Centre for Power Electronics Annual Conference

13 - 15 July 2021

The Centre for Power Electronics and IMAPS-UK organised the Annual Conference serving the Power Electronics, Machines and Drives (PEMD) Research and Development community, with over 160 people registered over the three afternoons of the online event. The Conference featured state of the art presentations from academic and industrial speakers, oral and poster presentations from Early Career Researchers, exhibitor videos and panel sessions on the status of adoption of wide bandgap devices and opportunities for working in this growing industry.

The Conference Chair, Professor Xibo Yuan (University of Bristol) welcomed participants to the blended event with an overview of the activities over the three days of the Conference.

Day 1: Tuesday 13th July 2021

Research Trends in Modular Multilevel Cascade Converters - Dr. Hirofumi Akagi, Distinguished Professor at the Tokyo Institute of Technology

Dr Agaki started with the following prototypes designed, built, and tested by his research team, showing their experimental waveforms:

- A modular multilevel SSBC (single-star bridge-cell) converter was applied as a STATCOM for reactive-power control in industrial and utility power systems.
- Two multilevel DSCC (double-star chopper-cell) converters were applied as an HVDC back-to-back (BTB) system intended for asynchronous intertie between two power systems with the same line frequency and for frequency change between those with different line frequencies.
- AC-link multi-drive system combining the common line-side modular multilevel DSBC (double-star bridge-cell) converter with multiple motor-side ones. This “versatile” system can drive multiple medium-voltage motors with different power, voltage, and/or frequency ratings. Each motor is characterised by being isolated galvanically from the other motors and the ac mains and is capable of voltage matching.

Driving the Electric Revolution – A Collaborative Future for Growth - Professor Will Drury, Challenge Director – Driving the Electric Revolution, UK Research & Innovation

Professor Drury explained how Driving the Electric Revolution is working to deliver ecosystems between organisations within the UK. Through collaborative funding this is growing and thus delivering impact to the UK in PEMD supply chains.

The importance of collaboration between organisations from academia, RTO and industry was stressed and the activities ongoing through Driving the Electric Revolution were described through setting up the Industrialisation Centres and collaborative Supply Chain projects. Opportunities in Skills Training are now being addressed and discussions are underway to continue engagement in future initiatives.

EPSRC Tranche 2 Project – Switch Optimisation - Ultra High Voltage Power Electronics, Realising the Full Potential of SiC Devices Rated at 10 kV+ by Professor Peter Gammon, University of Warwick

SiC power devices are reaching their potential in the 600-1700 V class, as they are used to deliver lighter, smaller and more efficient power conversion solutions. The Switch Optimisation Theme of the EPSRC Centre for Power Electronics has, for the last 3 years, sought to realise the full potential of SiC, beyond this limited voltage range. With applications that include traction and HVDC converters, there is demand for devices that can extend beyond the upper limit of existing Si devices, while offering similar boosts in efficiency and a reduction in system size and complexity. The consortium has therefore been at the forefront of the design and development of SiC UHV devices, developing SiC MOSFETs and IGBTs rated to

10 kV. The initial characteristics of these unique devices were presented for the first time, showing that SiC MOSFET results had R_{ds}on values of 288 mΩ-cm^2, more results will be made available over the coming months.

EPSRC Tranche 2 Project - Reliability, Condition Monitoring and Health Management - Professor Layi Alatise, University of Warwick

Professor Alatise highlighted the research achievements of the reliability and condition monitoring theme. The project has focused on advanced reliability analysis, condition monitoring and gate driving of the latest generations of WBG devices including SiC MOSFETs and GaN devices. Novel techniques for assessing gate dielectric reliability in SiC and GaN devices were explored along with the application of advanced gate drivers for assessing junction temperature as well as the latest developments on integrating copper interconnects with SiC devices. The importance of threshold voltage shift and its impact on the use of temperature sensitive electrical parameters in WBG devices was emphasised as well as demonstrating how programmable gate drivers and high speed current sensors can be used for condition monitoring of fast switching GaN devices. The latest generation SiC and GaN devices including Cascode devices and normally OFF current and voltage driven GaN HEMTs were evaluated. The use of current source gate drivers and their comparison to voltage source gate drivers in the control of SiC power devices was explored as well as the integration and performance of copper interconnects for improved thermo-mechanical reliability of SiC modules.

GaN based high voltage technologies and the advent of Cambridge GaN Devices (CGD) - Dr Giorgia Longobardi, Cambridge GaN Devices

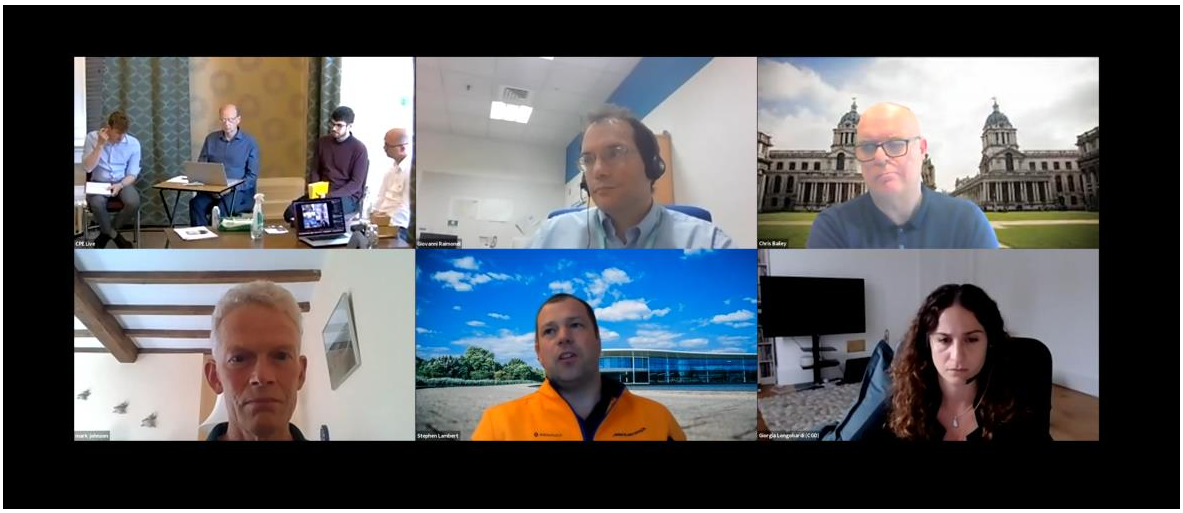
GaN has being considered the most efficient material to be used in power devices for applications rated at 650V. Such applications include power supplies, data servers, LED drives and automotive chargers and inverters. Still, GaN has to overcome reliability problems such as dynamic Ron and ease of use. The fragility of the gate remains an open issue to overcome.

Giorgia Longobardi gave an overview of GaN based technologies, the main applications and their market share. Cambridge GaN devices has developed an efficient and easy to use solution, based on a smart IC, (ICeGaN™), monolithically integrated alongside the HEMT device.

Panel Session, Chaired by Professor Phil Mawby: What is the role of Wide Bandgap (WBG) Semiconductors in the successful rollout of electrification and the UK perspective?

The growth in application of wide bandgap semiconductors is creating many opportunities for the power electronics, machines and drives community. Although there is a drive towards adoption, many challenges remain in establishing a sustainable and profitable supply chain and fostering a world class research environment in the UK. This panel session was organised to gain the opinion of several of the leading lights in academia and industry on the major issues facing adopters and considering possible solutions to bring the potential opportunities to fruition.

- Dr Giorgia Longobardi – Cambridge GaN Devices
- Professor Will Drury – Challenge Director, Driving the Electric Revolution
- Adam Dawson – Exawatt
- Craig Fisher – Maxpower
- Steve Lambert – McLaren Applied
- Giovanni Raimondi – Safran
- Professor Chris Bailey – University of Greenwich
- Professor Mark Johnson – University of Nottingham



The topics covered included:

- Building on the strength of the research base
- Competing with foundry capability worldwide and the multi-billion investment required
- Forging commercial agreements with foundries for semiconductor supply
- Serving the specific UK market needs for niche, high value products or for high volume products
- Investing in the complete supply chain or high value added segments (i.e. from epilayer deposition onwards) rather than starting at the crystal growth stage
- Packaging is seen as an opportunity to add value within the supply chain, which requires innovation to achieve superior product performance at reduced costs through Heterogeneous Integration for example

Day 2: Wednesday 14th July 2021

Day 2 started with a series of exhibitor presentations on the following topics:

- High Reliable Packaging Material Solutions for E-mobility Applications by Habib Mustain, Heraeus Electronics
- Potential Changes To REACH Legislation Regarding Chip Encapsulation Adhesives by Eamonn Redmond, Inseto Ltd
- Testing Today's High Speed Power Discrete Semiconductors by Robert Pullman, IPTest Ltd
- Scanning Acoustic Microscopy for Non-Destructive Analysis by Gavin Yeo Nordson Sonoscan (Cupio Ltd)

Challenges of running a national electricity system with a high penetration of inverter-interfaced resource - Professor Tim Green, Imperial College London

The replacement of electro-mechanical machines by inverter-based resources (IBR) is fundamentally changing the dynamics and stability properties of grids. A review was made of the needs of a stable and secure grid system. The requirements of voltage strength, frequency regulation and synchronisation were outlined in terms of how they are currently met by synchronous machines, grid-following converters and grid-forming converters. A case was made that there is advantage in not all resources being obliged to provide all system services and that new services can replace some traditional services. Thus, strictly following a virtual synchronous machine (VSM) approach may not yield the best solution.

Approaches to ensuring system-wide dynamic stability were explored noting that IBR have overlapping sets of dynamics but with details often hidden in black-box models. A method for identifying root-causes of poorly damped modes in black-box models was illustrated. This analytical grey-box method avoids exhaustive transient simulation. A toolbox for compiling models of composite grids with IBR and

synchronous machines was introduced. The talk concluded with some thoughts on modelling and analysis challenges that remain for IBR dominated grids such as stability and protection.

The Engineering and Physical Sciences Research Council: Opportunities for Early Career Engineers - Maisie England, Head of Civil and Electrical Engineering, EPRSC

This presentation focused on the opportunities within the Engineering theme at the Engineering and Physical Sciences Research Council (EPSRC) for Early Career Researchers, namely our New Investigator Award Scheme and our Early Career Forum. An overview of UK Research and Innovation (UKRI) and EPSRC was provided, followed by a more detailed look at the aforementioned schemes and opportunities, including a review of the EPSRC Peer Review processes.

What are the options available for starting and pursuing a career in power electronics, machines and drives? Chaired by Dr Paul Evans, University of Nottingham

Starting a new career in a particular subject area can be a daunting prospect. This panel session gave attendees the opportunity to hear first-hand from several people who have established their careers in the field of power electronics, machines and drives and engineering and to ask questions on how to approach and develop their skills to make a valuable contribution to the sector.

- Maisie England – Joint Head of Theme for Engineering, EPSRC, UKRI
- Tim Green – Imperial College London
- Richard Gibson – Nidec Control Techniques
- Volker Pickert – Newcastle University Sustainable Electric Propulsion CDT
- Marina Antoniou - University of Warwick, Royal Society Research Fellowship Holder

Early Career Researcher Oral Presentations

- Mitigation of the Terminal Overvoltage in SiC-Based Motor Drives with Slew Rate Profiling by Wenzhi Zhou, University of Bristol
- Control and Power Sharing Strategy of Dual Three-Phase Permanent Magnet Synchronous Motor for Fuel Cell and Battery Trains by Nursaid Polater, University of Birmingham
- A Wirelessly Synchronized Bidirectional HF-IPT System for Ultra-Low Coupling Applications by Nunzio Pucci, Imperial College London
- Characterisation and Analytical Calculation of Core Loss with High-frequency Rectangular Voltage in Power Converters by Jun Wang, University of Bristol
- Presentation of 4H-SiC n-GTO Simulation by Qinze Cao, University of Warwick
- Optimal co-design of semiconductors and passive devices by Andrea Stratta, University of Nottingham
- Current Sharing with Dual Phase-Shift Control for IPOP of Modular CLLC Dual Active Bridge DC-DC Converters by Ibrahim Alhurayyis, Queens University Belfast
- A Non-Galvanic SiC MOSFET Condition Monitoring Technique for High Frequency Applications by Javad Naghibi, Queen Mary University of London

Early Career Researcher Poster Presentations

- Common-Mode Current Reduction at DC and AC Sides in Inverter Systems by Passive Cancellation by Xie Lihong, University of Bristol
- Analytical Modelling and Optimisation of an Exciterless Synchronous Generator Using Wireless Power Transfer by Daniel Fallows, University of Nottingham
- Flexible Medium Voltage DC Electric Railway Systems by Sina Sharifi, University of Birmingham
- Redundant Level Modulation for Capacitor Voltage Balancing in Multilevel Converters by Jun Wang, University of Bristol

- Research Advancements in the Torque Ripple Minimization for the Permanent Magnet Synchronous Motors by Muhammad Saad Rafaq, Loughborough University
- Interconnection Design of a DC-DC Mini-Grid for Developing Remote Regions by Joan Marc Rodriguez-Bernuz, Imperial College London
- What if you can't afford a Tesla? A novel energy model for long distance travel by light battery vehicle by Fred Spaven, University College London
- A Multi-Active Bridge-based Automotive Inverter by Ferdinand Grimm, University College London
- Optimal Design Solution for Planar Magnetics by Pouya Kolahian, University College London
- Control Methods for Higher-Order Compensation Schemes in Wireless Power Transfer Systems for Electric Vehicle Battery Charging by Iman Okasili, Queens University Belfast
- A concept of quasi-three-phase dual active bridge converter by Olutayo Omotoso, University of Warwick
- Characterisation of Unclamped Inductive Switching in SiC Cascode JFETs by Nereus Agbo, University of Warwick
- Silicon Carbide Based Switched Reluctance Motor Drive for Automotive Application by Yohannes E Tecklehaimanot, Newcastle University
- Comparison of a Flux Reversal and Vernier Hybrid Machine for a Hinged Wave Energy Converter by Lewis Chambers, Newcastle University

Prizes awarded to Early Career Researchers

Oral Presentations

- 1st prize: Andrea Stratta, University of Nottingham
- 2nd prize: Nunzio Pucci, Imperial College London

Poster Presentations

- 1st prize: Lihong Xie, University of Bristol
- 2nd prize: Olutayo Omotoso, University of Warwick

Day 3: Thursday 15th July 2021

Day 3 started with a series of exhibitor presentations on the following topics:

- Who, why, what, how by Jon King, Driving the Electric Revolution – Industrialisation Centres
- Bode Plots and Control Loop Analysis by Chris Mountford, Rohde and Schwarz
- EBIC for Advanced Device Characterisation by Greg Johnson, Zeiss Microscopy
- Die top system (DTS) interconnect with pre-sintered silicon nitride AMB substrate for Power Module Applications by Habib Mustain, Heraeus Electronics

The impact of fast-switching converters on machine insulation and reliability - Professor Jiabin Wang, University of Sheffield

Power electronic converter-fed machines and drives are increasingly being used in a variety of applications. Converters or inverters operating in pulse width modulation (PWM) provide effective and efficient control of energy conversion and machine operation. However, the PWM voltage pulses at a high frequency and high voltage slew rate (dv/dt) can result in excessive voltage at the machine terminal and non-uniform voltage distribution within the winding. These voltage transients are expected to significantly reduce the lifetime of the insulation of the connected machine/generator owing to increased voltage overshoot, increased voltage across turns, phases and phase-to-ground, and higher frequencies.

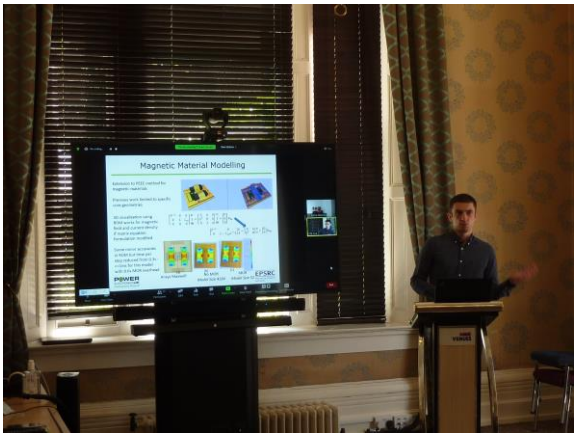
The effects of impulse and high frequency PWM voltages produced by fast-switching power electronic converters on voltage distributions in machine winding and insulation systems were analysed and

characterised. In particular, a low frequency oscillation mode associated common mode impedance of machines, was presented and its implication on inverter operation discussed. Lifetime test results under partial discharges caused by high voltage slew rate were highlighted.

EPSRC Tranche 2 Project - Virtual Prototyping - Dr Paul Evans, University of Nottingham

The Virtual Prototyping Theme is developing the tools that power electronic system designers need to be able to design optimal wide band-gap systems, right-first-time, on a computer using virtual prototyping techniques. The presentation described key achievements of the project including:

- Time domain techniques for accelerated 3D thermal and electromagnetic modelling of power electronic systems that are capable of running in real-time. An augmented reality application is used to demonstrate the speed and efficiency of the techniques.
- Time-domain loss models for magnetic materials, and averaged material models for winding loss estimation, that can couple with the accelerated 3D electro-thermal models.
- A coupled flow-network, CFD simulation approach for fast thermal boundary condition estimation
- Details of the software tool developed as a project demonstrator.



EPSRC Tranche 2 Project – Heterogeneous Integration – Professor Lee Empringham, University of Nottingham

Heterogeneous Integration is the combination of dissimilar materials and components to create multi-featured, functional power electronic blocks or systems. The main aim is to develop design and manufacturing methodologies to enable the integration of power devices, interconnect, passive components, EMI reducing structures and thermal management techniques in a single manufacturing process and to facilitate the adoption of Wide Bandgap semiconductors. This presentation outlined the aims of the Heterogeneous Integration project in order to exploit the advantages of WBG devices and gave update on the concepts and methodologies which have been worked on including gel casting of inductors.

EPSRC Tranche 2 Project - Converter Architectures – Professor Xibo Yuan, University of Bristol

This presentation provideed an update on the Converter Architecture project, which investigated optimal converter architectures, advanced passive components, control techniques and holistic optimisation to realise the full potential of wide band-gap (WBG) devices in achieving higher efficiency, high power density with extended voltage, frequency and power handling capability. Several converter prototypes have been built with WBG devices and have demonstrated how the adoption of WBG devices can benefit the system performance in terms of power density, operating frequency and temperature improvement with benchmarking results. Technical highlights such as novel design of magnetic components with hybrid windings, new multilevel converter topologies with novel redundant level modulation, highly efficient

wireless power transfer technologies and applications, and a holistic design optimisation tool were presented. Through this project, a demonstrator rated at 100kW and 1.2kV dc-bus with WBG device based dc/dc and dc/ac converter has been built, with the gate drivers powered through wireless power transfer. This demonstrator emulated scenarios with energy storage at one end and medium voltage motor drive at the other end.

The market opportunity for SiC in the UK EV supply chain - Simon Price, Exa-Watt Ltd

This presentation examined the opportunity for silicon carbide (SiC) power semiconductors in the UK electric vehicle (EV) market and considered the implications for transportation, energy and industrial applications more broadly. With a combination of superior power conversion efficiency and power density, SiC-based traction inverters offer a compelling case for widespread use in EV powertrains. SiC devices and modules are costly to manufacture, relative to the incumbent silicon-based technologies, but a compelling case for SiC can be made at the vehicle level, where significant net savings can be achieved by reducing battery pack size, taking advantage of the “fuel economy” benefits accruing to SiC. The improvements in SiC device manufacturing cost and performance were discussed and the impact of these improvements in the context of the growing EV market were examined. Finally, the potential impact of SiC in the UK EV market, as costs fall and performance improves as the automotive industry electrifies were outlined.

Professor Xibo Yuan thanked attendees at the Online Conference and hoped that a face-to-face event would be arranged in the future. He thanked the EPRSC Tranche 2 Project Leads, Professor Mark Johnson at the University of Nottingham, the organising team at the University of Bristol (Sarah Rogers and Joe Gillett), IMAPS-UK (Steve Riches, Martin Wickham) and the KTN (Paul Huggett) in putting the Online Conference together over the past year. The support of the Conference Exhibitors was acknowledged, along with the contributions for the Session Chairs and Panellists.

For further information, please visit the Centre for Power Electronics (www.powerelectronics.ac.uk) and IMAPS-UK (www.imaps.org.uk).