter, for example, is at least 5 and potentially greater than 15% more efficient than the silicon option. This saving translates to flexibility that OEMs can use to optimize for range and battery size (and battery cost). The higher power density of SiC also means weight and volume savings that can benefit overall performance and total cost of ownership for the vehicle design.

Over the last 7 years, Wolfspeed has been developing SiC dies, devices and power modules for the automotive industry, as this has revolutionised battery chemistries and specifications, and evolved more sophisticated motors. The same benefits extend the attractiveness of SiC to industrial and agricultural e-mobility, including applications in the skies and on the water. For these newer uses – where the product lifecycle is 20 to 30 years, rather than a car's typical eight – SiC's reliability is comparable to silicon when it comes to withstanding humidity or vibration, and SiC seems to be more resilient to conditions at altitude.

Wolfspeed's advances are driven by semiconductor and application innovation, such as working with motor manufacturers to realise more of the fast-switching potential of SiC, to further improve efficiency. But in e-mobility, there is also a need to innovate packaging, which is often as important as performance to guarantee integration with the up- and downstream components, and not least thermal dissipation systems.

At this year's conference, speakers from Wolfspeed will present on and discuss high efficiency motor drives, as well as renewable energy, fast charging, modelling and testing, and SiC design and optimization.

Wolfspeed, Inc. at the PCIM Europe 2024: Hall 7, stand 7-435



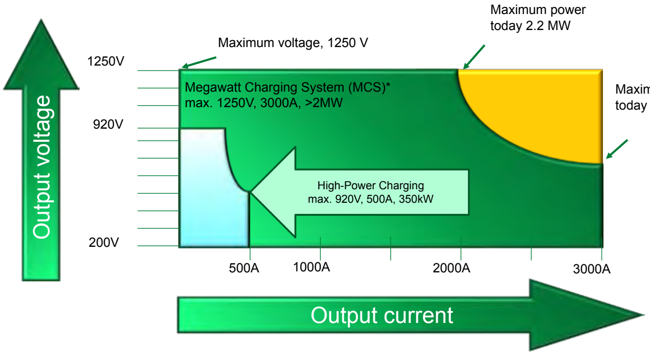
Silicon carbide is the best-in-class technology for 650 V to 3300 V e mobility power applications optimized for DC-link voltage classes from 270 V to 1500 V+

Image: Wolfspeed, Inc.

EV charging systems from e-scooters to mining trucks

As mobility goes electric, we need a whole spectrum of charging solutions, for vehicles from e-scooters to mining trucks. These extend from mobile chargers a user can put in a backpack, through domestic wall boxes, to infrastructure charging at up to 350 kW, which needs just 10 minutes to charge a car for the next 200 km. All these present challenges, with that challenge increasing with the current. In the extreme case, a megawatt charging system (MCS; with the standard covering up to 3.75 MW) may, for example, have to cope with 13 kW of losses at 1 kA in a single junction box, which is not unusual today. To reduce charging times for commercial vehicles to a third, by increasing the current to 3 kA, the same technology would have to deal with losses closer to 130 kW. Obviously, thermal management becomes a prominent topic.

Littelfuse is a concern spanning multiple technologies to provide customized, creative answers for customers unable to source what they need off the shelf. Littelfuse has been looking into low loss charging solutions. These start with stackable modules in the 60 to 100 kW range for single- or multi-phase supplies, using silicon carbide MOSFET and Vienna rectifier topologies, and achieving up to 98% efficiency. The modularity also contributes to the reliability of the systems in which they are combined. At Megawatt levels– inspired by B12C electrolysis technologies – Littelfuse already has thyristor solutions, with efficiencies up to 99.8% at 2.2 MW.



Today's charging standards address the growing range of electric vehicles, and present interesting challenges for technologies that will work in practice.

Image: Littelfuse Europe GmbH

Martin Schulz will present on "Charging Batteries from Scooters to Trucks" at the **E-Mobility & Energy Storage Stage,** 12 June 2024, 11:40 a.m. – 12:00 p.m., as well as on high power density designs.

Further speakers from Littelfuse will present on and discuss high voltage switches, charging station technology, encapsulation materials, novel and advanced semiconductor devices, and utility-scale battery energy storage systems.

Littelfuse Europe GmbH at the PCIM Europe 2024: Hall 9, stand 9-402

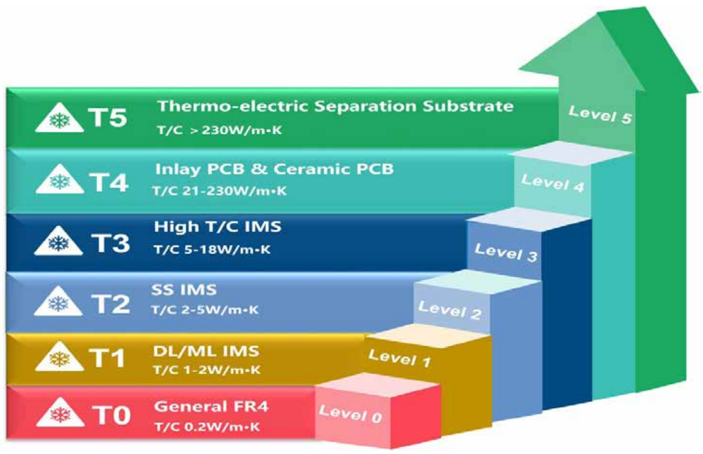
A role for the PCB in thermal management

The applications for power electronics are multiplying steadily. Often these are associated with increasing power densities and more need for miniaturization. This presents developers with a greater variety of thermal management challenges. Achieving optimal thermal dissipation is complicated by the number of variables involved, as well as the ever-changing working conditions many of these solutions face.

One important factor in thermal management and heat dissipation that often gets overlooked is the printed circuit board: The PCB has the potential to meet important heat sink requirements for high power devices. Kinwong Electronic is a PCB specialist with a long involvement in the R&D for PCBs used in high power, DC/DC automotive electronics, such as on-board charging and the related high-power-density power supplies and inverters. Apart from acquiring an expertise in the selection of power devices, these solutions have helped Kinwong develop a proficiency in thermal simulation technology, and the thermal conductivity of different materials, to get the optimal thermal dissipation solution under different heat flux and working conditions.

The outcome is a range of PCB technologies with potential applications that go far beyond EVs. These start with multilayer thermal substrates that can conduct 1 W/(m.K), proceed through solutions using copper or aluminium-based PCBs or embedded ultra heavy copper or ceramics, to the ultimate in thermoelectric separation technologies, which thermal conductivity can conduct up to 1000 W/(m.K). The resulting range of PCB solutions makes it possible to optimise for the thermal dissipation characteristics needed by many different high-power devices, modules and products.

Kinwong Electronic Technology (Longchuan) Co. Ltd. at the PCIM Europe 2024: Hall 5, vstand 5-426



Five levels of thermal dissipation PCB technologies make it easier to find the right heat sink solution for different types of high-power electronic devices and applications.

Image: Kinwong Electronic Technology (Longchuan) Co. Ltd.

E-Mobility and energy storage bringing movement to our smart grids and vehicles

Prof. Giuseppe Tomasso, Full Professor of Power Electronics, Electrical Drives and Machines, University of Cassino and Southern Lazio, Cassino, Italy; President, E-Lectra s.r.l., Greenergy s.r.l.; General Chair of the European PhD School on Power Electronics, Electrical Machines, Energy Control and Power Systems

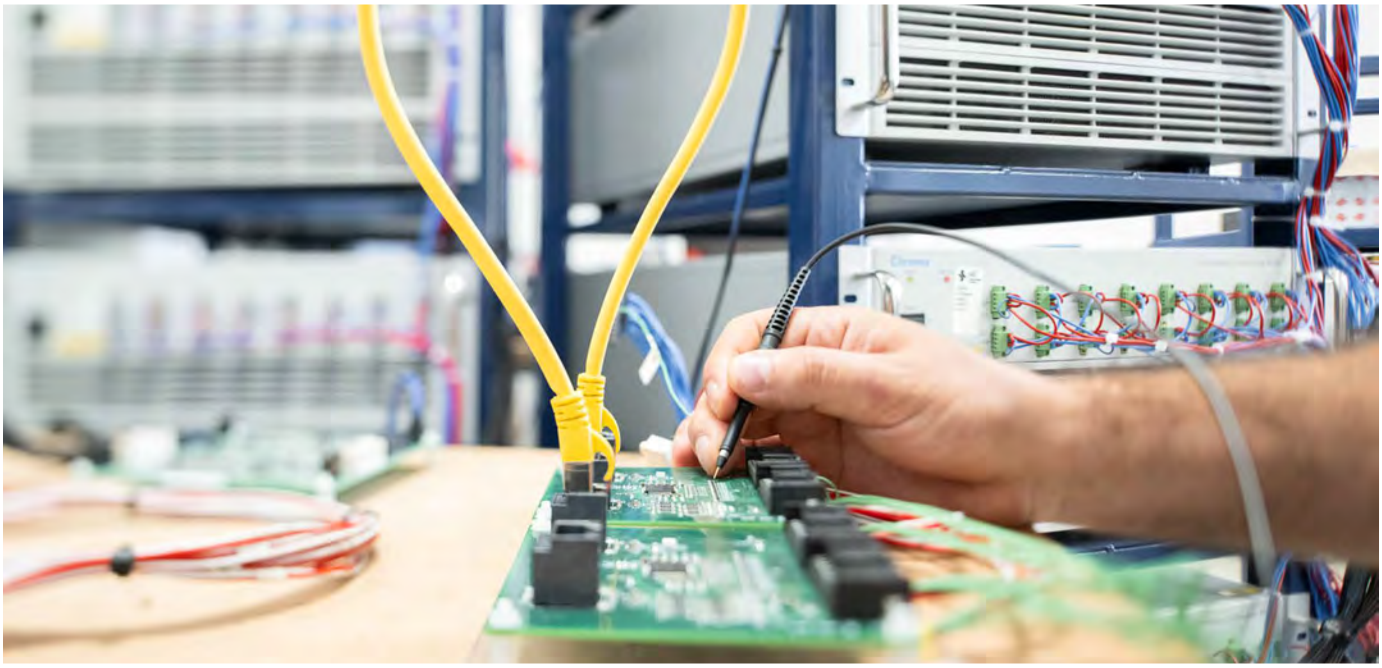


Image: University of Cassino and Southern Lazio

Our electricity infrastructure is having to get better at reacting to variable supplies of renewable energy at the same time as meeting the needs of increasing numbers of electric vehicles. Smart grids are an elegant way of not just addressing the challenges, but also making the most of the opportunities presented by these new technologies. The change is not just about taking a holistic approach to generation, production and consumption, but also looking at new ways that providers, manufacturers and consumers can benefit.

New ways of thinking about the electricity grid

Smart charging solutions can serve as an essential tool in seamlessly integrating renewable energy sources into the power infrastructure, while also optimizing the role of energy storage. This can obviously maximize utilization by synchronizing energy consumption with renewable energy generation peaks. But it can also be used to enhance grid stability, by dynamically adjusting energy demand, for example, by balancing charging over the electric vehicles (EVs) connected, and thus decreasing impacts on the grid. Extending this to the stationary storage systems in the infrastructure, can create an energy buffer and optimize not just the demand, but also the supply of energy over the daily cycle.

With the pending rollout of vehicle to grid (V2G) technology, EVs will not only consume electricity, but also be able to feed energy back into the grid, if needed. While this nominally increases the overall grid storage capacity, rather than using EV batteries to meet peaks of consumption, it would most likely be used in the form of more subtle grid services. For example, to respond rapidly to fluctuations, by using energy to stabilize frequency or support voltage levels. Obviously, for vehicle batteries, this could only use a small percentage of the capacity. But with today's large vehicles, with capacities of 100 kWh and more, as well as the 100s of connected vehicles with lower capacity, grid support can be achieved without significantly impacting on range.

From the technical point of view, this is enabled by bidirectional power converters for charging stations and new communication protocols (such as the Combo CCS Type 2) and increasing numbers of vehicles that are capable of bidirectional power flow. The challenge now is to work out contracts between energy providers and EV owners. The advantage to the owner

Image: University of Cassino and Southern Lazio, Cassino, Italy

or user needs to be obvious, in the form of discounted or free energy volumes, for example, to overcome any concerns about reducing battery life (through using up charging cycles), or reducing range. For the energy providers, this is interesting because the cost of these discounts or energy volumes can still be a lot lower than running extra generation capacity to meet peaks in demand.

The battery management system as a differentiator for battery systems

The battery management system (BMS) is central to the technical success of V2G, but also to the more usual issues of battery performance, health, and safety. As such, it is probably the most important part of the battery system.

At the most immediate level, the BMS needs to serve the user's needs, with information on status and likely range, and effective control of charging. But because the battery is the largest single cost in the power train of an EV, the BMS also needs to guarantee the health of the battery – to maximise the battery life. As the performance of cell chemistries converge, and the power densities of electric motors are already hard and expensive to improve, it is the BMS that can become an important differentiator for EV manufacturers. How it manages the storage can make the difference in how the vehicle performs, as well as on the life of the battery pack, and its safety.

To be effective, the BMS has to control voltage, current and temperature at the cell, module and pack levels. When it comes to safety, the BMS has to recognize potential problems early. For example, to activate the appropriate safety procedure as soon as it detects a problem in a single cell, or as soon as voltage, current, temperature, and vibration data predict an emerging issue across a module: recognizing a thermal runaway problem when it is already affecting a module or the whole pack is too late.

Detailed control is also part of ensuring balanced charging, so every cell can reach its maximum storage, rather than stopping when the first cell reaches 100%, as well as ensuring battery life by distributing charging cycles across the battery, rather than exhausting some cells early.

Reusing traction batteries: second life or fundamental function

The BMS can also supply important data to support the "second life" of an EV battery. This is a crucial contributor to reducing the overall CO2 impact of EVs, by getting the greatest possible return on the environmental footprint involved in production. Usually after up to 2,000 charging cycles, the battery pack on an EV cannot guarantee the performance for the vehicle anymore. However, at 70 to 80% of its original capacity it is still useful for stationary applications, and is probably good for another 2,000 to 3,000 charging cycles. This is interesting, for example, to energy providers building out their storage, not least because the cost is much lower than new.

The BMS plays a strategic role in providing comprehensive information about the battery pack: the state of health, whether there are critical cells that need to be changed, and so on. As this market increases in importance, there is growing awareness among battery OEMs, who are making refurbishment easier, making reconnection possible, and not least enabling the BMS to continue to manage the battery in its second life. This is also the thinking behind the EU battery passport regulation, due to come into effect in 2027, which mandates battery data being available to enable reuse, or efficient recycling.

Second life for traction batteries is also facilitating new business models. Such as the owner of an EV not having to buy a battery, but instead renting it (from an energy provider, for example) for the length of its "first" life. When it can no longer deliver the necessary vehicular performance, the energy provider can then use it in their stationary application. Second life might not just reduce the lifetime CO2 impact of a battery, but also improve attractiveness of EVs, by reducing battery costs.

Testing battery safety (at spin-off E-Lectra) is essential in balancing increasing energy densities with the risks that brings for potentially explosive reactions

The changing face of battery safety

When it comes to safety, the BMS has an active role, as discussed above, in managing cell, module and pack temperature, and guarding against thermal runaway. But there are passive contributors to battery safety too, mostly in battery construction and chemistry. The balance that needs to be found is between increasing energy density, to reduce the space taken up by the battery, and the potential that tight packaging has for literally explosive reactions, for example, by short circuits caused by mechanical intrusions during vehicle impacts.

In part, this has to do with creating flame retardant barriers to limit thermal runaway, or at least to slow heat transfer for long enough that passengers can get clear of the vehicle. It is also the driver behind exploring more stable chemistries, such as lithium iron phosphate (LFP), rather than the more usual lithium nickel manganese cobalt oxides (NMC).

Safety is an area in flux as we gather more data on events in the real world. As in the case of aircraft safety, the regulations and certifications are likely to keep changing, in reaction to the emergence of new, unforeseeable incidents. There is a lot of very fast evolution in this area, that is likely to pick up momentum as the number of EVs increases, and we have better statistics.

Prof. Giuseppe Tomasso is chairperson for the poster presentations on E-Mobility Charging, on 12 June 2024, 3:30 p.m., **foyer entrance NCC Mitte**

Wide bandgap semiconductors: possibilities in SiC and GaN

Prof. Dr.-Ing. Andreas Lindemann, Head of the Chair for Power Electronics, Institute of Electric Power Systems (IESY), Otto-von-Guericke-University Magdeburg

While power semiconductors have traditionally been silicon (Si) devices, in the meantime wide bandgap devices have gained a considerable and increasing market share. In particular SiC and GaN are frequently used in various applications where they are particularly advantageous. The state of the art and prospects for their application are highlighted in the following interview with Dr. Andreas Lindemann, Professor for Power Electronics at Otto-von-Guericke-Universität Magdeburg.

Andreas Lindemann holds a diploma and doctoral degree in electrical engineering. He has worked on R&D in power semiconductor industry for ten years. Since 2004, he holds the Chair for Power Electronics at Otto-von-Guericke-Universität Magdeburg. His research interests include the use of novel power semiconductor devices in circuits and systems for various modern applications with a special focus on aspects like reliability and EMC. He is among others engaged for IEEE PELS, VDE and ECPE, co-chairing the biannual International Conference on Integrated Power Electronics Systems (CIPS) and the ECPE SiC & GaN User Forum.

Can you give us an overview of current developments in GaN power devices?

GaN devices in production have voltage ratings up to some 650 V and current ratings up to the order of magnitude of 100 A. All of them are lateral transistors, i.e., HEMTs (which means high electron mobility transistor) or GITs (which means gate injection transistor). HEMTs are purely voltage controlled with low gate capacity and can be normally-on or normally-off, while GITs require a small gate current to fully turn on, which makes a difference for the driver design. Current is carried exclusively by electrons which means that the devices are purely unipolar, thus fast switching and not avalanche-rated. Even normally-off devices can conduct in reverse direction similar to a diode but remaining unipolar, i.e., they don't show a reverse recovery current peak. Normally-on devices can either be controlled directly – i.e., be turned off by applying a negative gate voltage – or via a low voltage MOSFET in a cascode circuit, while the control of normally-off devices is basically similar to MOSFET control which is often preferred for straightforward circuit design even though the driver parameters are different.

The lateral structures can be integrated, allowing to join multiple switches and parts of the control circuit. For cost reasons they are usually manufactured on silicon substrates with an intermediate buffer layer.

Beyond this state-of-the-art research is ongoing: For example, vertical devices have been demonstrated to e.g. achieve higher voltage ratings.

Why are applications – such as E-Mobility –suitable for GaN transistors?

GaN power devices have been frequently used in switched-mode power supplies up to the kW range. This seems natural because those often operate with DC link voltages up to 400 V which fits well to the devices' rated blocking voltage. There often is no need for parallel connection of devices because of the achievable current ratings which facilitates circuit design. In addition, at least low power levels can benefit from the aforementioned integration. The low switching losses – in hard- and even more in soft-switching operation – allow for high efficiency even at high operating frequency which is beneficial to minimise the size of transformers, inductors, or filters.

Of course, the technology is not limited to these most typical applications. Higher currents can be achieved by paralleling devices, higher voltages with appropriate circuits like three-level converters. Drives – in particular high-speed drives – may also profit from the device properties, especially when efficiency is important. Application-specific requirements – like for instance overload or short circuit capability – need to be taken into account in addition.

This leads to your question regarding E-Mobility: An electric car needs a small onboard charger which basically is a switched-mode power supply. In addition, there is a corresponding converter between the traction battery, which often has a terminal voltage of about 400 V, and the 12 V system. Further, there are auxiliary drives – such as for electric power steering or air conditioning – as well as the traction drives, both requiring inverters. Power converters in electric vehicles should be as compact and efficient as possible. In view of these considerations, it seems natural to equip at least some of them with GaN devices.

Can you give us an insight into the research to solve problems such as undesirable dynamic RDSon and current collapse effects?

GaN power devices profit from the fact that the technology has been adopted from RF electronics where it already had reached a high level of maturity. Specific fundamental questions have been scientifically clarified – let me mention as an example a doctoral thesis which has shown that the piezo-electric properties of the material and the related mechanical stress do not lead to a lifetime limitation of GaN power devices. Reliability tests have been carried out and reported and field experience has been gained with the considerable production volume. This means that a lot of research has already been carried out but of course and as always, we are not done:

Drift effects are observed like the dynamic RDSon you mention. It basically leads to a higher conduction voltage drop and thus higher conduction losses. The effect depends on the operating conditions, in particular the applied blocking voltage prior to turning the device on. It is temporary, i.e., decreases within the conduction time, but may accumulate in continuous switching operation. A deep physical understanding of such effects which are related to charge trapping in the individual semiconductor structures of the different devices we discussed is important to optimise the devices. Ongoing research and development have already permitted to reduce such effects as researchers and manufacturers reported e.g. on the occasion of the recent 10th ECPE SiC & GaN User Forum.

Another challenge concerning circuit design and application is device ruggedness. As mentioned, the devices are unipolar and thus not avalanche rated. For this reason, the device manufacturers usually provide a considerable safety margin between the rated blocking and the breakdown voltage. Suitable circuit design is of course also required to avoid overvoltages, especially when considering the steep switching slopes. In a similar way, also the driver circuit must be carefully designed because the different gate structures partially are rather sensitive to overvoltages. A good match of potentially optimised devices with the circuit will be required to achieve the desired operational behaviour under all conditions which finally is also important on system level where e.g. EMC standards need to be fulfilled.

How has the development of SiC components –SiC MOSFETs and JFETs in particular – continued in recent years?

Generally speaking, SiC MOSFETs have clearly become the mainstream SiC transistors: They are normally-off and thus convenient for the design of most circuits. Many issues which had been observed in the earlier development phase of the technology have been mostly solved, concerning e.g. material quality; this increase of maturity is basically a similar development as observed earlier with Silicon. While SiC MOSFETs were initially commercialised in the voltage range from 650 V to 1200 V the ratings have increased in the meantime and reached 3.3 kV. The chip sizes remain smaller than we are used to from silicon which contributes to the production yield.

Regarding the applications this means that the voltage range of commercial SiC transistors begins where GaN transistors' ends. The devices thus are of interest e.g. for converters connected to the 400 V three-phase grid or DC link voltages significantly above 400 V. The high voltage ratings can be used for example in traction or industrial drives. Of course, parallel connection of chips is then required in many cases to cover the required power ratings.

This leads to the aspect of packaging: While lateral GaN devices – which we discussed before – mostly use some kind of chip-scale package the SiC devices are vertical and can in principle be packaged in a similar way like silicon devices. However – as has been learned quite early – the packages must be adapted. This on one hand concerns the joining technique which must cope with the different material properties, such as higher stiffness and thermal conductivity. On the other hand, the electrical properties are different, too, and the package must for example be low-inductive because of the steep switching slopes. As of today, there are SiC transistors in a considerable variety of packages, beginning with conventional footprints like TO-247 – which obviously is hardly optimised, but cheap – and ending with advanced modules.

Ongoing research allowed to fabricate various samples beyond commercial products, for example 10 kV SiC MOSFETs. They demonstrate the technological possibilities and challenges. This also applies to the application circuits where for example the handling of the steep and high switching slopes with sufficient galvanic isolation and avoiding partial discharge is an issue.

How do electric vehicles, railroad and similar applications benefit from SiC?

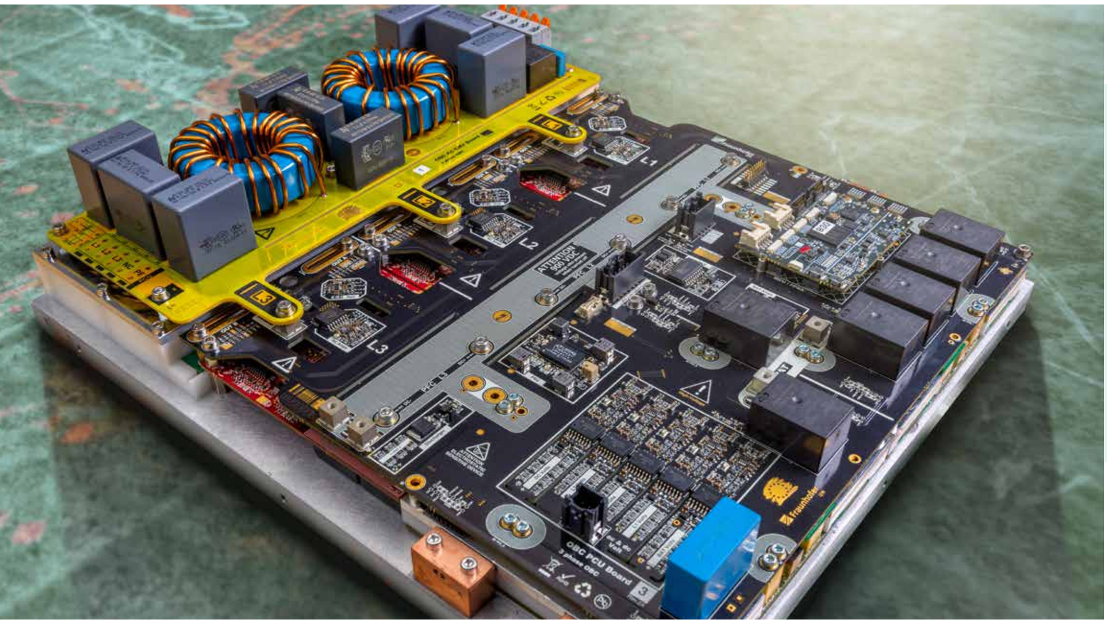
It is known that suitable unipolar devices – i.e., MOSFETs – allow to increase the efficiency of drive inverters because of the lower switching losses and the resistive on-state characteristic in contrast to IGBTs where this has a knee voltage. When the losses are lower the thermal design allows to shrink the power section, i.e., to increase the power density. Although the requirements in electric cars are quite different from those in rail vehicles – also concerning expected lifetime and cost – increased efficiency and power density are beneficial for both. The rated voltage range of today's SiC MOSFETs allows to use such devices in high performant cars with battery voltages also above 400 V as well as in railway traction drives. This has been demonstrated some years ago already and, in the meantime, has reached volume production in car industry. In turn this helps to grow the production volume and decrease the cost we didn't talk about too much.

The load profile of traction drives is cyclic. A proper inverter design must make sure that the power semiconductor components will achieve an appropriate lifetime under such operating conditions. For this purpose, they are qualified in reliability tests such as power cycling. SiC MOSFETs deliver meaningful and satisfactory results here which nevertheless also uncover effects which are subject to further research: For example, carriers can be trapped in a partially reversible way, leading to a drift of threshold voltage and a change of device characteristics. Again, it is important to understand such effects in order to on one hand develop suitable test methods and on the other hand appropriately consider the effects in the circuit design.

Prof. Dr.-Ing. Andreas Lindemann chairs the oral session on GaN Ruggedness on 11 June 2024, 11:00 a.m., **stage Brüssel 1,** and the poster session on 12 June 2024, 1:00 p.m., **Hall 10.1.**

Designing for production: Smart Power System Integration

Prof. Dr.-Ing. Eckart Hoene, Chief Expert Power Electronics, Fraunhofer Institute for Reliability and Microintegration (IZM), Berlin, Germany



The 22 kW onboard charger, on a cooling plate, showing how PCB technology can be used to implement designs to make manufacturing more efficient, and bring down costs.

Image: Fraunhofer / Volker Mai

Power electronics has long been taken for granted, as a stable, established discipline. This is being shaken up by the tremendous increase in applications, as we shift from fossil-based to renewable energy generation, add AC and DC grids at different voltage levels, and supply the many different, and new consumers of electric power. The devices to consider include solar- and wind-inverters, power supplies for office and domestic equipment, the controllers and the many motors in heat pumps, air conditioning and electric vehicles, and the DC-DC converters for graphic and tensor processing units with transients reaching 1000 A. Altogether, the amount of power electronic devices is likely to increase by an order of magnitude over the next 20 years. And there is an expectation that they all work, and are inexpensive. Meeting such expectations means rethinking how we produce these devices.

The potential numbers raise the profile of the material choices. As production volumes increase, material costs become a dominant factor in prices, as well as driving the environmental impact. Achieving the necessary volumes also means that manufacturing has to adapt: something as fundamental as the winding of a coil requires a different approach if production numbers are in the hundreds of millions.

Design for manufacturability

In a discipline as mature as power electronics, it is not unusual for a chain of different specialists to be involved during product development, from the concept, to the circuit diagram, components and control strategies, to the layout and defining of the bill of materials. The awareness of established and possible production methods needs to be considered ever earlier in this chain to enable the production of ever larger quantities.

Of the mass production technologies for electronics, few are as widespread as printed circuit boards (PCBs). Although PCBs have been around for decades, it is still possible to push the envelope. DC-DC converters for GPUs and TPUs, for example, can embed semiconductors in the PCB, and include PCB inductors to make voltage regulation modules (VRMs) with reduced interfaces and conductor lengths, that are volume optimized and can handle high currents with low losses.

Inductors using PCB technology can also be applied at higher voltages. We have used these, for example, in a 22 kW onboard charger: if a designer knows they have that degree of freedom they can adapt the topology to shift from manual manufacturing – instead of winding a coil that needs through-hole technology and potentially even mechanical mounting – to something that is a surface mount device (SMD) that is easier for a machine to handle. PCB technologies are also already being used for traction inverters in the automotive industry, where there is both the commercial motivation and the engineering depth to make the most of such advances.

Economies of scale

Another way of improving the efficiency of manufacturing is to use larger PCB panels – up to 60 × 60 cm in large scale production – to produce many more units in parallel. (This is the same approach that the semiconductor industry has been using for years in increasing silicon wafer sizes.) By dividing the production steps by the number of units, the cost per unit decreases.

The same idea can be applied to manufacturing components, shifting transfer moulding from the common 10 × 30 cm size batch to 60 × 40 cm. This is a current research project – financed by a consortia of industry partners – at the Fraunhofer IZM. The close collaboration with industry is important. Input, guidance and accountability to industry partners helps meet real needs, not least ensuring the right production machines can be prepared, to smooth the transfer to practice.

The current challenge in the project is understanding the different shrinkage as the polymers of the larger batch sizes cure. Solving this ensures the transfer mould aligns correctly and reliably for the following stages of production. Otherwise, for example, the laser might not find the pad it expects on a chip.

Expanding the parameter set for further optimization

Enabling electrification contributes to the more efficient use of energy – one only has to compare the 25% efficiency of an internal combustion engine with the 80% efficiency of an electric vehicle. But more than this, power electronics is essentially about pushing the boundaries of that efficiency, to minimise the losses in the energy flow chain. Add in the push, particularly in automotive applications, to create solutions that are as small and lightweight as possible. This reduces the materials needed, which is good for the environment as well as the costs.

Work has begun in looking more at the whole lifecycle: how a product is manufactured has an important role to play in how easily it can be reused or recycled. This becomes a further parameter to be optimized from the conceptual phase on. An important additional opportunity here would be to design to use more recycled materials, like copper or aluminium. Or – even when the raw materials are not economically or ecologically expensive – to look for opportunities to use renewables, for example for the energy intensive growing of silicon carbide crystals.

The next horizon will be gathering more information about the carbon footprint or environmental price for different materials. This is a further parameter that could be considered for optimization, if the data were sufficient. There is an awareness already, and the signs are optimistic.

Prof. Dr.-Ing. Eckart Hoene is chairing the oral presentations on "GaN Converters" on 11 June 2024, 2:30 p.m., **stage Brüssel 1**.

Pushing back the boundaries of characterisation

Gallium nitride (GaN) and silicon carbide (SiC) wide-bandgap semiconductors are enabling remarkable increases in efficiency and power density of power electronic converters. However, the control of these devices, and the systems they work in, is more complex than for silicon. Precise characterisation is an important step on the path to developing reliable and efficient solutions, as well as in realising the full potential of these newer technologies.

Density, efficiency, reliability

Getting to the limits of any power system, in terms of power density and efficiency, relies on having an accurate characterization with high confidence. The more uncertainty there is in this data, for example, the greater the thermal safety margins of an overall design need to be. Apart from performance this can also have repercussions for the acquisition and operation costs. Precise characterisation also opens the door for digital twins, facilitating the running of varied simulations, as has become more prevalent in power electronics development in recent years.

The higher densities of energy and currents, as well as the shift in assembly from bond wires to sintering, surface mounted and embedded components, as well as new packaging configurations, also increase the complexity of electrical and material interactions in new solutions. This all has potential implications for reliability. Given that, in applications from wind turbines to heavy vehicles, the power electronic components are expected to work for decades, the role of power cycling is more important, whilst becoming more complex at the same time.

The foundations for simulation

Compared to characterisation of silicon, the switching speeds of wide bandgap materials necessitate a rethinking of measurement methods to be sure of getting the required information. This starts with the equipment and setup. A double pulse test for silicon, for example, is easily done with bandwidths in the tens of MHz. However, this is insufficient for GaN, which is more than ten times faster than silicon, and has switching transients in the nanosecond range. Part of this challenge is being met by the advances in technology, for example, using optically isolated probes, or novel current sensor techniques, which promise very wide bandwidths.

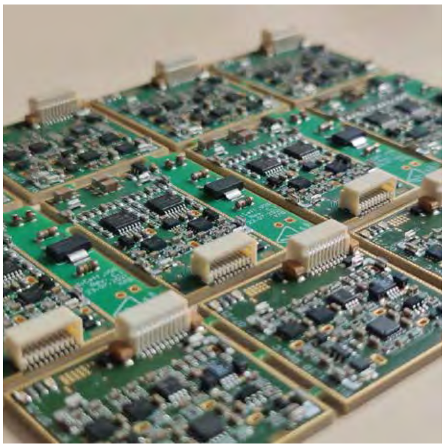
Beyond this evolution of the equipment, there is also a need to explore new measurement procedures. For example, characterising soft switching losses of SiC or GaN pushes beyond the envelope of practical electrical measurements: de-skew needs to be down to picoseconds to differentiate the positive and negative currents. Instead, calorimetric measurements are in development, though these have challenges, not least in the measurement duration.

An explosion of data points

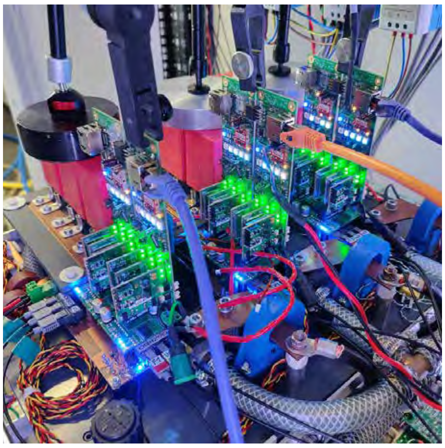
The higher bandwidth measurements, as well as new measurement procedures have resulted in a dramatic increase in the amount of measurement data. For example, for some power cycling tests, each of the many switching events produces six different, temperature-sensitive electrical parameters, using specially developed acquisition boards. These need to be analysed, to separate out the temperature and aging effects, as well as any measurement error. This would be possible with fitting functions. However, this is precisely the kind of problem for which machine learning is well suited. AI can identify correlations that might otherwise go unnoticed – and there is potential for establishing correlations that might reduce the number of tests needed. On the other hand, sometimes working on an algorithmic approach benefits a fuller understanding of the physical behaviour.

University Stuttgart at the PCIM Europe 2024: Hall 7, stand 7-579 (University Research Zone, on 12 June 2024)

Modular characterization board



Novel Measurement and Acquistion Circuits



Application Demonstrators and Reliability Tests

Images: University of Stuttgart – Institute of Robust Power Semiconductor Systems (ILH)

Using a digital twin to improve the predictive maintenance of critical electrical machines

Digital twins of electrical machines are proving to be cost-efficient tools for the management of sensitive, or critical equipment. Monitoring conditions remotely and automating diagnosis – often tailored to the individual machine – can lead to the early detection of faults and aging effects, thus enabling preventive maintenance that extends reliable operation, even under varying speeds, loads, and environmental conditions.

A digital twin to detect disparities

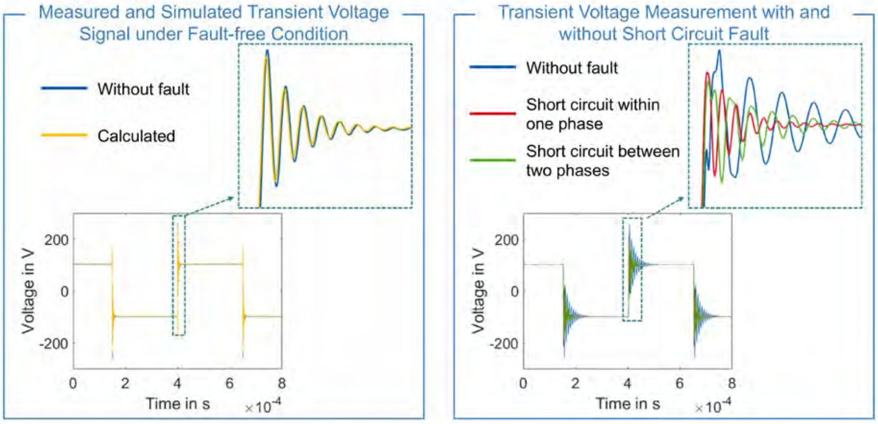
The Institute of Electrical Machines (IEM), at the RWTH Aachen, is developing a monitoring system that can be applied to determine the changing insulation condition of motors. The approach combines data from electrical sensors and sophisticated modelling, to predict faults before they impact operation.

The digital twin applies high frequency modelling technologies to calculate the expected common-mode current, based on the voltage signals measured. The simulated current (which represents fault free conditions) is then compared with a real-time measurement. The disparity between the simulated and measured transient behaviours during switching show alterations in the parasitic capacitances that indicate stator winding deterioration.

Validated insights

Experimental data has validated the high accuracy of the simulated transient signals, and the sensitivity of the system for effective, real time detection of even small changes. The trend of the disparities between the simulated values and the measured voltage and current signals provide valuable insights into thermal and electrical aging processes, and make it possible to proactively avoid device failure.

RWTH Aachen University at the PCIM Europe 2024: Hall 7, stand 7-579 (University Research Zone, on 11 June 2024)

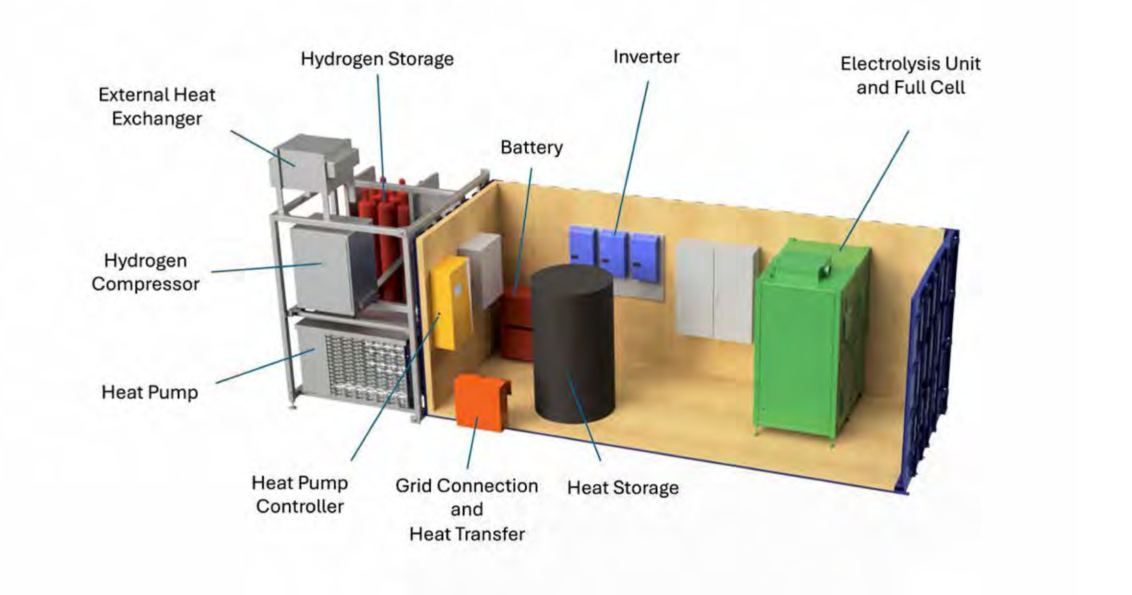


Results from the digital twin show (left) accurate prediction the transient signals under no-fault conditions and (right) disparities for different fault conditions.

Images: RWTH Aachen

Using heat loss in the hydrogen economy: a container solution as multi-energy storage system

The global energy transition and the urgent fight against climate change require not only a switch to sustainable sources, but also an intelligent optimisation of how we coordinate and consume the energy we have. A key challenge in efficiently using many renewable energy sources stems from their intermittent nature. The generated energy needs to be stored effectively and used flexibly. Hydrogen storage is often discussed in this context, although it is often criticised for perceived inefficiency in terms of production and reconversion to electricity.



The "Renewable Energies and Electromobility" research team in the Department of Electrical Engineering at Fulda University of Applied Sciences is working closely with industrial partners to take an innovative approach: Instead of viewing the supposed inefficiencies as hurdles, their COMLEE-H2 research platform investigates practical ways of re-using the losses to increase the overall system efficiency.

Intelligent dovetailing of electrical, thermal and chemical energies

While battery storage offers high dynamics and efficiency (90-95%), the storage capacity is limited due to the volumetric energy density. Hydrogen, on the other hand, is worth considering for larger amounts of energy, particularly if the high conversion losses– often released as heat – can be used effectively.

The team at Fulda is realising a multi-energy storage system capable of supplying a four-person home with its energy needs for three to five days. This uses intelligent storage management that applies predictive analytics to harmonise the use of energy sources and storage with generation and consumption forecasts. It links different energy sources, various storage types, and the consumption of electricity and heat. It also combines new technologies with existing resources and processes to minimise cost-intensive components, and therefore ensure cost-effectiveness.

The multi-energy storage system

The prototype system centres on an electrolysis unit with a maximum electrical power consumption of 5 kW, which is connected to hydrogen low- and high-pressure tanks, that can store up to 400 kWh. The built-in fuel cell, with a maximum electrical output of 8.4 kW, can convert the stored hydrogen back into electricity.

To overcome the high inefficiencies of the hydrogen system, the heat losses are stored in a thermal buffer storage tank. An integrated heat-pump can be used for additional cooling and heating.

To this end, the various components are intelligently linked, controlled and operated with foresight using predictive analytics. The overarching aim of the research is to operate multi-energy systems with hydrogen, battery and heat storage combinations as efficiently as possible, to reduce cost-intensive components to a minimum and to ensure the cost-effectiveness of these systems for apartment buildings and neighbourhoods.

Fulda University of Applied Sciences at the PCIM Europe 2024: Hall 7, stand 7-579 (University Research Zone, on 13 June 2024)

Funded by the European Union
NextGenerationEU

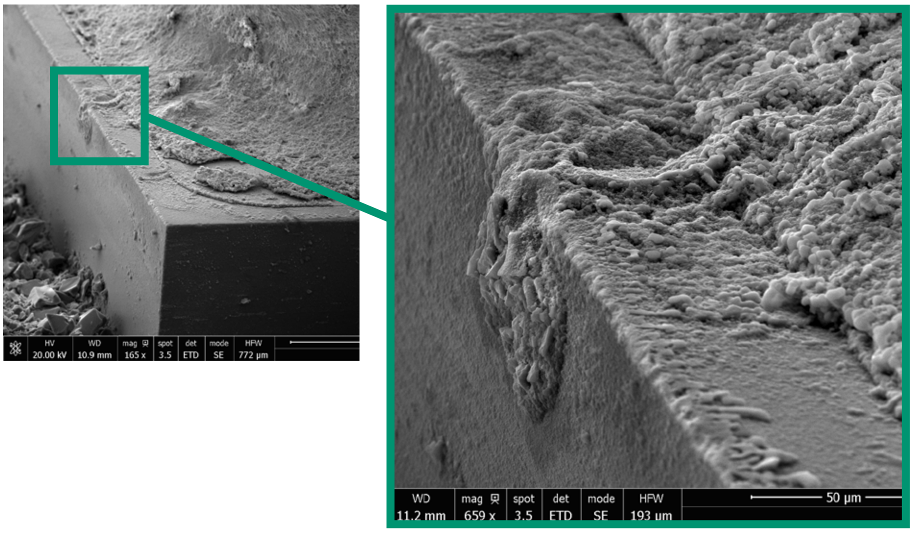
Funding information

This project is funded by the European Regional Development Fund as part of the Union's response to the COVID-19 pandemic.


HESSE
MECHATRONICS
It all starts with a good connection!
Hesse GmbH - Your reliable equipment partner for:
Visit us in Hall 5 - Booth 406
Wire Bonding
Smart Welding
Laser Welding
Automation
www.hesse-mechatronics.com

Extending the robustness (and useful life) of electronic devices and systems

Environmental exposure – whether it is to humidity, gases, or other contaminants – can corrode electronic devices and systems. For power electronics used in wind turbines, for example, corrosion is commonly seen. But whether it is renewable energy sources, electric vehicles, or domestic appliances, exposure to the external environment can lead to deterioration of parts that compromises functional performance at best, causes outright failure, or in the worst case leads to fires.



With the help of the 3D imaging centre at the Technical University of Denmark, the CRED team could scan a failed diode, to pinpoint precisely the place where ECM had created the short circuit.
The closeup shows how material migrated over the edge.

Subtle changes with big impacts

Corrosion of electronics can affect operation by different means. Perhaps the most important failure mode is caused by the formation of water-films on electronic surfaces exposed to humidity. This can lead to unwanted leak currents, or electrochemical migration (ECM). Another common problem is the formation of conductive anodic filaments (CAF) within the laminates of printed circuit boards. These can compromise functional performance, or cause failures. But particularly in high voltage applications, the resulting potential for short circuits can ultimately result in the outbreak of fire.

As corrosion is a robustness issue, failure often happens suddenly when exposure conditions are conducive. This is why it is important to understand the mechanisms and factors involved thoroughly, and to know how to interpret the impact they can have, to try to remove factors that cause interaction with humidity, for example. The Centre for Electronic Corrosion (CELCORR) at the Technical University of Denmark has more than 16 years of expertise, across industries and around the world, in solving corrosion challenges in electronic systems.

Identifying vulnerabilities for power electronics

CELCORR has long worked on joint industry research programs as part of an industrial consortium, and it is out of this work that it identified a specific need to extend its capabilities in developing preventive solutions for power electronics applications. The resulting Centre for Climate Robust Electronic Design (CRED) funded by the Poul Due Jensens Foundation, Denmark, is helping CELCORR to develop practical and experimental expertise for environmental effects in high voltage/power electronics and different application situations. These are unique capabilities, that combine materials, corrosion, and electronics knowledge to understand root cause and using that understanding to boost robustness. The goal is to have a body of know-how that can be widely used for designing better devices and systems, from EVs to wind turbines or other applications.

Unlike other research groups with power electronics background, the centre approaches issues from a unique corrosion and materials perspective, looking at the interactions of materials with conditions, that is, the aspects of surfaces, interfaces, process related factors, and so on. This makes it possible to identify the root causes of vulnerabilities: information that can be used to replace, modify, or adapt designs to attain greater robustness and extended product lifetimes.

CELCORR research group at the PCIM Europe 2024: Hall 7, stand 7-579 (University Research Zone, on 11 June 2024)

Images: Technical University of Denmark - Center for Electronic Corrosion (CELCORR)

Integrating High-Power Electrolyzers into the Grid

One phase of a thyristor-based multi-MW rectifier stack, developed by Infineon specifically for electrolysis applications.

Hydrogen has a fundamental role to play in decarbonising our economy. It is especially useful for energy hungry industries that are otherwise hard to decarbonise just using electricity. These include the chemical, steel, maritime, fertiliser, and various other industries. An S&P Global study from 2022 indicates that 4.4 TW of electrolyser capacity could decarbonize the whole economy. Accomplishing this would involve developing new infrastructure for distributing the hydrogen produced. While this accessibility is mostly about enabling the demand, there are supply-side challenges that can be addressed more immediately: to integrate electrolysers to already enable the productive use of electricity from renewable sources at times when it is not needed by the grid.

Grid code requirements for consumption

Integrating electrolysers into the grid is part of the overall challenge for power electronics to provide distribution system operators with the control they need of the modern energy landscape. The attention has been on updating the grid code to ensure power quality and grid stability, and to accelerate the integration of renewables. Much of this is to support the grid under different fault scenarios, such as voltage or frequency changes, short circuits, and so on. Not as much work has been done specifically on the consumption side. This is where electrolysers fit into the picture.

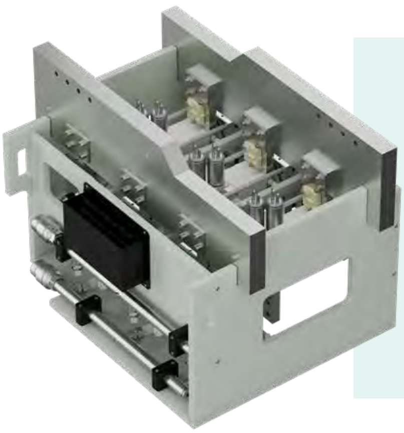
As potential consumers of hundreds of megawatts, electrolysers do have a role to play in supporting the stability of the grid. This is usually by meeting requirements for total harmonic distortion (typically <5%) and power factor (typically >0.95).

Power electronics topologies for electrolysis

Familiar power electronics technologies – as are often developed for generation systems – tend to have more capabilities than an electrolyser needs. These solutions are over-specified for "just" keeping total harmonic distortion and power factors in check. While they might provide extra capabilities that are nice to have, this can mean higher capital expenditures.

The choice of the right topology is influenced by a number of other considerations. These include technical issues at the point of common coupling, such as the robustness of the grid (affecting the impedance needed), and whether the electrolyser is at the start or end of the generation line. Then there are factors that influence operational costs, such as levels of efficiency and reliability, and ease of maintenance, as well as any size needs for the specific implementation. Taking such factors into account can optimise operational expenditures, to minimise the total cost over the lifetime of the device.

This involves carefully considering the different technologies available, such as IGBT-based, thyristor- or diode-based solutions, along with passive or active compensation to manage power factor and harmonic requirements. Each option presents its own unique considerations, and the decision should be based on a thorough evaluation of technical and operational factors to optimize overall costs.

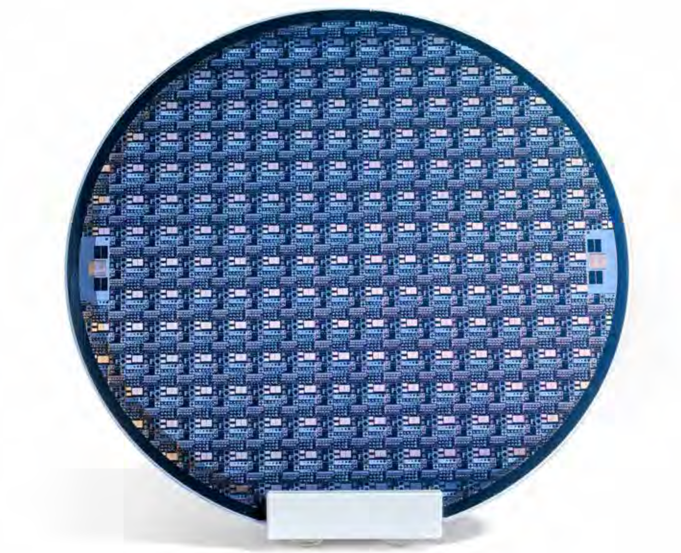


Three rectifiers are combined in a solution that is highly efficiency and reliable, competitive on price, and compact, at around 400 l for up to 8 MW.

Mohamad El Ghouti, Infineon Technologies Bipolar, will examine the different factors in selecting the right topology during his presentation "Meeting Grid Code Requirements for High Power Electrolyzers: Choosing the Right Power Electronics Topology" on 12 June 2024, 10:25 a.m., **Technology Stage**

A bright future for GaN power devices

Apart from being necessary to maintain our quality of life, the energy transition is also an opportunity to secure Europe's economic strength, through developing future-facing technologies. This encompasses everything from air conditioning (heat pumps) and mobility (electric vehicles, and the charging infrastructure) to the energy market (solar, wind power, and storage technologies). Power electronics plays a key role in enabling the transformation. The price-performance point of these solutions, which is largely determined by the power semiconductor technologies they use, is a central concern of the energy transition.



Processed wafer with vertical GaN-CAVET transistors

A significant role for GaN today

Compared to silicon technologies (Si-MOSFET and Si-IGBTs), silicon carbide (SiC) MOSFETs offer very good efficiency and switching properties. This is why they are being increasingly used in energy transition solutions. But the relatively high substrate costs make SiC MOSFETs comparatively expensive.

Gallium nitride (GaN) offers an alternative. GaN devices are efficient and fast-switching, and – thanks to processing on large-area (≥ 8″), low-cost Si carrier substrates – cost-effective. This is proven by 10 years of commercial availability, and the frequent use of lateral GaN HEMTs in consumer voltage converter applications.

However, the constrained thicknesses of the GaN layers in GaN-on-Si technology means they are stress-limited, typically up to reverse voltages of 650 V. This means GaN components are not in consideration for many energy transition applications. However, there is research into higher voltage classes, through the continuous development and optimization of substrate quality, crystal growth layers, process technology, and device structure.

Insulating substrates to boost voltage classes

Such research has already shown reverse voltages of up to 1200 V are achievable for GaN-on-Si HEMTs . There is also a trend to replace the conductive Si carrier substrates with highly insulating carrier substrates (sapphire, SiC, GaN, ...). Preventing a vertical breakthrough path to the substrate, removes the practical voltage limit for lateral GaN HEMTs on insulating carriers. There are commercial products with GaN HEMTs on sapphire that can handle reverse voltages up to 1250 V[i], and voltage classes beyond 1200 V can already be found in the current scientific literature.

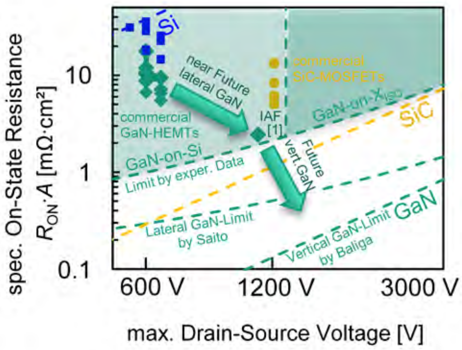
GaN-on-sapphire is very interesting for commercialization, because the sapphire substrate has already been developed for LED applications on large-area wafers (6″) This should pave the way for attractive pricing, with good material quality. It seems likely that in the next 3 or so years, high-performance, efficient and cost-effective GaN HEMTs on insulating substrates will be available for applications ≥ 1200 V).

Vertical GaN technologies on the horizon

Longer term, the full potential of GaN semiconductors can only be realised with vertical GaN transistors. Currently, GaN wafers for vertical devices have limited availability, for smaller diameters (≤ 4″), at significant costs. However, larger diameters, improved material quality, and lower costs are in development.

There is also research on other component technologies (GaN-CAVET, GaN-FinFET, GaN-JFET, GaN-MOSFET, ...). These aim to reduce the on-state resistance relative to the chip area (Ron·A), to define gate modules suitable for use in products (normally-off, leakage currents, robustness, ...), as well as improving reverse voltage resistance. The next 10 years should see lots of exciting GaN technologies, to enable further leaps in the development of energy transition applications.

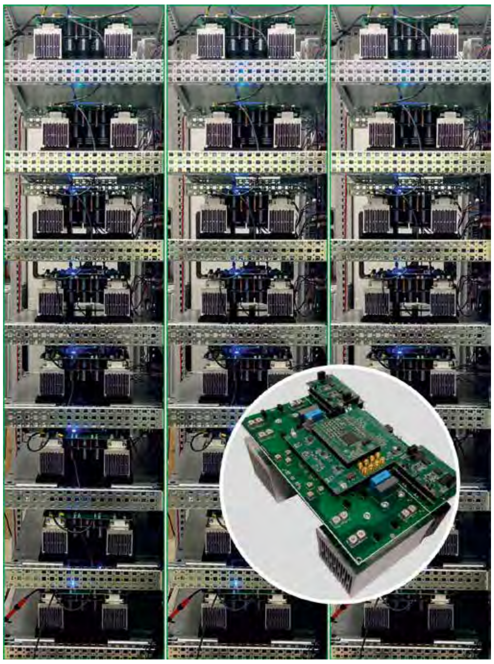
Dr. Richard Reiner, Fraunhofer IAF, will present an overview on these subjects on 12 June 2024, 10:50 a.m, **Technology Stage**



Future development of the performance of GaN power transistors based on figure-of-merit chip face-specific resistance (component efficiency) vs. reverse voltage

Images: Fraunhofer IAF

i R. Reiner et al.,"More than 1200 V Breakdown and Low Area-Specific On-State Resistances by Progress in Lateral GaN-on-Si and GaN-on-Insulator Technologies", in Proceedings of the PCIM Europe, 2024.


500 kVA - 9 levels modular multilevel converter (MMC)

Solid state transformers: A stabilizing influence in distribution grids

Distribution grids are experiencing a rapid transformation driven by the massive integration of non-dispatchable renewable energy sources (RESs) and highly variable loads. Smart solid-state transformers (SSTs), with advanced control and communication capabilities, are attractive for improving the stability of grids faced with the unpredictability involved. The benefits are significant, and standardisation work continues on the open issues to make them even more attractive.

Effective stability means increased capacity

Smart SSTs can compensate for disturbances, by regulating voltage to change the operating point of the grid. For example, the frequency variations resulting from a RES going offline were the focus of a cooperative study between the Chair of Power Electronics of Kiel University and University College Dublin, Ireland. This found that smart SSTs could change the voltage and thus vary power to produce a damping effect that smoothed the frequency oscillation. The result of being able to control this variability meant at least 10% more capacity for RESs in the grid, without extra investment in storage systems. In some cases, a smart SST can even create controlled perturbations in the grid to gauge how much of a benefit it can deliver.

And of course the same principle applies on the load side too. For example, to support charging areas for electric vehicles (EVs) in urban areas as well as remote, motorway services. Here smart SSTs not only enable different charging modalities for heavy vehicles, hurried business users and private users with more time, but can also coordinate power usage with the grid: A study in the German "Ensure" and "Kielflex" projects have shown how the smart support from SSTs can increase the overall capacity of such a charging infrastructure.

Contributing to transmission grid stability

There is an emerging tendency to see the capabilities of the smart SSTs that can be installed in primary and secondary distribution grids as a source of flexibility to support the transmission grid. They achieve this by (cumulatively) offering reactive power or frequency services (as mentioned above). This relies primarily on renewable sources, but can also use the voltage dependency of many of the devices consuming power. Other studies have looked into the possibilities to transfer these finding to high voltage DC (HVDC) transmission, including HVDC supporting AC lines in which they are embedded; as well as smart SSTs working as static synchronous compensators (STATCOMs) and even with battery storage in distribution grids.

Another potential for smart SSTs to improve overall grid stability is by acting as a restoration service for black starts. The smart SST uses local generation to autonomously restart the low-voltage grid (as a controlled island), then rebuilds the voltage to restart the medium voltage grid. Of course, if there is integrated storage, this can help further by buffering immediate mismatches between production and consumption.

The time has come for smart SSTs

As the expectations for high and medium voltage grids change, the time is ripe for the widespread deployment of smart SSTs. The possibilities for reacting to variable supply and demand, and the ability to control decoupling for black starts are part of this. Although hybrid transformer solutions (partially based on power converters) are still often the default choice, modular multilevel converters (MMCs) are likely to replace these over time – much as wind turbines began with soft starters and variable resistance in the rotor, but have since shifted to full power electronics. An MMC with full bridge cell can work also in buck-mode, protect DC links against short-circuit, and enable the grid for a wide range of applications in charging stations, and so on.

To enable and support the range of applications involves standardization. This extends from the task force looking into potential smart functionalities, and how these are influenced by topology (IEEE PES Task Force), through recommendation to make SST hardware topologies comparable, so network operators can make confident decisions (IEEE SA P3105), to the workgroup looking at power system and power electronics aspects across AC, HVDC and MVDC (CIGRE WG B4.91). As with any part of the energy infrastructure, there is also work being done in the robustness of smart SSTs against cyber-attacks, not only through unwanted access, but through potential disturbance through induction effects.

The article is written by **Prof. Marco Liserre,** University of Kiel. **Prof. Dr.-Ing. Giovanni De Carne,** Karlsruhe Institute of Technology, will present "Standardization for Solid State Transformer Integration in Distribution Grids" on 11 June 2024, 11:55 a.m., **Technology Stage**

MVDC technologies for solar application

Photovoltaics have an important role to play in decarbonizing society. In Europe, 41.4 GW of new solar was installed in 2022, mostly in medium scale power plants (<100 MW)[i] . As the distance from these photovoltaic (PV) plants to their grid connection increases, the losses in the collector and connection network also increase significantly. There are similar challenges in the dual purpose approaches that are also emerging, such as agro- and linear-PV, where the PV plant is spread over a larger area for a given installed PV power. Medium voltage DC (MVDC) networks have been identified as a viable technical solution for integrating such remote or distributed renewable energy resources to the grid. However, there remain several technical challenges, including the development of DC/DC converters and equipment for protection systems.

Solving these issues could have benefits for enhancing and modernizing power distribution[ii]: Apart from being better suited to long-distance underwater and underground use than AC, MVDC technology can solve many of the challenges of distribution and the impacts of distributed energy resources on the network.

Development of MVDC technologies

As an independent innovation and research company, one of the objectives of the SuperGrid Institute is to increase the maturity of power electronics technologies for future power grids. SuperGrid Institute also develops protection and control solutions. Among recent developments are a hybrid DC circuit breaker and a DC solid-state transformer (DCSST) for MVDC applications. These are currently under functional test, with demonstrations expected soon.

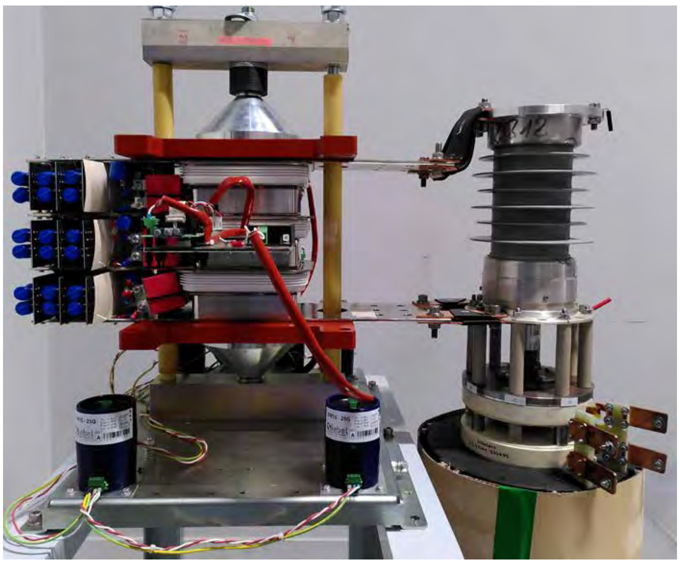
The DC circuit breaker, the HyBreak, has been developed to support the use of MVDC networks in grid, mobility and industrial applications. It uses SuperGrid Institute HyBreak technology, a hybrid of both solid-state breaking, using IGBT semiconductors, and mechanical breaking, using a vacuum interrupter with an ultra-fast actuator. The result is an excellent compromise between on-state losses, mechanical endurance, and breaking speed.

The DCSST has been developed specifically for connecting photo-voltaic (PV) low voltage DC networks to an MVDC collection system. To address the specific needs of this application, the design is a monolithic, unidirectional DC/DC converter, integrated with maximum power point tracking (MPPT) technology[iii]. Galvanic insulation is ensured by a medium frequency transformer operating at a frequency of a few kHz and enclosed in an oil tank for compact insulation.

MVDC networks are becoming a reality for PV applications

Developing MVDC technologies is one of the goals of the OPHELIA[iv] project, in France. This addresses the limited availability of land for new PV installations by enabling dual purpose approaches that can be deployed on long, narrow land surfaces, with collector networks often stretching well over 10 km, for example, running beside dikes, roads, and railways.

In this context MVDC become the technology of choice, especially when the plant sites are also far away from the connection to the grid. As part of the OPHELIA project – as well as



The HyBreak prototype

Nominal DC Voltage	5 kV
Nominal DC current	2000 A
Peak breaking current	6000 A
Transient interruption voltage	9 kV
Breaker opening time	1 ms (typical)

i https://www.pv-magazine.com/2022/12/19/europe-added-41-4-gw-of-new-solar-in-2022/
ii As identified by CIGRE https://electra.cigre.org/309-april-2020/technical-brochures/medium-voltage-direct-current-mvdc-grid-feasibility-study.html :
iii https://ieeexplore.ieee.org/document/10173142
iv Ophelia is an innovative R&D project comprising, and involving CNR (the project coordinator), Nexans, Schneider Electric, SNCF, and the SuperGrid Institute (https://www.supergrid-institute.com/fr/2023/08/31/news-official-launch-of-the-ophelia-project-a-solar-canopy-demonstrator-along-the-viarhona/).

Images: SuperGrid Institute

developing a dedicated DCSST – the SuperGrid Institute contributes with expertise on system design, and provides testing facilities and expertise for validating MVDC cables, switchgear, and other components.

By 2026, the project aims to install a demonstrator along the "ViaRhôna" cycling route along the river Rhône, to validate the technological developments.

Benhur Zolett of the SuperGrid Institute presents "Power Electronics Technology for MVDC Networks: Developments and Perspectives for Solar Application" on 11 June 2024, 10:25 a.m., **Technology Stage**

The DCSST-250-10-PV prototype

Maximum input voltage	1500 V
Nominal input power	250 kW @50°C
Number of MPPT inputs	6
Maximum input power per MPPT	50 kW @50°C
Nominal output differential DC voltage	10 kV
European Efficiency	>98.5% for V = 1000 V

Revolutionizing power semiconductors: transformation and trends

In the ever-evolving realm of power semiconductors, the past decade has seen remarkable shifts, with reliable indicators that there is significant change to come. The total power electronics market, including discretes and modules, was worth US$20.9 billion in 2022, and is expected to grow to US$33.3 billion by 2028. Historically, silicon has been the dominant technology – and silicon's evolution continues, with the adoption of 300 mm Si MOSFET and IGBT platforms, ensuring its continued cost competitiveness. But it is the rapid rise of wide bandgap (WBG) technologies (notably silicon carbide (SiC) and gallium nitride (GaN)) that are doing most to reshape the industry.

SiC is witnessing substantial growth. The power electronics market for SiC is projected to reach US$10 billion by 2029, capturing 28.6% of the global market. This is being driven by technological trends like 200 mm platforms, higher power densities, and optimized power module packaging. The trends are supported by a shift towards vertical integration within the SiC ecosystem. Leaders like STMicroelectronics, ROHM, onsemi and Wolfspeed, for example, are enhancing their supply chains to include internal substrate production capabilities. Meanwhile, there has been a tremendous effort in expanding the SiC wafer capacity, especially by Chinese players such as Tankeblue, SICC, SemiSiC and numerous others.

GaN technology is also showing robust growth across multiple applications, including consumer electronics and automotive, particularly in areas like fast chargers and overvoltage protection, as well as in power supply applications in home appliances and data centres. Innovation is also driving the exploration of the next generation of semiconductors, like bulk GaN, gallium oxide, and diamond.

Automotive electrification transforms power module technology and market trends

Electric vehicles (EVs) have already gained considerable market acceptance and represent a significant share of the overall power electronics industry. In 2023, almost 30% of all passenger vehicles sold globally were electric. This percentage is expected to increase in the coming years, with the projection that EVs will make up 50% of all passenger vehicles by 2028.

EVs represent a significant and sustainable market opportunity, but they also have a much wider impact. The automotive industry has a reputation for driving standards and introducing new technologies in power electronics. The immediate motivation is to improve driving range and to lower costs. But the advances have repeatedly altered trends in power module technologies and the development of battery packs, and streamlined supply chains. This then creates new opportunities as the technology is adopted in various industrial applications requiring robust performance and enhanced efficiency.

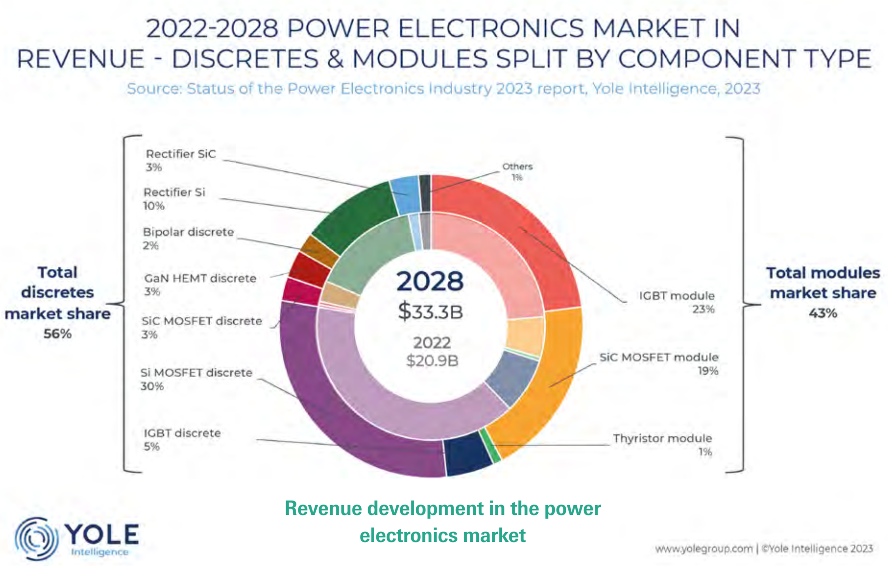
The impacts of the trend toward more affordable EVs

EVs are entering a new phase of market expansion, commonly referred to as the 'move towards more affordable vehicles.' Following the initial rush towards high-power, long-range vehicles, vehicle manufacturers are broadening their customer base to include those seeking EVs in the US$20,000 to US$25,000 price range. This involves various strategies for cost reduction, such as reducing electric motor drive power, downsizing onboard charger power, decreasing battery capacity, increasing system integration, and reducing the SiC content in vehicles. These trends are impacting the EV supply chain, with different strategies emerging in China than in Europe and the United States.

The performance and cost dynamics of SiC

Even as affordable EVs look for ways to use more silicon, the automotive sector is still forecast to dominate the demand for SiC devices for the foreseeable future. SiC made its breakthrough in the Tesla Model 3, and enjoys widespread use in 800 V battery electric vehicles (BEVs), which are expected to account for nearly 80% of the market. Major manufacturers, like Tesla and BYD, are increasing their use of SiC technologies, with BYD also developing in-house SiC capabilities and collaborating with other semiconductor firms for SiC supply.

There are cost considerations associated with the adoption of SiC technology. But recent capacity expansions in both SiC wafer and device



Revenue development in the power electronics market

Images: www.yolegroup.com | ©Yole Intelligence 2023 technology, as well as advances in packaging techniques, and market dynamics are driving down costs and making SiC technology more accessible to a wider range of applications.

Smart integration is about more than size

Cost reduction is also a fundamental driver of smart integration in power electronics. The main focus is on minimising energy waste, and maximising on the potential of renewable energy, to ultimately reduce environmental impacts. Smart integration does this at all levels of the energy ecosystem, by exploiting possible synergies between the different applications in generation, distribution, energy storage, and consumption. It is being applied to interconnect everything from wind, wave and photovoltaic systems, to battery storage or hydrogen production systems and the grid, as well as to domestic, e-mobility and industrial consumption.

This trend influences a range of technological developments needed to reduce the size and cost of solutions, to ease deployment and foster adoption. Encompassing everything from liquid cooling to WBG technologies, solutions require development across multiple domains, thus challenging developers with diversifying their areas of expertise, and organisations with exploring new business opportunities to offer complete solutions. In this sense, smart integration is reshaping supply chains, and mergers and acquisitions are to be expected.

Challenges and forecasts

As capacity expansions, particularly in SiC, come online in 2024, there is a potential that supply constraints will ease. This will encourage significant growth and market opportunities across not only automotive but also industrial and energy sectors, which will in turn drive further adoption of power electronics technologies. Yole Group is an international company recognized for its expertise in the analysis of markets, technological developments, and supply chains, as well as the strategies of the leading players. Visit Yole Group at the PCIM Europe – or online all year round –to share its insights on trends in power electronics.

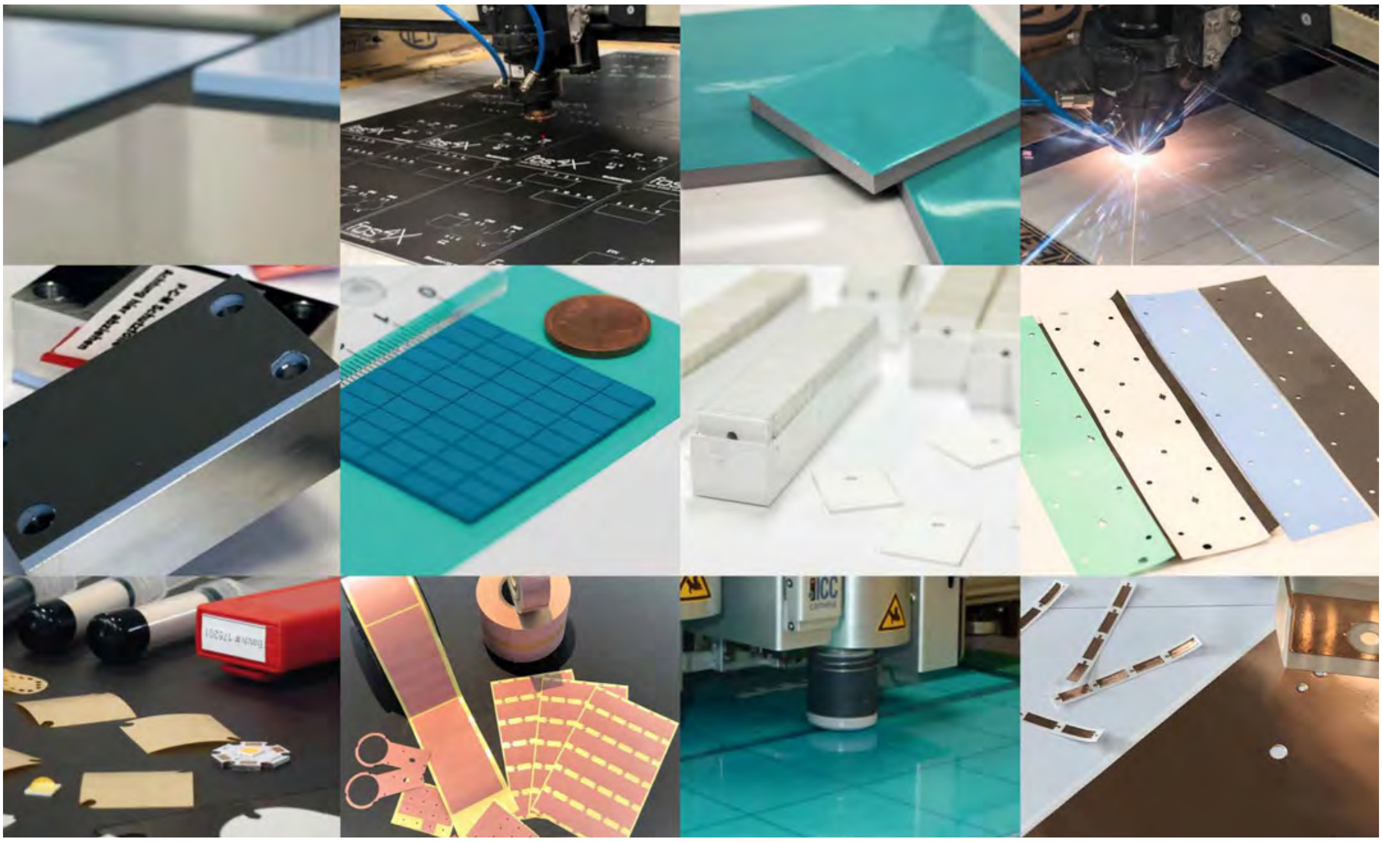
Yole Group is presenting its findings on a number of topics at the conference:

- "Revolutionizing Power Semiconductors: Decade of Transformation and Future Trends", on the Technology Stage, 11 June 2024, 12:20 p.m.
- "How automotive electrification is transforming power module technology and market trends." on the E-Mobility & Energy Storage Stage, 13 June 2024, 12:05 p.m.
- "How will the trend toward 'more affordable vehicles' Impact EV technologies and the supply chain?" on the E-Mobility & Energy Storage Stage, 11 June 2024, 12:05 p.m.
- "Catalyzing the Future: Unveiling the Performance and Cost Dynamics of SiC Power Technology" on the E-Mobility & Energy Storage Stage, 12 June 2024, 12:05 p.m.
- "Smart integration is more than just making systems more compact." on the Smart Power System Integration stage, 13 June 2024, 12:40 p.m.

Yole Group at the PCIM Europe 2024: Hall 7, stand 7-731

Staying cool as things heat up - Innovative thermal management for power electronics

Electromobility is expanding rapidly. Consequently, battery systems need to get smaller, lighter, and more cost-effective, taking into consideration, that the energy density within the system is increasing. The resulting requirement leads to higher performing thermal components.



ICT SUEDWERK offers all-in-one thermal management solutions – from pre-development to serial production

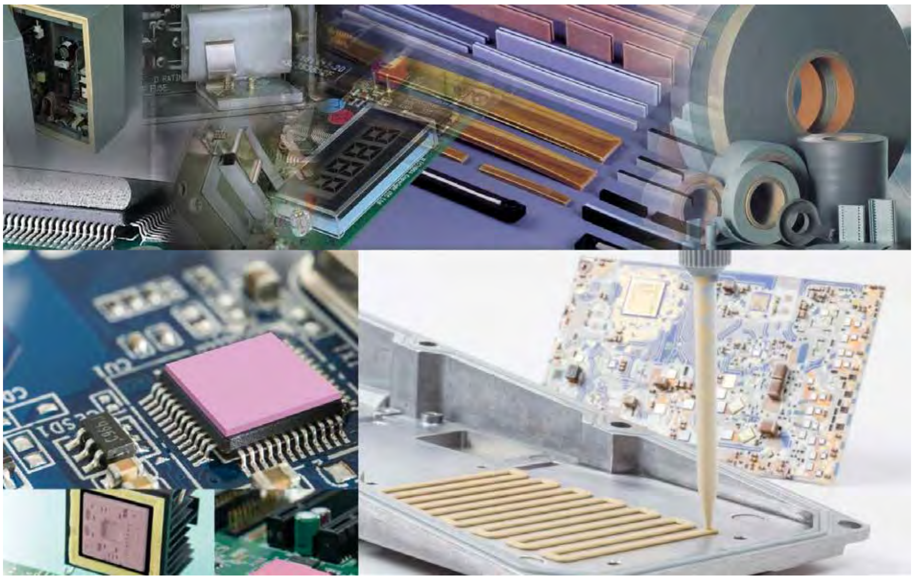
Passive and active thermal management

Improving the design of the power electronics is crucial. Electronical monitoring of every battery cell when charging or discharging, is essential for safe operation. This is the task of the battery management system (BMS), which measures current and temperature within the battery modules and packs, as well as the voltage of each cell. The common assumption is, that the BMS is extending the range of the battery, enabling longer battery life by compensating voltage differences between cells. An even more important role of the BMS concerns the thermal management: the BMS

This year at the ICT SUEDWERK booth, visit:

- **ICT SUEDWERK GmbH,** The Heat-Management Company
- **ZFW - Zentrum für Wärmemanagement,** High-precision measuring systems and professional solutions
- **Nucletron Group represented by**
  - **Nucletron Technologies GmbH,** Passive and active thermal management and electromechanical solutions
  - **SINUS Electronic GmbH,** innovative products for industrial, military and broadcast applications
  - **HVC Technologies,** for DC-contactor and HV-relays

ZFW: T.I.M.-Tester


Nucletron GmbH – High Reliability & Performance

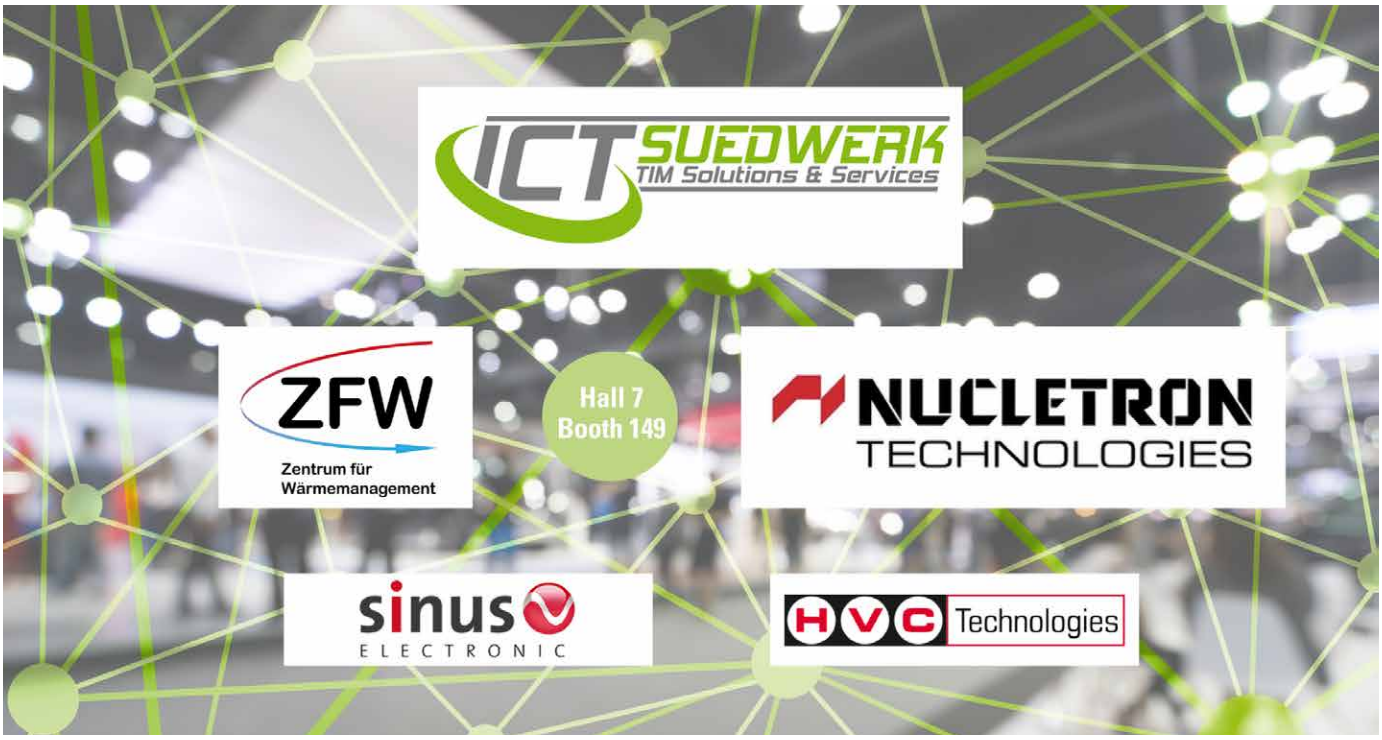
is detecting potential damage or hazardous behaviour early enough to shut down operation before thermal damage or even fusing occurs.

Thermal Interface Materials (TIMs), serving as galvanic insulation, providing safety measures against shortcuts. TIMs are helping to reduce the delay time within the BMS significantly, reacting on critical situations. Depending on the application, the range of usable TIM's can range from conventional passive heat control with high-performance TIMs, to new, active developments, such as thermal conductive films or elements, form-in-place TIMs, or different kinds of gap filler, such as elastic or plastic thermal pads, or disposable gap fillers.

Core competences

Proper thermal management solutions are widely varying. This is the reason, why ICT SUEDWERK is joining this year's PCIM exhibition together with its cooperation partners Nucletron Group and ZFW (Center for Thermal Management). Main mission is to present a wide variety of components and materials, as well as tools and support for effective thermal design. A range of microwave and RF shielding solutions, protective electronics and relays (from miniature to 70kV) complete the portfoilo. One of the highlights of this year's exhibition is a new measurement technology for thermal analysis, presented by ZFW.

ICT SUEDWERK GmbH and its partners at the PCIM Europe 2024: **Hall 7, stand 7-149**



Everything from a single source – all you need to manage your heat!

Progress depends on the exchange of knowledge.

Albert Einstein

Messe Frankfurt Group

PCIM MAGAZINE

Stay tuned for the next edition in Autumn 2024

mesago

pcim

IMPRINT
PCIM Magazine
Event Edition 2024

PUBLISHER

mesago
Messe Frankfurt Group

Mesago Messe Frankfurt GmbH
Rotebühlstraße 83 – 85
70178 Stuttgart, Germany
Phone + 49 711 61946-0
info@mesago.com
mesago.com

Register Court Stuttgart,
HRB Stuttgart 1 33 44

VAT-Identification Number:
DE147794792

Responsible for content
under German Press Law:
Miriam Zinth

EDITED BY
David Hegarty
david.hegarty@lexsys.com

DESIGN
bateau blanc GmbH & Co. KG

PRINTING
Offizin Scheufele Druck
und Medien GmbH & Co. KG

CIRCULATION
9.000 copies

NEXT EDITION
Autumn 2024

ADVERTISING
Mesago Messe Frankfurt GmbH
Phone +49 711 61946-501
Stefan.Rapp@mesago.com

READER SERVICE
pcim@mesago.com

Insert notice
This issue includes an insert
from Profusion Ltd.

pcim EUROPE

Visit us: **Hall 9**
Booth 442

PROVEN AND RELIABLE SOLUTIONS

for every field of application

- Independent Trench-IGTB Technology with ultra-low losses for maximum performance
- Designed for applications such as industrial drives, EV, solar-PV, battery storage, welding and UPS

starpower

StarPower Semiconductor Ltd.
is a leading power module company located in Jiaxing, China.
Founded in 2005 with venture funds, StarPower designs and manufactures IGBT/MOSFET/IPM/FRD/Rectifier modules and customized modules for applications in the area of inverters, welding machines, inductive heating, UPS, EV, solar/wind power and etc. in the power range of 0.5kW up to more than 1MW.

StarPower Europe AG · www.starpowereurope.com