POWER ELECTRONICS UK
Underpinning Research

EPSRC
Engineering and Physical Sciences Research Council

# CENTRE FOR POWER ELECTRONICS NEWS

**Newsletter Winter 2017**

## Wide Bandgap Event

On 11 October 2017, the Centre held an event to explore the future direction of Wide Bandgap power electronics. This included talks on the latest developments in this area from the Centre for Power Electronics (CPE), Powerelectronics UK, the Compound Semiconductor Applications Catapult and leading semiconductor manufacturers.

The outputs from the workshops will be presented to CPE's steering group, and will help shape the future direction of the Centre.

"It was great see the in-depth discussions with delegates expressing their views on Power Electronics Road Maps and policies," said Director of the Centre, Professor Mark Johnson. "We will be collating the feedback and using it to direct our thinking on policy."

***Inside this issue:***



**Workshop discussion at our Wide Bandgap event**

Wide Bandgap feedback:

*"It was a good event - worth while attending"*

*"It would be good to have some actions and get going on addressing some of the issues raised."*

## CHALLENGE NETWORK - FEASIBILITY SANDPIT

The EPSRC Challenge Network in Automotive Power Electronics held a Feasibility Study Sandpit in November. Participants were encouraged to progress their ideas, build consortia and start to develop proposals for a feasibility funding call.

At the end of the event, projects were pitched to the Challenge Network Steering Group and given feedback to guide development of proposals for submission of applications for funding.

"It was good to see so many great ideas being generated," said CPE's Director, Professor Mark Johnson, "I look forward to seeing the next stage of these proposals being developed."

## IMPACT ACCELERATION AWARDS

Earlier this year, the EPSRC Centre for Power Electronics (CPE) and EPSRC Challenge Network in Automotive Power Electronics (CN) held a joint call for Impact Acceleration Fellowships. Three awards of around £36K each were made, two from CPE and one from the Challenge Network. Below is a brief outline of each project being funded - for further details visit our website: **www.powerelectronics.ac.uk**

### Centre for Power Electronics Fellowships

**A Heterogeneous Platform for GaN Power Electronics (Het-GaN**) - Prof M DeSouza, University of Sheffield.

This project will explore a solution for "integrated control functionality via multi-wafer integration of power and logic functions" as a means of achieving power conversion at frequencies greater than 20 MHz in GaN. This topic has recently been identified as a priority by PEUK .

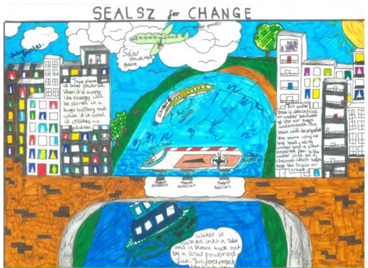
**A robust, compact, high-efficient, soft-switched AC chopper for smart residential distribution network using SiC power electronics** - A Amiri, Loughborough University.

This research will develop a soft-switched version of an existing Power Electronic Converter (PEC). The PEC will form part of the so-called smart-electrical-grid, which is forecast to save £19 billion in UK grid costs and boost exports by £5 billion.

### Challenge Network Fellowship

**AC batteries for electric cars** - Dr P Tricoli, University of Birmingham

This project will look at an innovative technology based on low-voltage power MOSFETs, which can integrate both the functions of cell balancing and power conversion, removing the need for low voltage balancing electronics and high voltage IGBTs.



Abbey Rd Primary's poster

We are delighted to announce that we are once again supporting the APC Greenpower Challenge to encourage young children to get involved in an exciting engineering project.

Through the competition, the winning schools have the opportunity to design, build and race their own electric kit car at race courses around the UK.

The Greenpower Challenge gives students a taste of the exciting world of engineering, inspiring them to put themselves on track to becoming the faces of future UK automotive engineering.

**Winning schools & supporting institution:**

**Stoke Primary** - Advanced Propulsion Centre

**Curwen Primary** - Loughborough London University

**Fairfield Primary** - Loughborough University

**Bournmoor Primary** - Newcastle University

**Kings Priory Primary** - Newcastle University

**Northburn Primary** - Newcastle University

**Abbey Rd Primary** - University of Nottingham/ Centre for Power Electronics

**Richard Crosse C of E Primary** - University of Warwick

## BUSINESS DEVELOPMENT NEWS

**Industrial Champion - Geoff Haynes**

Exhibits at our Wide Bandgap event sparked a lot of interest from delegates. They included compound semiconductor development kits, a Fraunhofer tiny half bridge module and examples of a University of Bristol wideband current sensor. A number of companies are now evaluating the sensors in a wide variety of applications.

Geoff commented: "I am working with the University of Sheffield's commercial exploitation group to build a case for future industrial development funding . This is to support University Impact, Innovation and Knowledge Exchange funding for next stage GaN PSJ process development." Geoff also developed a draft dissemination strategy for the ECOMAP project led by RAM Innovations and including University of Nottingham and start up business The Thinking Pad Innovations to involve academia in demonstrator design and industry partners in evaluation.

**Business Development Manager - Steve Earl**

In the last three months, Steve Earl has been making links with companies such as Sevcon, Turbo PowerSystems, Avid Technology and UTCAS

Steve said: "Questions arising from my discussions with these companies include: How can universities meet companies' technical needs? How can companies more easily engage with the wider sector and universities? And, how can companies access research outcomes more quickly?"

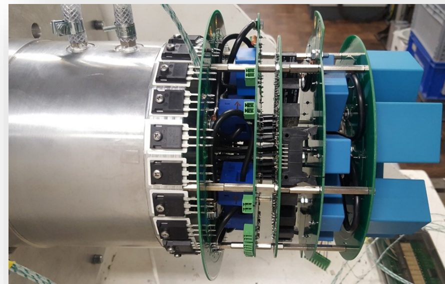
Steve has introduced a company to potential investors, and helped them to apply for funding. He is also working with AESIN and PEUK to discuss a long term engagement strategy for the Power Electronics landscape and - in partnership with TechWorks - is working on an academic capability directory.

**Get in touch:** businessdevelopment@powerelectronics.ac.uk

Our phase one themes are now drawing to a close. Here we highlight the headline achievements for each theme.

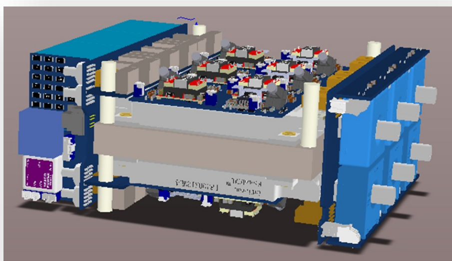
## Drives Theme

This group researched advanced technologies to enable a step change in electric drives, providing greatly increased power density, efficiency and reliability alongside lower lifecycle cost. The headline achievements are:

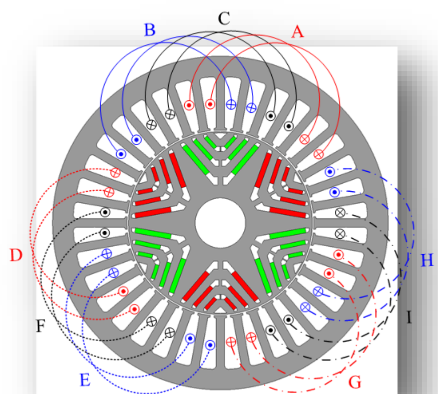


**Integrated Drives**

- Integrated AC input filter inductors into the machine with 85 percent reduction in mass.
- Attached bare silicon die directly onto machine windings.

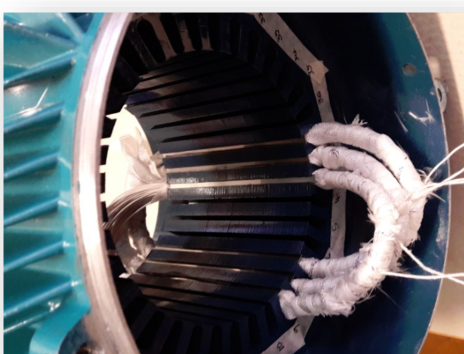


- **Fast Switching Drives**
- Produced open ended inverter for fast switching drives.
- Characterised material losses at high frequency.
- Produced super high power density drive inverter.




**High Reliability and Availability**

- Produced on-line insulation and bearing health monitoring.
- Developed lifetime prognostic techniques.
- Developed active thermal management schemes.
- Built and tested 3X3 phase fault tolerant drive.



**Drive System Optimisation**

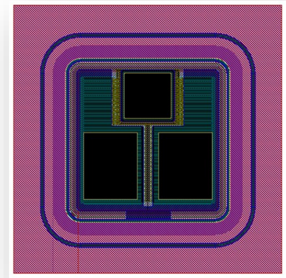
- Developed methods of producing machine windings using fibre-glass weave coating.
- Built and tested induction motor with windings operating at over 300$^{O}$C.
- Developed variable switching frequency inverters, giving large reduction in inverter loss.
- Produced multi-drive control strategies, based upon optimal time and efficiency modes, showing significant improvement over existing methods.

**Universities:**

Bristol, Manchester, Newcastle, Nottingham, and Sheffield.

For further information contact: Barrie Mecrow

## Devices



This group aimed to make a significant contribution to semiconductor power device technology performance, in a number of strategic areas, including power IC technology, advanced super-junction IGBT structures in silicon, as well as wide band-gap devices in silicon carbide and gallium nitride. The headline achievements are as follows:

- **Advance Silicon Trench IGBT Architecture**

A novel method to enhance the performance of trench IGBTs was developed using "p-ring" technology. The concept was fabricated in a foundry and experimental results demonstrated a 20 percent improvement in on-state performance without affecting off-state performance.

- **Advance Silicon Lateral MOSFETs**

A revolutionary lateral MOSFET design was developed and the efficiency of using a foundry service has been demonstrated. These devices can be used in power IC applications for very compact power supply management applications, and this has been demonstrated in an LED driver.

- **Improved SiC Gate Oxidation Processes**

This is a vital issue for all SiC MOS based devices and is a major industrial bottle neck. The project team applied novel high (Warwick) and low (Newcastle) temperature oxidation techniques to grow these oxides and have, in both cases, doubled the channel mobility compared to standard oxidation processes.

- **Trench SiC MOSFET Development**

Trench MOSFETs have far better performance than their planar counterparts. The team developed a trench etch process, and built a number of 1.2kV and 3.3kV power MOSFETs which demonstrate the higher performance. These are the first such devices to be built in the UK and amongst the first in the world.

- **High Voltage SiC Planar MOSFETs**

SiC MOSFETs have much superior performance compared to silicon equivalents. The team designed and fabricated a number of high voltage (10kV) devices. This involved some detailed modelling and process development, not in in the termination structure developed.

- **Understanding GaN Power HEMT Current Collapse Mechanisms**

For the first time the main causes of the current collapse mechanism in GaN power MOSFETs has been identified. This is a critical issue when it comes to device reliability and is possibly the main issue that needs to be solved in order that the technology can see serious market uptake. Detailed modelling identified that vertical defects in the material allow a current path for trapped surface and interface charge to leak away through these defects.

For further information contact: [Phil Mawby]

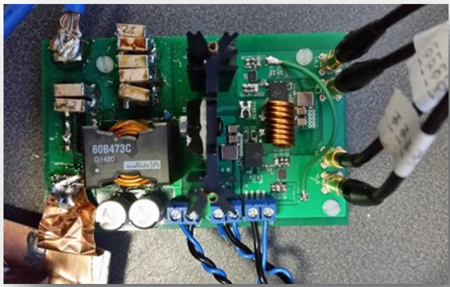
**Universities:**

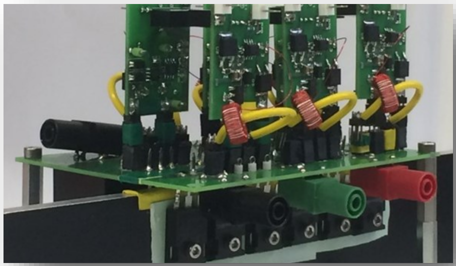
Bristol, Cambridge, Newcastle and Warwick.

## Converters Theme

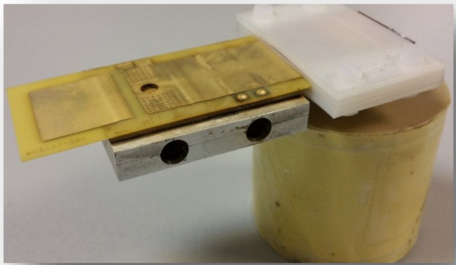
The Converters Theme produced almost 40 publications covering advances in grid-scale converters and compact, low voltage converters. Some of the most significant achievements include:

- Thyristor-based architectures with IGBT auxiliary switching legs have been identified which increase the efficiency of very high voltage DC-DC and DC-AC converters.





- Wear-levelling techniques have been identified and assessed for nursing degraded switching cells in modular multi-level converters, thereby extending converter life.
- Analytical switching models have been derived for SiC MOSFET and BJT devices, including the dominant parasitics, enabling rapid simulation and design optimisation.
- Soft-switching topologies have been developed for Wide Bandgap devices in DC-DC converter and resonant inverter applications, enabling reductions in passive component size.
- A design optimisation framework has been developed for SiC-based DC-AC and DC-DC converters, allowing rapid identification of minimum-size converter designs.



- A planar interconnect has been devised, providing a compact, low-inductance connection between a power module and DC-link capacitor, enabling very high frequency operation.

**Universities:**

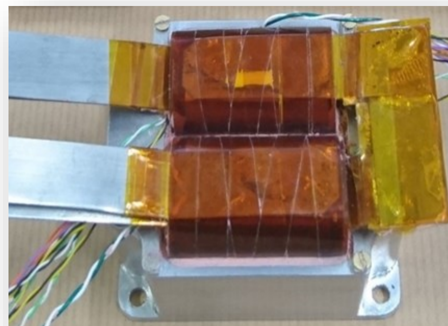
Bristol, Imperial College London, Manchester, Nottingham and Strathclyde.

For further information contact: Andrew Forsyth

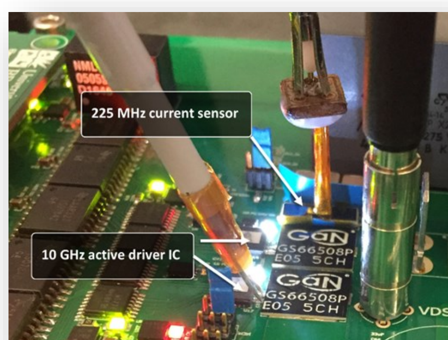
## Components Theme

The Components Integration Theme drew together underpinning research into packaging technologies, passive components, device switching control, reliability modelling and operational management.  Together, these will transform the future integration and exploitation of new power semiconductor devices within power modules and as ‘building blocks’ within power conversion circuits. The overarching focus was to deliver new capabilities in reliable switch units to maximise the potential offered by Wide Bandgap power semiconductor devices. This was identified as having the highest potential for transformative and collaborative research. The research has generated 40 deliverables including many practical demonstrations of the underpinning technologies, and over 60 international journal and conference publications.

Highlights include:



- Novel **Power Module Assembly Technologies** based on solder-bonded ceramic-based structures and flexible PCB structures that under test have been shown to be at least twice as reliable as the aluminium wire bond standard used to interconnect die in power semiconductor modules.
- Computationally efficient design and analysis software has been developed that provide new capabilities in the **Design for Reliability and Robustness** of power modules.
- Research into **Condition Monitoring Strategies for SiC Power Devices** has identified means by which the state-of health can be monitored in real-time, backed with extensive test characterisation of the long term behaviour of these devices.
- Novel **High-Speed Gate Drive Technologies** have been realised with capabilities to profile the gate waveform to improve the switching operation of Wide Bandgap power semiconductors.




- Efficient gate driving of GaN power devices at MHz switching frequencies and sub nanosecond control resolution of the gate waveform have been demonstrated in kW rated power converters.
- A suite of improved design and analysis methods has been established for high frequency, high current filter components and transformers. The use of these, alongside innovations in thermal management, have led to a halving of the weight and volume of **Compact Wound Components**.

For further information contact: Phil Mellor

**Universities:**

Bristol, Greenwich, Imperial College London,  Manchester, Nottingham and Warwick.

As the Centre for Power Electronics research programme moves into its second phase, our research will focus on five new theme areas. It is widely believed that the next generation of power electronics will use Wide Bandgap (WBG) power transistors, made from materials such as silicon carbide (SiC) and gallium nitride (GaN), which are able to overcome the limitations of silicon. Our new themes will each be investigating different aspects of WBG technology so that we can fully exploit the potential of WBG based systems, understand the challenges posed by the more extreme operating range of WBG devices, and tailor system designs accordingly.

## Switch Optimisation

**PI – Dr Peter Gammon University of Warwick**

Silicon carbide insulated-gate bipolar transistors (IGBTs) have the potential to enable new and highly efficient ultrahigh voltage applications enabling a low carbon society. However, there are considerable challenges associated with their fabrication. This multidisciplinary project aims to be among the first groups in the world to develop these devices, and to push the boundaries of what has been achieved so far.

The Switch Optimisation theme members will work together towards these ambitious goals, with the work packages split by expertise (materials development, simulation, fabrication and testing) to cut across each of the objectives.

## Converter Architecture

**PI – Professor Xibo Yuan University of Bristol**

Power electronics plays a very important role in the electrical power conversion and is widely used in transportation, renewable energy and utility applications. By 2020, 80 percent of electrical power will go through power electronics converters somewhere between generation, transmission, distribution and consumption. So converters that are highly efficient, reliable and have high power density will be vital.

WBG technologies enable compact, more efficient power converters, operating at higher voltages, frequencies and powers to meet the increasing demand by a range of existing and emerging applications. However, maximising the performance benefits of WBG technology at a converter level brings its own challenges. For example, high voltage and current changing rates of WBG devices will generate significant electromagnetic-interference (EMI) and affect the running of other equipment. This Converter Architecture project brings together academic and industrial expertise to investigate optimal converter architectures, advanced passive components design methods, fast speed control techniques and holistic optimisation to realise the full potential of WBG devices in achieving higher efficiency, high power density with extended voltage, frequency and power handling capability.

## Multi- Domain Virtual Prototyping Techniques for WPG Power Electronics

**PI - Dr Paul Evans University of Nottingham**

This research project will develop the tools that power electronic system designers need to be able to design optimal WBG systems, right-first-time, on a computer using Virtual Prototyping. This will allow faster design times, as fewer physical prototypes must be built, and it will allow engineers with Silicon system experience to quickly develop high performance WBG systems.

We will do this by developing mathematical techniques that can be applied to predict how a potential system will behave in the electromagnetic, thermal, mechanical, reliability and semi-conductor domains. These techniques will then be combined into a proof-of-concept design tool that will be demonstrated on real wide-bandgap systems developed at the partner institutions, and through parallel work with the other themes.

## Heterogeneous Integration

**PI - Professor Lee Empringham University of Nottingham**

To fully realise the potential of WBG technologies, new design and manufacturing approaches will be needed – from switching devices through to system level connections.

'Heterogeneous Integration' can be described as 'the combination of dissimilar materials and components to create multi-featured, functional blocks or 'systems'. This project theme will address aspects related to the inclusion of components more traditionally seen at a system level, within new and innovative power module structures.

This technology will not only reduce the problems associated with the thermal management of the system but will also create a much easier to use 'system block' for the designer. This should accelerate the uptake of WBG semiconductors by manufacturers by bringing added benefits such as a reduction in the use of raw materials and increased energy savings.

## Reliability Condition Monitoring & Health Management Technologies for WBG Power Modules

**PI - Dr Olayiwola Alatise University of Warwick**

Understanding the reliability of WBG semiconductors is becoming increasingly important as these new devices are being used more widely in industrial settings. However, for applications with high failure costs - for example, automotive traction, aerospace and grid connected converters - the uptake of this new technology is slow. By developing technologies that can improve the reliability of these new devices and monitor their health on-line, then the likelihood of uptake of new WBG power modules will be increased. This project aims to do just this, by providing a condition monitoring and health management platform for WBG based power electronic modules.

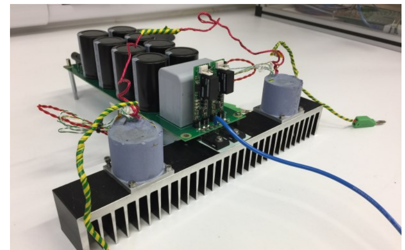
## Multi-domain Optimisation & Virtual Prototyping for High Density PE Systems

Currently, power electronics converter systems are usually tested through hardware prototyping. This is time-consuming and increases the cost of product development.

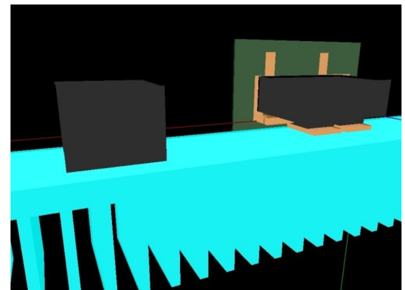
This project looked at how this process could be replaced by “virtual prototyping” which is faster, likely to result in a better design and also reduce product development costs.

The key research challenges were how to accurately predict and optimise the converter performance using computer simulation techniques and how to address the different aspects (electrical, magnetic, thermal, mechanical) of the power electronics design.

Researchers used a combination of models to increase the simulation speed and a range of methods were tested to identify which was the best one to use. Software was developed that can perform detailed analysis for typical power electronics systems. As a result of this process, component models have been improved and future research areas have been identified.



**Hardware prototype**



**Virtual prototype**

Contact: **Xibo Yuan**

## Packaging of Future High Current Press-Pack Silicon Carbide Modules

The aim of this  project was to further enhance the benefits of silicon carbide power devices by demonstrating improved reliability using a pressure-packaged system. SiC is capable of increased power density and higher switching speeds, but the reliability performance is still under scrutiny both in industrial and academic research. The project involved:

- Design and simulation of the pressure-packaging system.
- Assembly and characterization of the pressure packaging system.
- Reliability testing using power cycling.

The main challenges in the project were customising the designs of existing press-pack assemblies for the SiC die sizes, study of the impact of the intermediate contact (aluminium graphite vs molybdenum) as well as assembling, testing and evaluation of the multi-chip press-pack assembly.

The key results and achievements of the project include:

- Critical evaluation of aluminium graphite and molybdenum as thermal interfaces in SiC press-pack systems.
- Evaluation of SiC devices in pressure packaging under power cycling conditions.
- Electro-thermal simulations and characterisation of SiC pressure packaged devices.

  Evaluation of electro-thermal stability in multi-chip SiC pressure packaged systems.

The project generated four journal papers in IEEE Transactions / Microelectronics Reliability as well as eight conference presentations including ECCE, ESREF, ISPSD, THERMINIC and PCIM.

Contact: **Olayiwola Alatise**

## Compact and efficient off-line LED drivers

The majority of LED lights used today in domestic, industrial, automotive and display markets need to be highly compact, efficient and very competitive in price. Compactness is usually achieved by increasing the switching frequency but this is not a trivial task since the requirements for improved electrical performance typically conflict with those for improved thermal management, EMC compliance and reliability. Moreover, high-end converters require lot of peripheral components such as current/voltage sensors, start-up devices, snubbers, filter components etc. to maintain a well-regulated lumen output and a high level of efficiency across a wide range of load and supply conditions.

This project aimed to offer a solution to this thermal, electrical, mechanical and commercial challenge by using specific advantages of Lateral IGBTs. They offer very low foot print compared to currently used vertical MOSFETs for the same ratings and allow monolithic integration of other components such as sensors, drivers etc. They also allow for the simplification of packaging due to lateral construction making it possible to use flip-chip type packaging.

Project partners have designed and developed suitable Lateral IGBTs, a high voltage compatible chip on board packaging technique and simulated the components and the system in multi-physics domain to verify and optimise the performance and reliability.

Contact: **Florin Udrea**

## Next Generation Integrated Drives

The goal of the Next Generation Integrated Drive (NGID) project was to produce a demonstrator for an automotive traction application showcasing innovative technology in all aspects of integrated drives. An 80kWm, 30krpm permanent magnet machine has been designed for this project.

The drive uses a high speed machine design to achieve high power density. To cope with the large forces it will experience, the rotor is enclosed in a carbon fibre sleeve. This exhibits exceptional strength for its thickness and results in minimal additional airgap. The stator is constructed from very thin 0.1mm JNEX electrical steel laminations giving very low loss.

The electromagnetic design has been optimised for efficiency using a bespoke OptiNet procedure.

The machine is highly integrated with the power electronics hardware. The stator coils are formed of U-shaped sections which are connected at one end by PCBs, which form the end windings, reducing the axial length of the machine. The winding sections are pre-formed to allow them to be assembled through the stator slot baffles.

Flooded stator common cooling: de-ionised water flows through the stator slots, between the coil conductors, cooling both the motor and power electronics. Baffles in the slots separate the conductors to give maximum surface area for heat transfer, and provide optimum flow. The stator is sealed by a carbon fibre sleeve. To achieve sensor-less control, saliency was introduced into the surface mounted PM machine. This was done by adding steel to the rotor between the magnets, up to the magnet surface, resulting in an increase in Q-axis inductance compared to the D-axis.

The power electronic converter is based on cutting-edge silicon carbide device switched at 60kHz, integrated into the motor winding circuit. The controller architecture features a local controller for each sub-machine, and a single supervisory controller.

Separate, identical vector controllers are used to control the current in each of the three sub-machines. The current demands are determined by speed and field-weakening controllers via a Maximum Torque-Per-Ampere strategy.

Contact: **Simon Lambert**

## JANUARY 2018

**31 January** Future Power Challenge poster submission deadline

## MARCH 2018

**TBC** **Future Power Challenge** Poster competition

## APRIL 2018

**17-19 April** IET PEMD Conference including CPE workshop: the Future of Power Electronics below 650V

## May 2018

**TBC** Centre for Power Electronics **Post Graduate Summer School.** If you would like to nominate a PG student to be part of the steering group please email the Centre.

## July 2018

**4 & 5 July** Centre for Power Electronics **Annual Conference**, Holywell Park Conference Centre, Loughborough University

# SEASON'S GREETINGS

*From all the team at CPE!*

**Centre for Power Electronics**

The University of Nottingham

Tower Building

University Park

Nottingham NG7 2RD

t: +44 (0) 115 951 5545

**w:** powerelectronics.ac.uk

**E:** correspondence@powerelectronics.ac.uk

POWER ELECTRONICSUK Underpinning Research

EPSRC Engineering and Physical Sciences Research Council