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Power Electronics Research at the University of Nottingham

Power Electronics, Machines and Control (PEMC) Research Group

UNIVERSITY OF NOTTINGHAM, UK

Professor Pat Wheeler

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The presenter would like to acknowledge support from the Universidad Tecnica Federico Santa Maria and CONICYT through project MEC 80130065, "Estructuras de Avanzadas de Convertidores de Potencia para Conexion a Red".

Introduction

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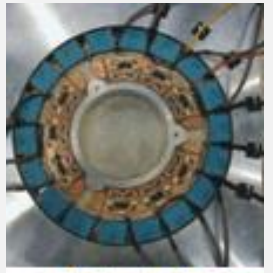
- Introduction to the University of Nottingham
  - Location in the UK
  - City of Nottingham
- Introduction to the Power Electronics, Machines and Control Research Group
  - Facilities and people
  - Research topics
- Working with Industry
  - Links with Industry
  - Some examples of projects




Nottingham

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City of Nottingham

Population 300,000

The city famous for the legend of **Robin Hood** and **Brian Clough** [one time manager of the Nottingham Forest football team]

UoN Profile

The University of Nottingham
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Top 1% worldwide and ranked 7th overall in UK in 2008 RAE exercise.

- University consistently ranked in the UK's top 10 universities
- Ranked 5th in Engineering
- Ranked in the world's top 70 universities by the Shanghai Jiao Tong and Times Higher

42,070 high calibre students with good completion record

- 32,972 UK based/12,848 international from 143 nations
- 5,974 post-graduate students
- One of the highest graduation employment rates in the country

>7,000 staff – a major employer and regional citizen

- Contributes £400 Million annually to the local economy
- Campuses - 4 in Nottingham, 1 in China, 1 in Malaysia.

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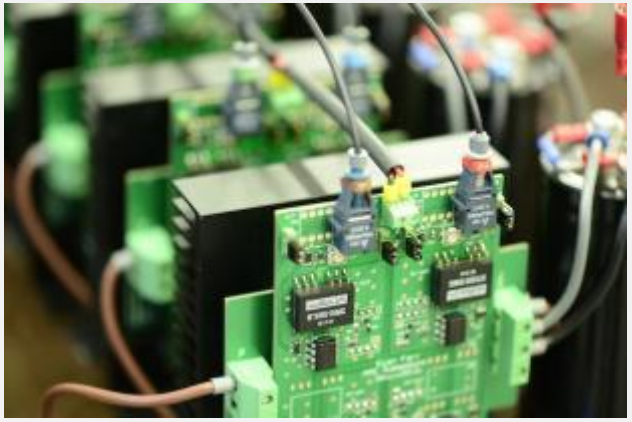
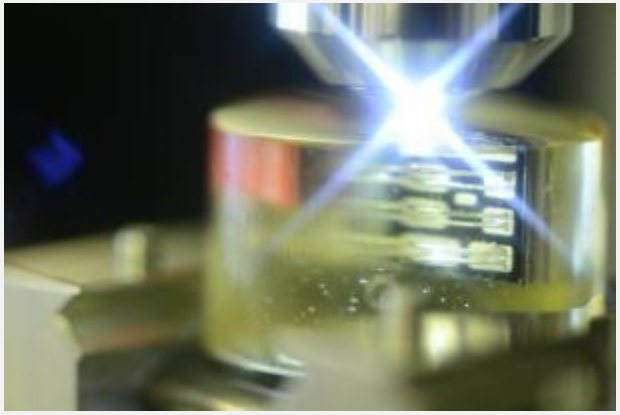
Power Electronics, Machines and Control Research Group





Power Electronics, Machines & Control Group

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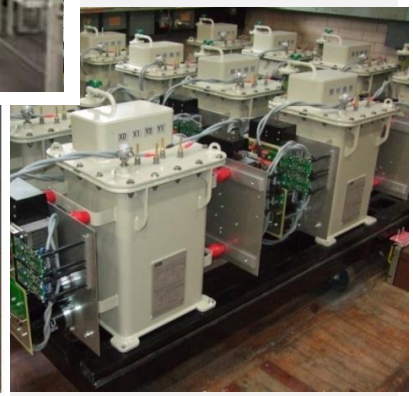
Research Themes

- Advanced motor designs
- Power Electronics for Aerospace and Energy
- Energy management system
- High density power conversion
- Electrical power systems (AC/DC/Hybrid)
- Diagnostics and Prognostics
- Electromagnetic compatibility

Underlying scientific research

- Power device packaging and cooling
- New actuator topologies
- Cooling methodologies & thermal integration
- New modelling methods



Application Areas

- Future Electricity Networks
- Renewable Energy
- Aerospace (More Electric Aircraft)
- High-energy Physics applications
- Automotive and Marine
- Industrial Applications

Group Facilities

- 1500m^2 laboratories with three 1.5MVA power supplies
- Motor rigs 1kW to 750kW, voltage supplies to 13kV
- Electrical Machine/Actuator manufacture
- Machine and Power Systems testing to 800kW
- Environmental testing chambers
- Facilities for surface mount & FPGA

Power Electronics, Machines & Control Group

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15 Academic Staff [Faculty}

Full Professors

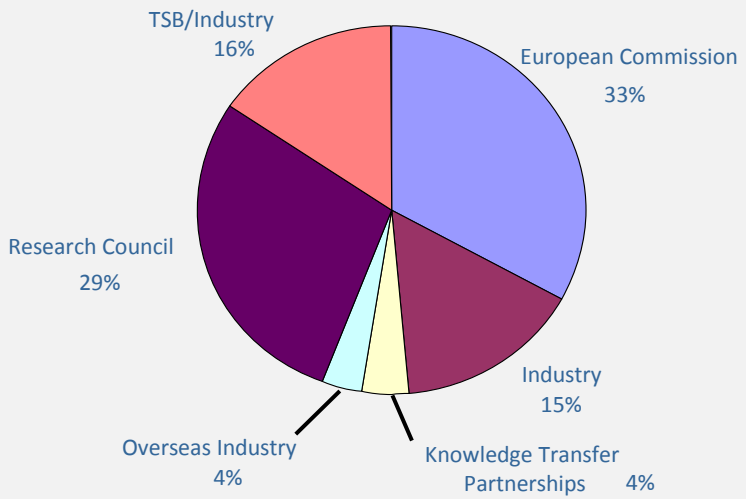
- Prof Jon Clare (Power Electronics)
- Prof Greg Asher (Drives, Control) – *Emeritus Professor*
- Prof Mark Johnson (Power Device Technologies, Energy)
- Prof Pat Wheeler (Power Electronics)
- Prof Mark Sumner (Drives, Power Quality, Energy)
- Prof Pericle Zanchetta (Control, Power Quality)
- Prof Chris Gerada (Machines, Drives)

Associate Professors

- Dr Christian Klumpner (Power Electronics)
- Dr Alberto Castellazzi (Power Device Technologies)
- Dr Sergei Bozhko [Aerospace Electrical Systems]

Lecturers

- Dr Mohand Hamiti (Machines)
- Dr Alan Watson (High Power Electronics)
- Dr Paul Evans (Power Device Technologies)
- Dr Alessandro Costabeber (Power Converters and Control)
- *Dr Michael Galea [Machines and Drives]*
- *Dr Tom Cox [Electromagnetics, Machines*]



> 125 Researchers/Academics

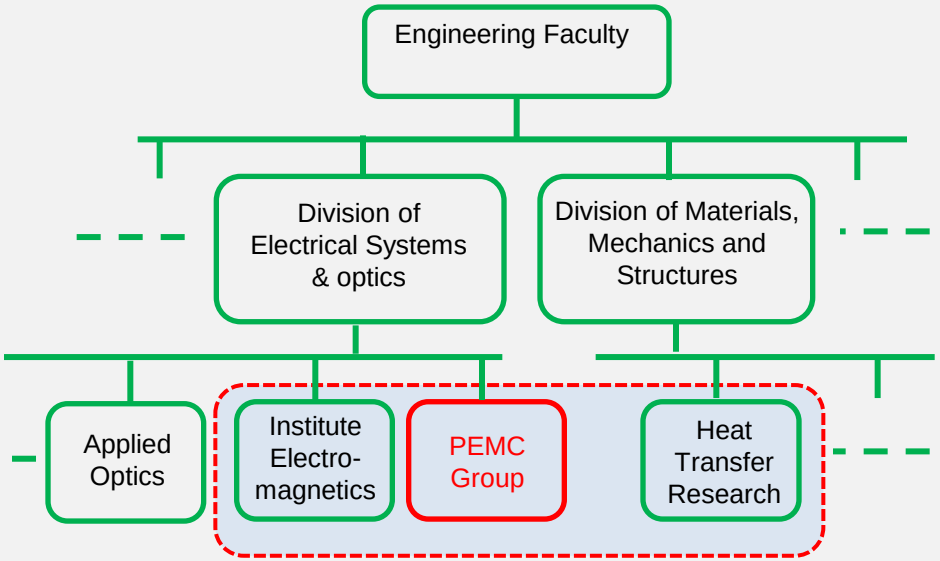
15 Academic Staff [Faculty]

≈ 45 Contract Research Fellows

≈ 64 PhD students

≈ 4 Visiting Scholars

Current Research Grants ≈ US$35M



Some of our International Agreements and Collaborators

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PEMC Group has strong relationships not only in EU but also in all over the world

Some of our Industrial Collaborators

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Aerospace(Power Electronics, Machines and Control)

AIRBUS AN EADS COMPANY
BOEING
GE Aviation
SAFRAN Messier-Bugatti-Dowty
LIEBHERR
THALES
BAE SYSTEMS
EADS EADS INNOVATION WORKS
EUROCOPTER AN EADS COMPANY
DASSAULT AVIATION
GOODRICH
MBDA MISSILE SYSTEMS

Power conversion/management

ALSTOM Grid
e·on
GE Energy
e2v
Cummins
CASTLET ENGINEERING THE SOLUTION
B&F Seamless Control
南方安华 NOWFOREVER

Power devices

Infineon
ROHM SEMICONDUCTOR
DYNEX SEMICONDUCTOR
TT electronics SEMELAB

Automotive

NISSAN

PEMC Group

Power converters and Power Quality

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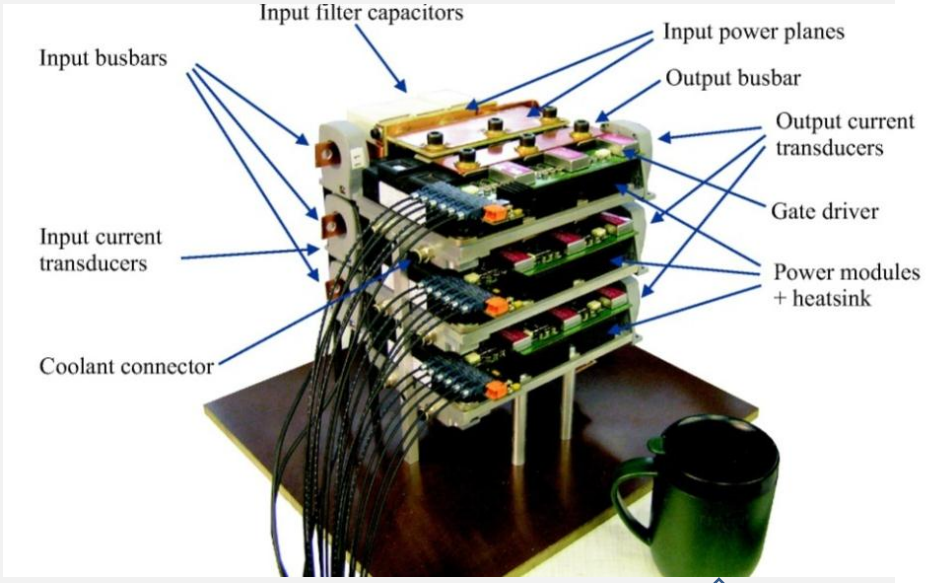
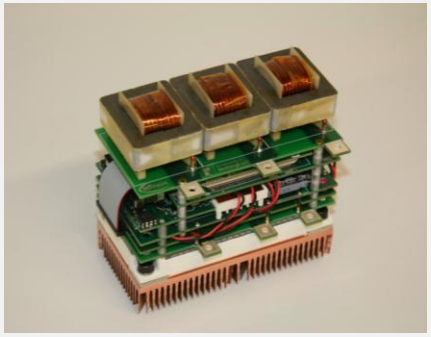
- Power Converters will be essential part of aircraft Electrical Power System
  - Power distribution; conversion from 300-900Hz to ±270VDC, to 115VAC, to 28VDC
  - converters for flight control actuators, landing gear, steering, environmental control drives, fuel cell interface
- High power density and optimised thermal management
- Meet aircraft EPS specifications
- Fault tolerance and fault tolerant system control

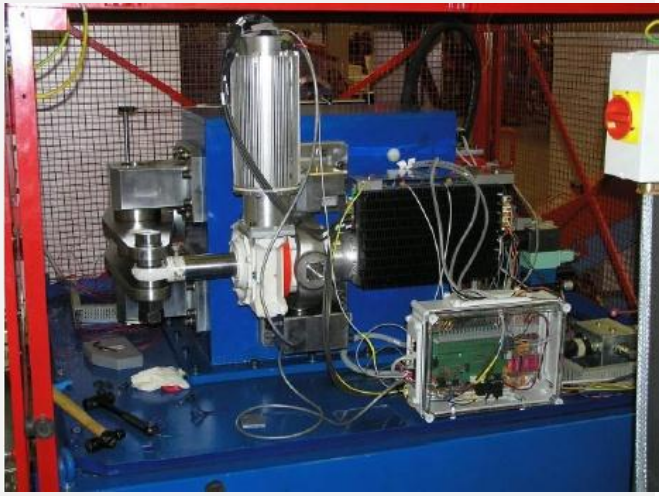


120kVA matrix converter



High density air-cooled SiC 22kW converter (approx 20kW/litre and 10kW/kg)

Rudder actuator drive



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Converters for High Power Applications

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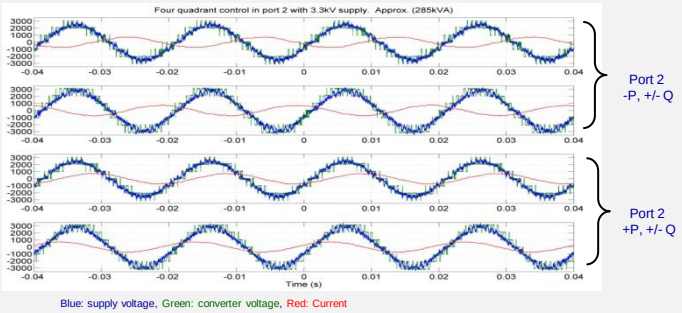
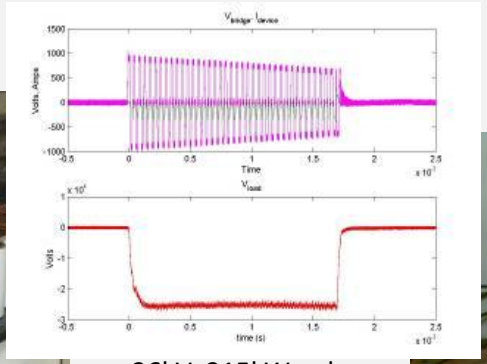
High-power converters

- Multi-level converters and multi-cellular converters
  - eg multi-level AC-AC converters with medium frequency transformer isolation
- Applications: traction, FACTS, solid state substations
  - eg renewable energy interfaces and HVDC
- Converters for high power RF applications
  - eg Klystron modulators
  - CW (DC) and pulsed outputs
  - Resonant techniques, HV and HF transformers

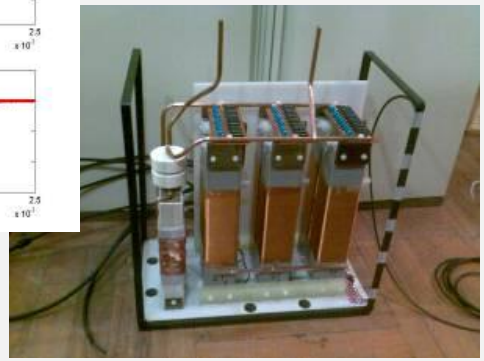


Multi-level, multi-cell : 500kW prototype

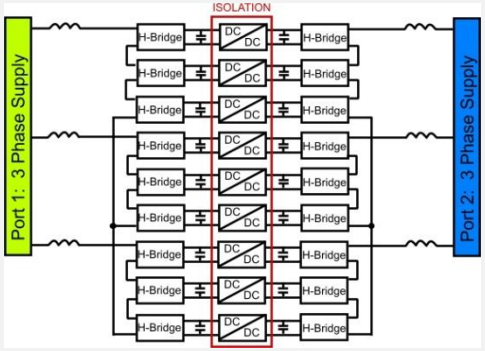
Multi-phase resonant converter (pulsed)



26kV, 315kW pulse



HF, HV transformer rectifier



PEMC Group - Some recent practical power converter research demonstrators

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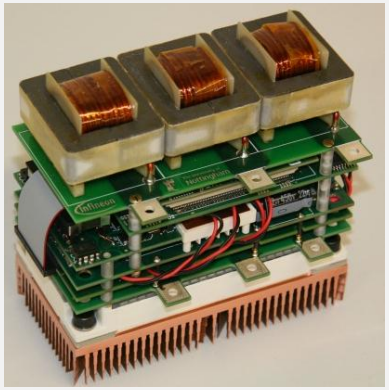
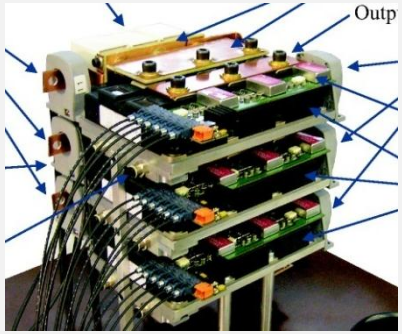
30kW matrix integrated into machine endplate

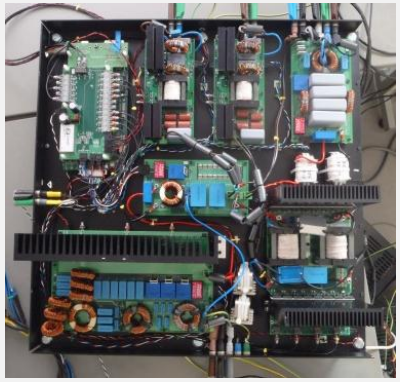


20kW/litre SiC JFET matrix converter



150kW Si/SiC matrix converter (aero spec)

3.3kV, 500kW modular AC-AC converter



Aerospace SiC MOSFET DC-DC converter

100kV DC, 200kW resonant converter

150kV resonant converter XFMR/rectifier

450kW dual-bridge CSR

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Power Device and Packaging Technologies

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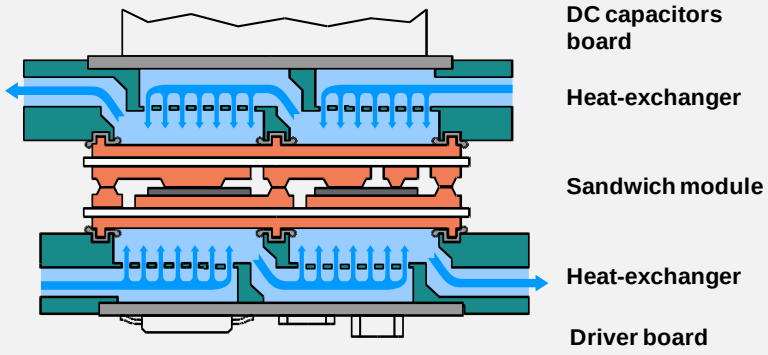
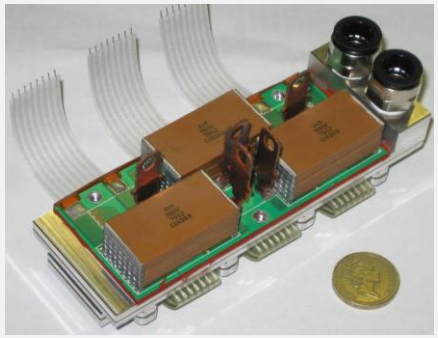
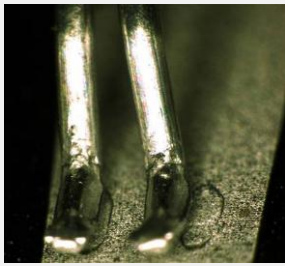
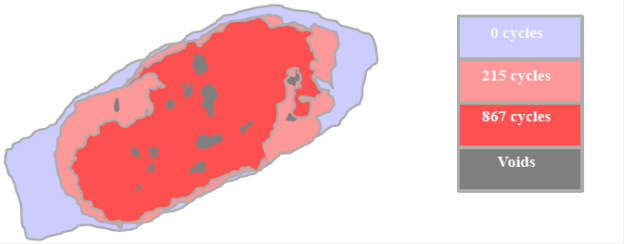
- Device technology developments crucial for future success of MEA
- New Construction & Thermal Technologies
  - Bonding and attachment technologies
  - Cooling technologies and heat spreaders
- Physics of Failure & Reliability Evaluation
  - Identification of failure modes and failure models
  - Environmental cycling (real aerospace conditions)
  - Accelerated testing methods
- Integration
  - Reduced weight, volume, cost
  - Reduced inductance and EMI
  - Enhanced thermal and electrical performance
  - Higher temperature materials (SiC, GaAs)



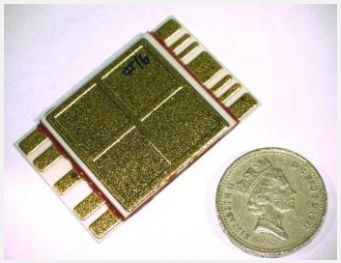


Direct double side liquid cooled assembly incorporated into a 3-phase compact inverter

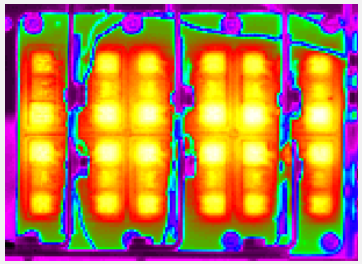




Wire Bond Failure Mechanisms



New Packaging Technologies



Thermal Analysis

Electrical Machines and Drives

Examples

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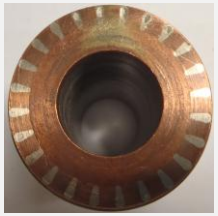
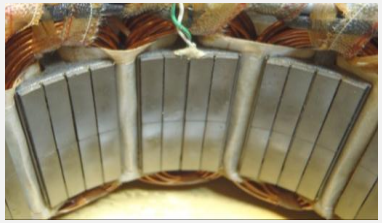
Novel machine topologies

Research into high temperature machines without magnets.



Multidisciplinary modelling and design of novel, high performance machines.



Fault-tolerant machine design

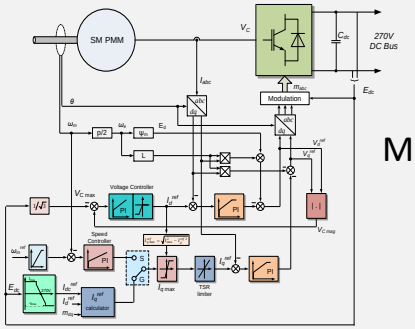
Advanced Control

Sensorless Control

- High speed model based
- Low speed signal injection

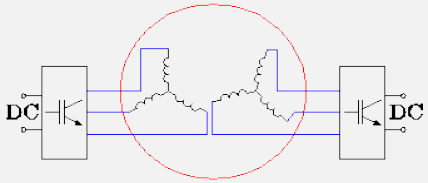
Fault-tolearnt control strategies

Predictive control, parameter estimation, modelling

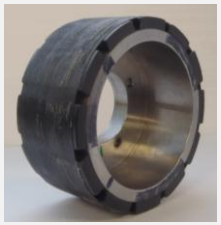


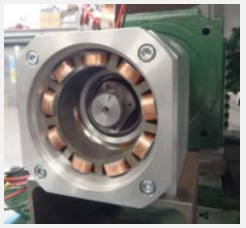
Minimum loss generator control

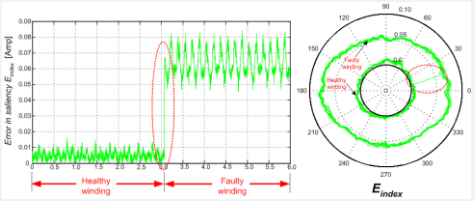
Modular motor control



Diagnostics, Health and Usage Monitoring







Diagnostics from current signatures (including active techniques for actuation systems)

- Winding faults
- Bearing, mechanical drive faults
- Rotor demagnetisation etc…

Integrated sensory network (fibre) for lifetime monitoring

Power Electronics and Applications
Smart Grid Facility

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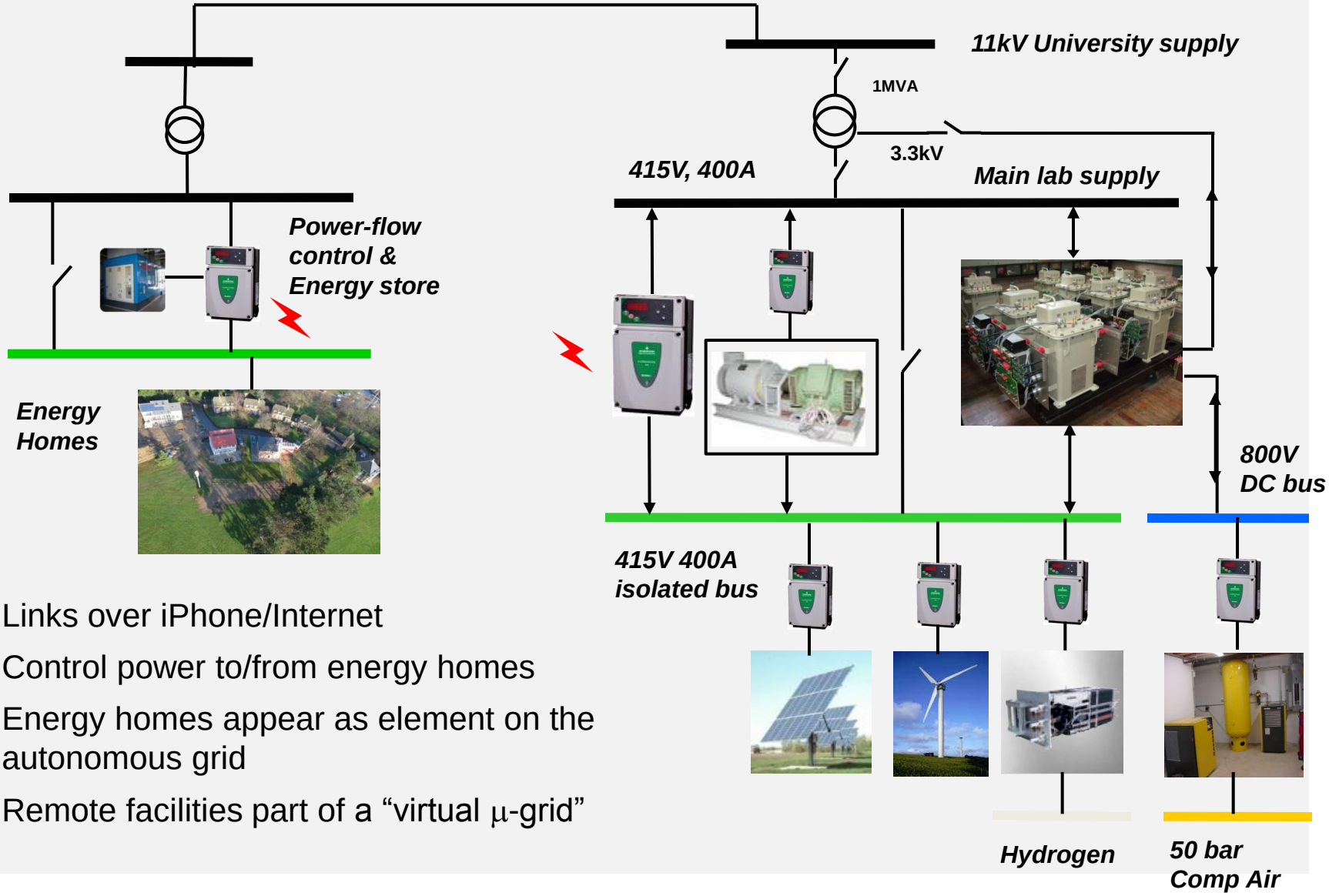

- Links over iPhone/Internet
- Control power to/from energy homes
- Energy homes appear as element on the autonomous grid
- Remote facilities part of a “virtual μ-grid”

Aircraft Power Systems

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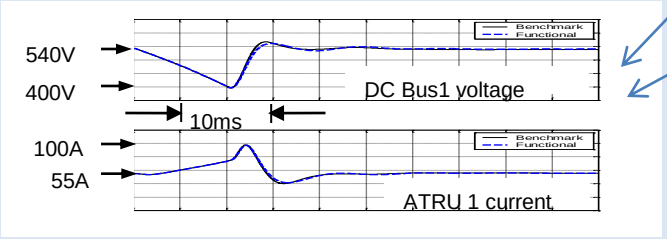
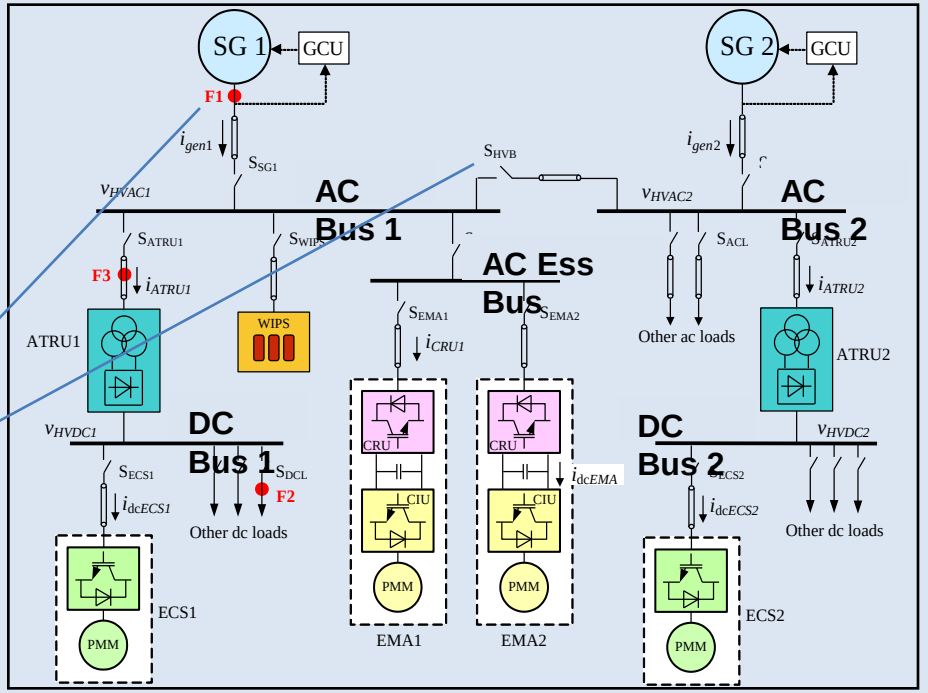
- Virtual Laboratory for Aircraft Electrical Power Systems
  SABER/Matlab/Modelica

- Fast simulation of total power system – generator to load
  - Impacts of load transients on system and power quality specifications
  - Power quality; weight optimization
  - System stability and impact of regeneration, load impact
  - Impact of faults; propagation; bus re-figuration; load dispatching

Model level	Type of model
Architectural	Steady state Relay switching
Functional	Dynamic effects to 130Hz & 5% accuracy
Behavioural	Sub-cycle (<1ms), switching & harmonics (to 100's kHz)
Component	Hf electrical, mechanical, thermal



Bus voltage response to loss of Generator
CPU time 1-4s for 2s real time



Working with Industry

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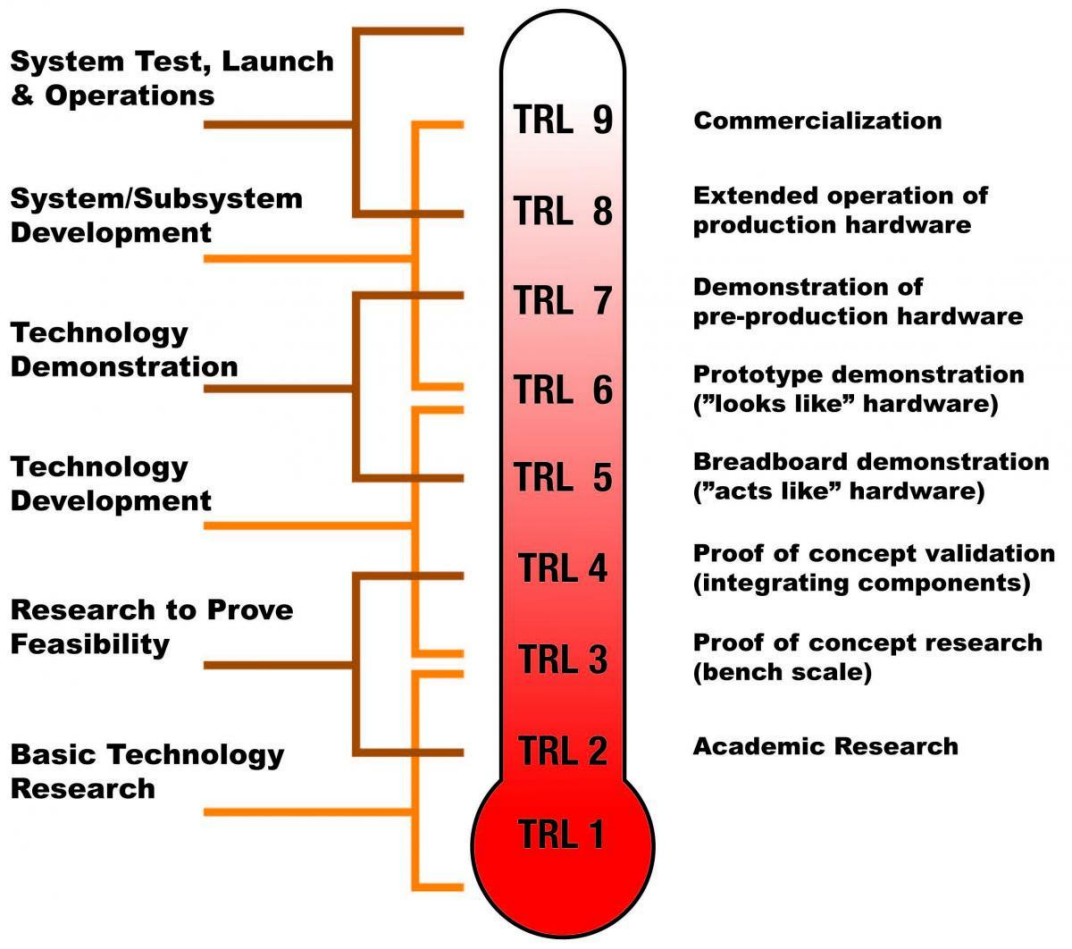
Some examples of ways in which Universities can work with Industry on R&D topics

Technology Readiness Levels



Working with Industry

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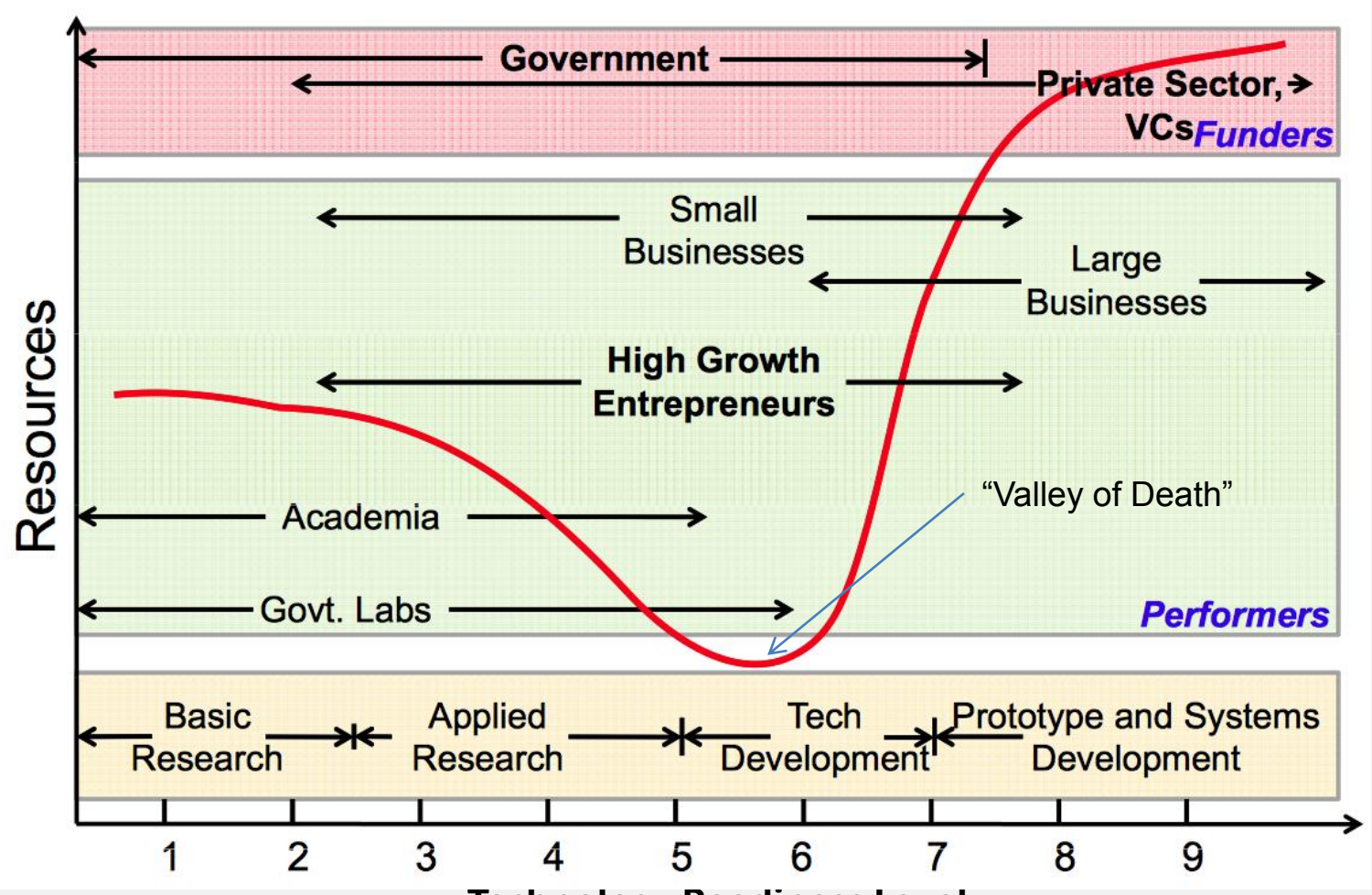
Some examples of ways in which Universities can work with Industry on R&D topics

Avoiding the "Valley of Death" for good ideas



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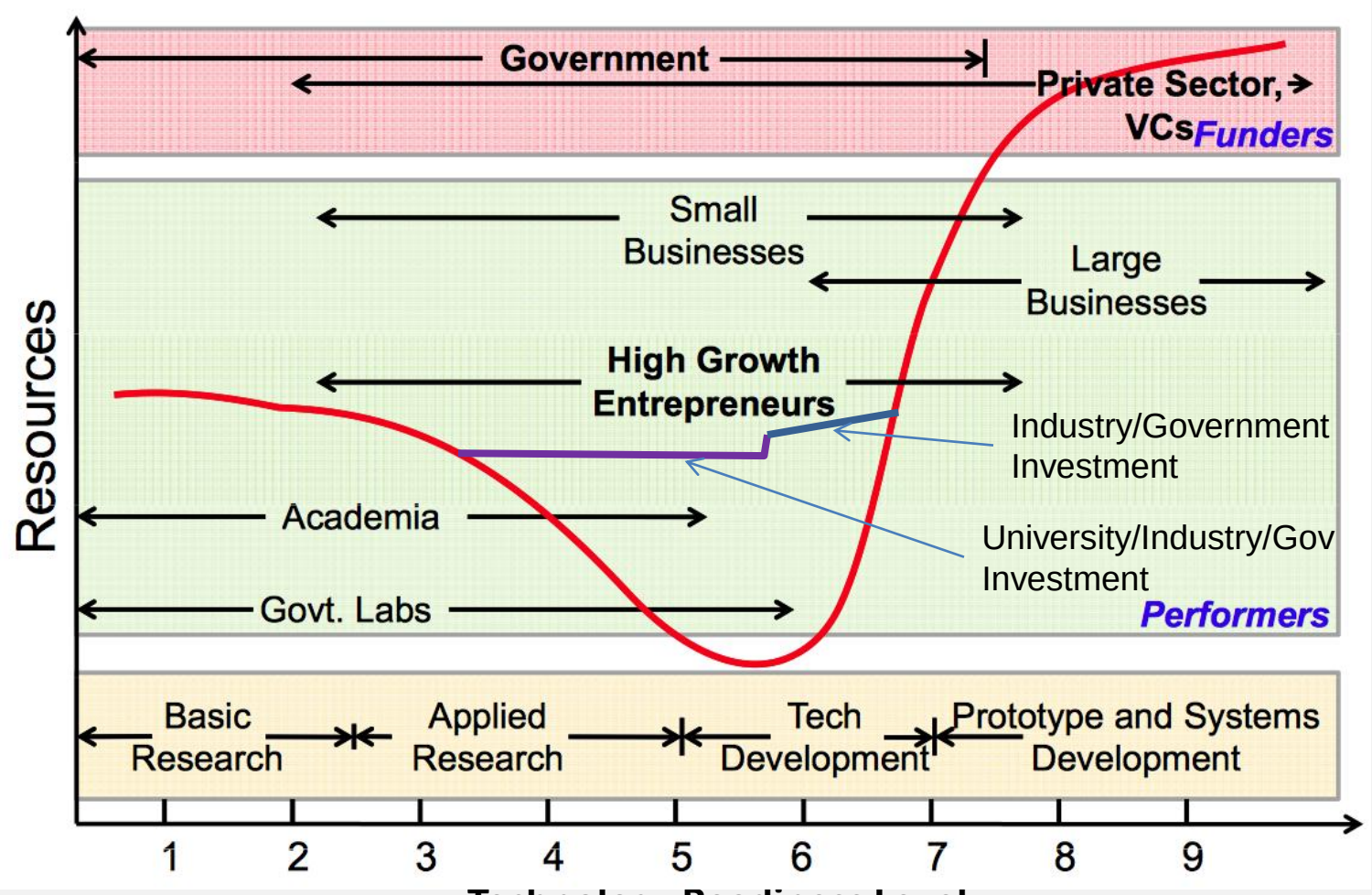

Working with Industry

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Some examples of ways in which Universities can work with Industry on R&D topics

- Industry-led research projects
  - 1 to 4 years
  - Direct funding or TSB
- European Framework Programmes
  - 2 to 7 years
  - Collaborative R&D as partners in a programme or project
- Scientific research projects
  - 3 to 6 years
  - Basic research – eg EPSRC funded projects
- Knowledge Transfer Partnerships (KTPs)
  - 0.5 to 3 years
  - Embedding technology into business
- Newton Fund projects
  - 2 to 4 years
  - International research funding from the British Council
- Sponsored PhD studentships
  - 3 years
  - Research/low TRL
- Industrial research fellows
  - 1 to 5 years
  - Support for dedicated research staff at the University
- Technology licensing
  - Access to patents and know-how

Industrial Research - Motor Drives

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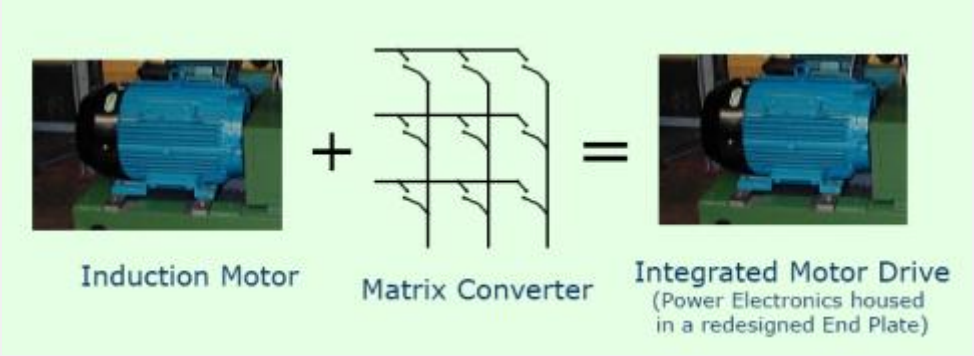
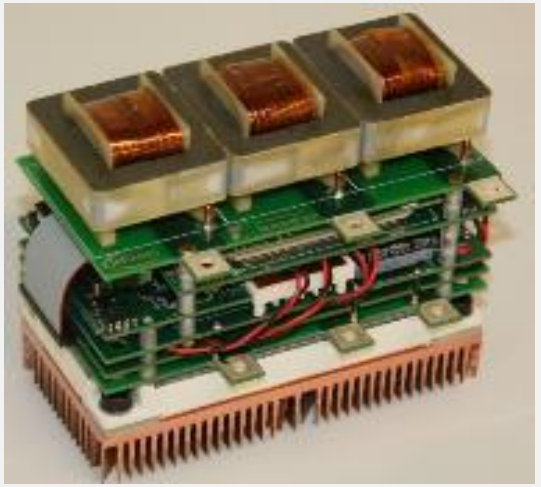
Integrated Motor Drive



- Matrix converter can be mounted inside motor housing
  - Reduced EMC, cabling, installation
  - Redesigned end plate housing IGBTs, diodes and filter capacitors (inductors in terminal box)
  - Bespoke semiconductor packaging
- 30kW prototype shipped to industry in 2012
- Started as an EPSRC research project in 1997
- Product launch planned for 2014

SiC JFET Matrix Converter

- 20kW/litre SiC JFET based matrix converter
  - Industrial Funding directly from Infineon
- Key Features of the converter design
  - Heat sink
  - Power planes
  - Gate drive circuitry
  - Gate drivers power supplies
  - Input filter
  - Controller boards
- Key Integration Challenges:
  - Minimise thermal resistance using forced air convection
  - Decoupling capacitance and gate drives must be physically close to the power module



Power Electronics, machines and Control

Example Projects

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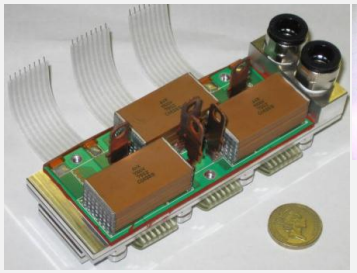
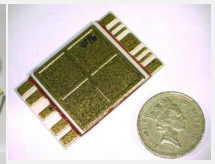
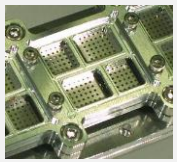
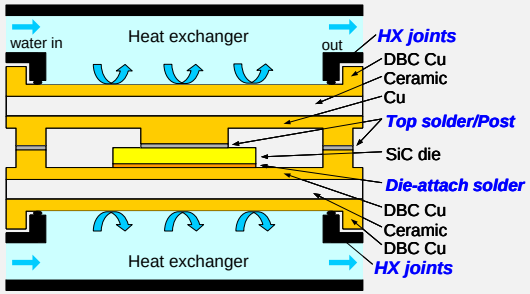
Power Electronic Packaging



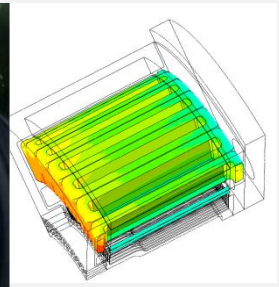




- Device technology developments crucial for future success of MEA
- New Construction & Thermal Technologies
- Physics of Failure & Reliability Evaluation
- Integration and use of Sic devices



Taxiing on Ground

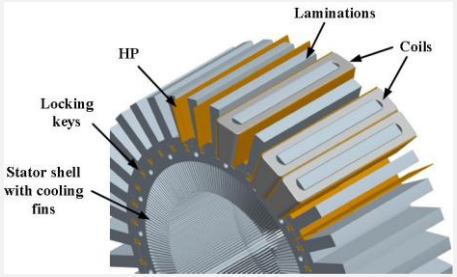


Rotor with Hallbach Array

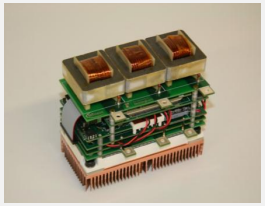
7 kNm peak torque requirement

Torque density : **226kNm/m3**

Special windings and high conductivity thermal paths introduces



Automotive Power Converters



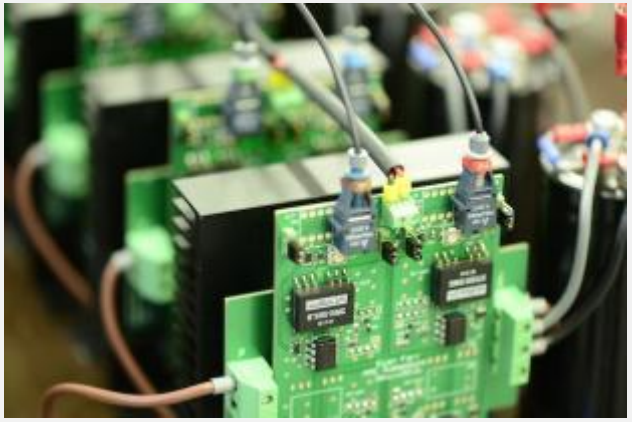
High density air-cooled SiC 22kW converter (approx 20kW/litre and 10kW/kg)

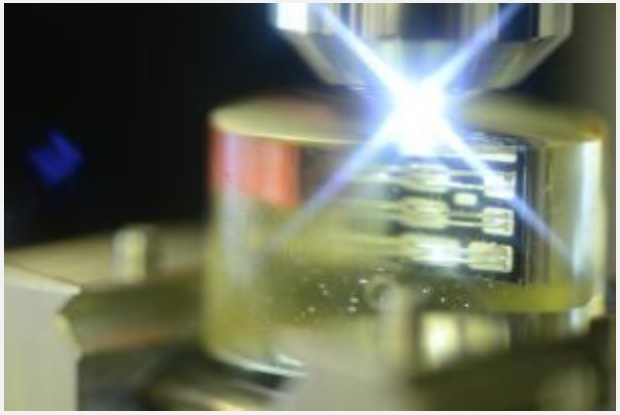
- Working with supply chain and primes, including Nissan and TRW
- Power Converter topologies, multi-use applications and Power by wire applications
- Racing Electric motorbikes

University of Nottingham bike racing at Donnington Park – sponsors needed!

Summary

- Nottingham has one of the largest research groups in Power Electronics and related technologies
- Research spans:
  - Basic technology research (e.g. physics of failure)
  - Applied research (e.g. advanced technology demonstrators)
- Expertise spans:
  - Device and component technology → Complete systems
  - Analysis → modelling → practical validation
- We are committed to working with industrial partners to maintain relevance and exploitation of our research

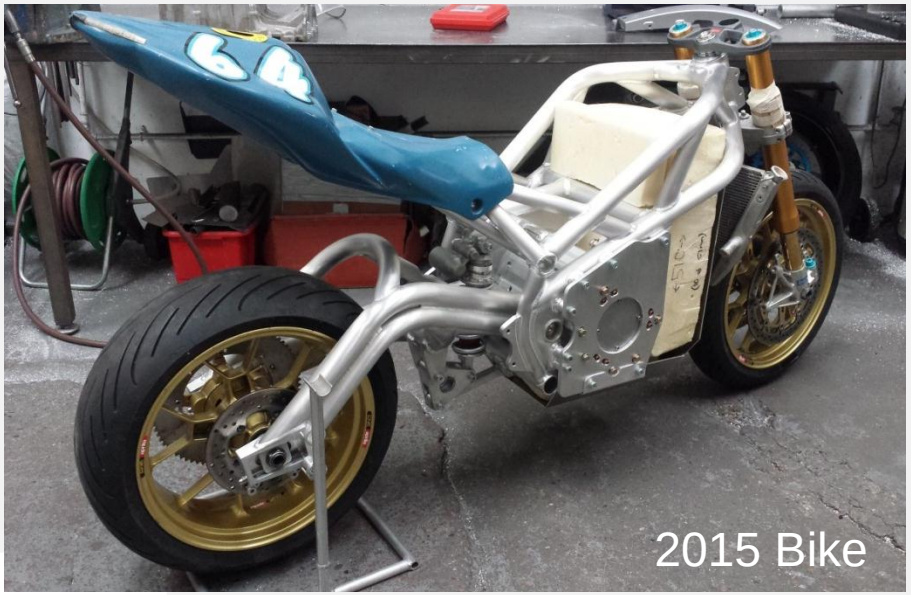




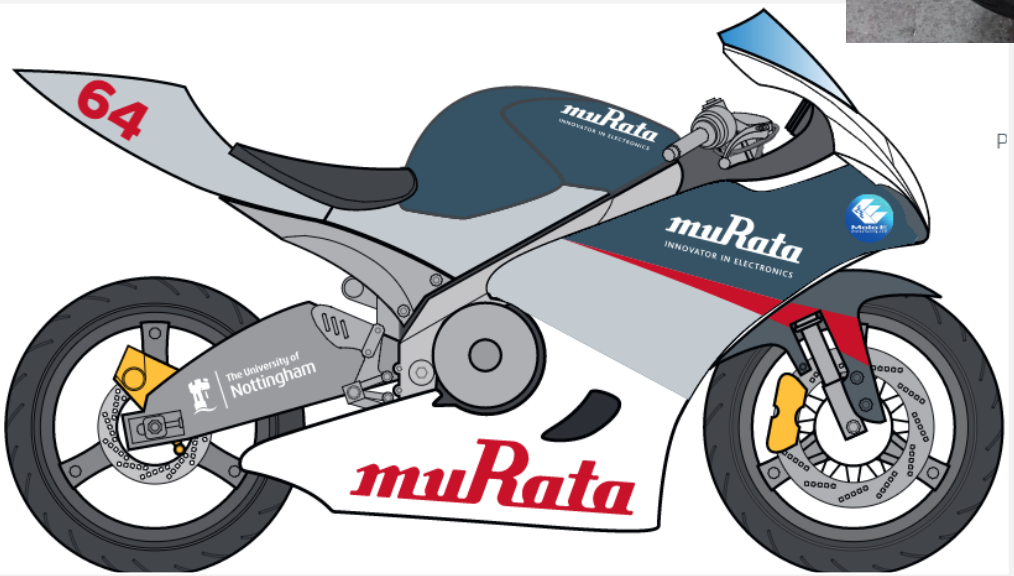
2015 Season eSuperBike

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

- 2015 electric bike will have 3 x Torque of the 2014 bike
- Custom designed and built frame
- Motor and Controller built by the team in Nottingham
- TT on Isle of Man in June 2015!
- > 280km/hr



2015 Bike




2014 Bike