Vehicle Electrical Systems Integration

EPSRC
Pioneering research and skills

EP/I038543/1

VEHICLE ELECTRICAL SYSTEMS INTEGRATION (VESI) PROJECT

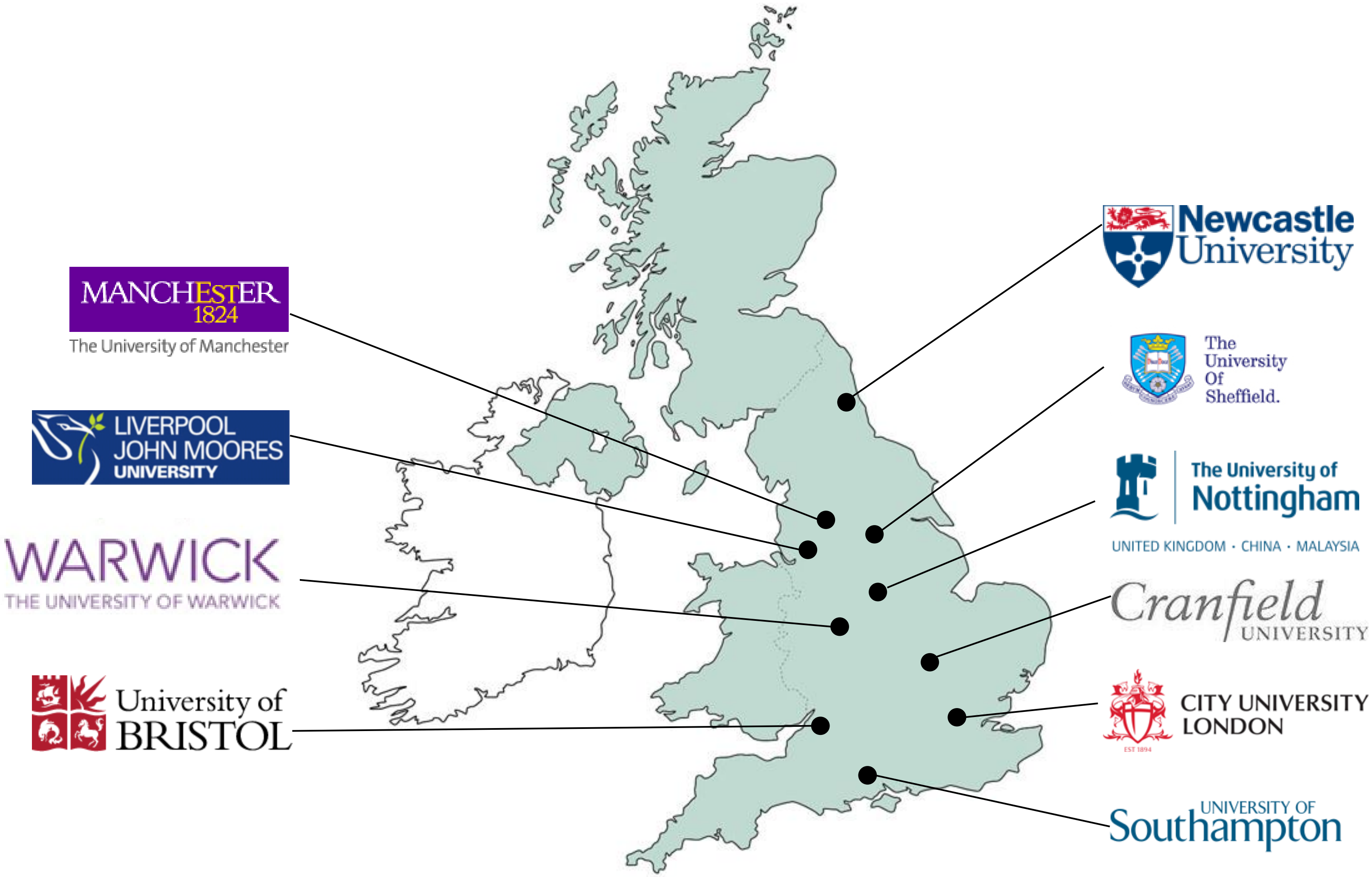
Phil Mawby

University of Warwick

Facts & Figures

- EPSRC-funded project: £3.8 M
- Low TRL (1-3) to support EV technology development
- 10 partners
- 4.5-year project: Oct 2011-Mar 2016.
- To develop new EV technologies to meet challenges + opportunities facing the EV market.
- 6 research themes + 3 technology demonstrators
- Integrate electrical motor + power electronics:
    - **reduce cost/weight** and **increase power density**
    - **improve reliability** of electrical power systems
    - **maintain manufacturability** for a mass market

Location of Research Groups



University Partners

- Experts in power electronics, electrical machines, and mechanical engineering

Prof Phil Mawby
(Warwick)

Prof Phil Mellor
(Bristol)

Prof Keith Pullen
(City)

Prof Patrick Luk
(Cranfield)

Prof Emil Levi
(Liverpool John Moores)

Prof Andrew Forsyth
(Manchester)

Prof Volker Pickert
(Newcastle)

Prof Mark Johnson
(Nottingham)

Prof David Stone
(Sheffield)

Prof Andrew Cruden
(Southampton)

Industrial Supporters

MLE

Liberty Electric Cars

sse

JAGUAR

LAND ROVER

TATA

ARNOLD MAGNETIC TECHNOLOGIES

Integrated Magnetics Ltd.
湖州汇磁金锐磁材有限公司

IST Power

RICARDO

TT Electronics
Make Possible

PRECISION SCORPION PERFORMANCE

prodrive

JM
Johnson Matthey
Battery Systems

FluxSys

Motor Design Ltd

CONTINENTAL SINCE 1871

DYNEX

TIRIUS

Allied Vehicles™
Driving for Perfection

TECH/OPS
SEVCON

ZF

HIFLUX
HIFLUX

infineon

LYRA ELECTRONICS

Six Research Themes

1. Power Semiconductors (Warwick)
2. Design Tools (Newcastle, City, Manchester)
3. Packaging (Nottingham)
4. Motors (Cranfield and Newcastle)
5. Converters (Manchester, LJMU, Newcastle, Southampton)
6. Passive components (Bristol, Manchester, Sheffield)

Demo 1: Integrated Non-Rare-Earth High Performance Drive
£311,982

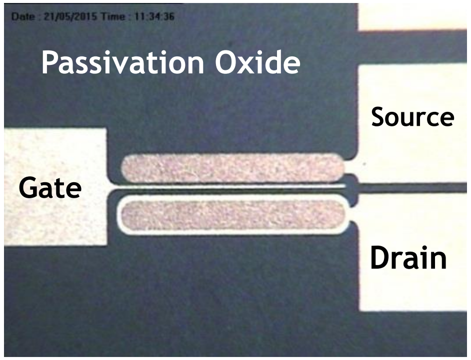
Demo 2: Integrated Power Conversion for Reduced EMI
£310,661

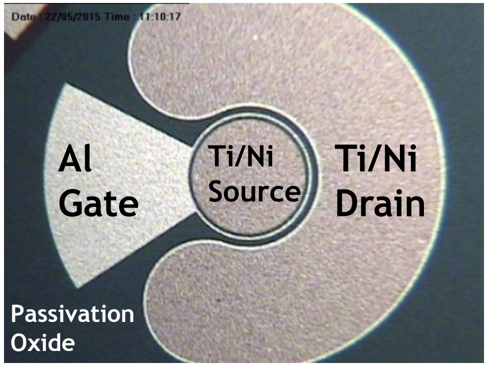
Demo 3: An Integrated On-board Battery Charger using a Nine-phase Machine, with V2G Capability
£269,437

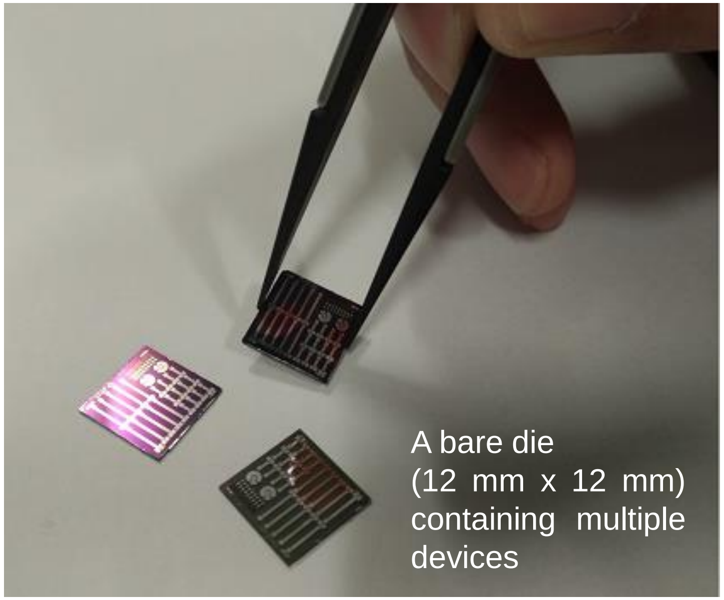
Theme 1: Semiconductors

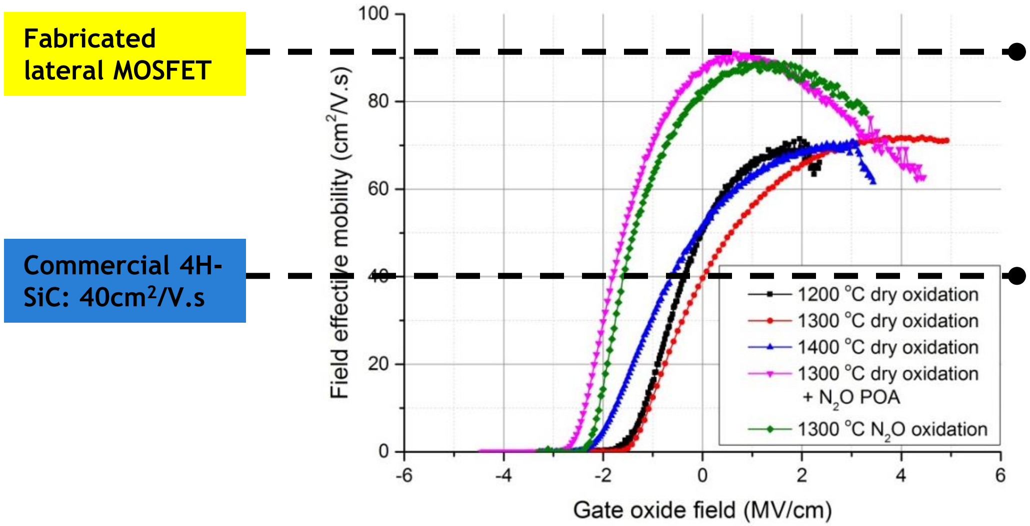
- Aim was to create **lateral MOSFET devices** with:
  - medium/high blocking voltages
  - high current → permits high torque, high acceleration
- Target = **1200V** and **10A** = for high performing EV power trains.

Finger vs circular structure:









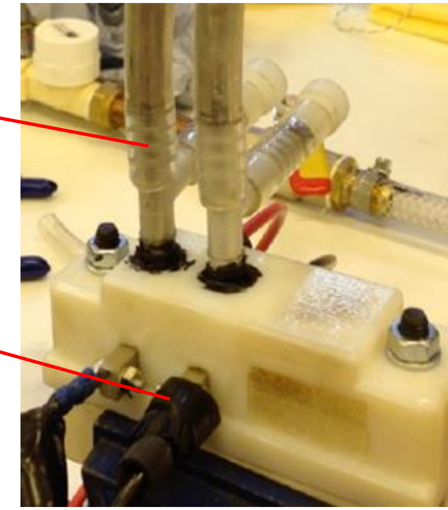
Achieved:

- Grew **3C-SiC on Si wafers** for high current and HV power devices.
- Lateral MOSFET with a **channel mobility of around 90 cm²/Vs** which is much higher compared to 4H-SiC.

Theme 2: Design Tools

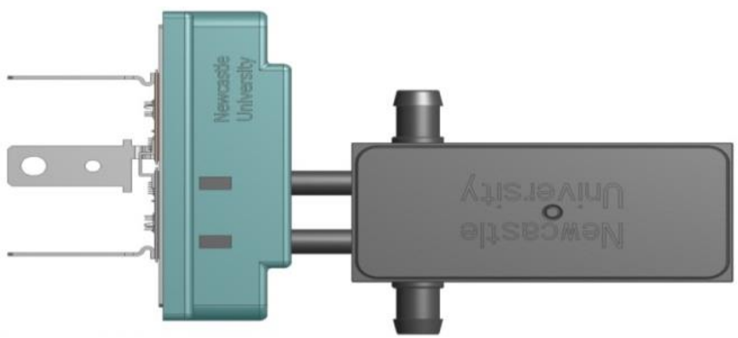
Pipes containing the liquid-metal coolant.

Power supply for the internal pump (no mechanical rotational component).

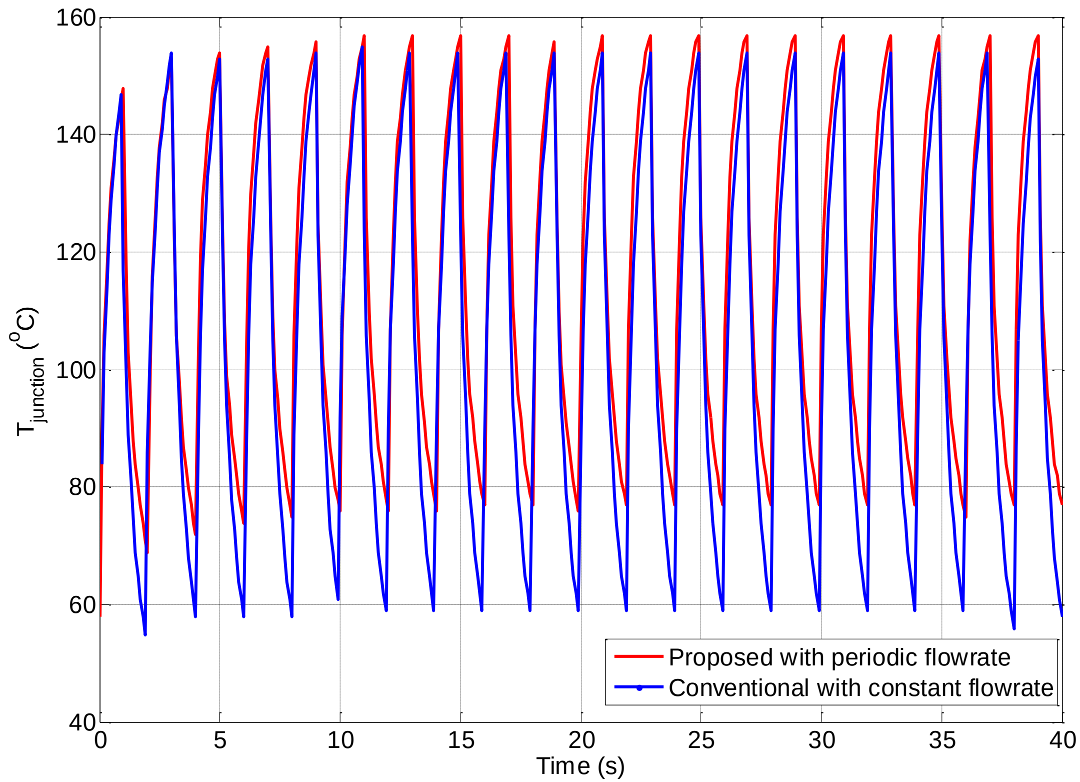


Achieved:

- Newcastle have integrated a cooling medium to a power module to cool power chips individually.
- Temperature fluctuation **reduced by 10 ºC** using liquid-metal material → has potential to **double chip lifetime** compared to conventionally cooled power modules.

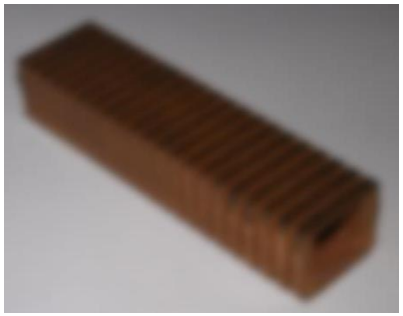


Power module and cooling circuit



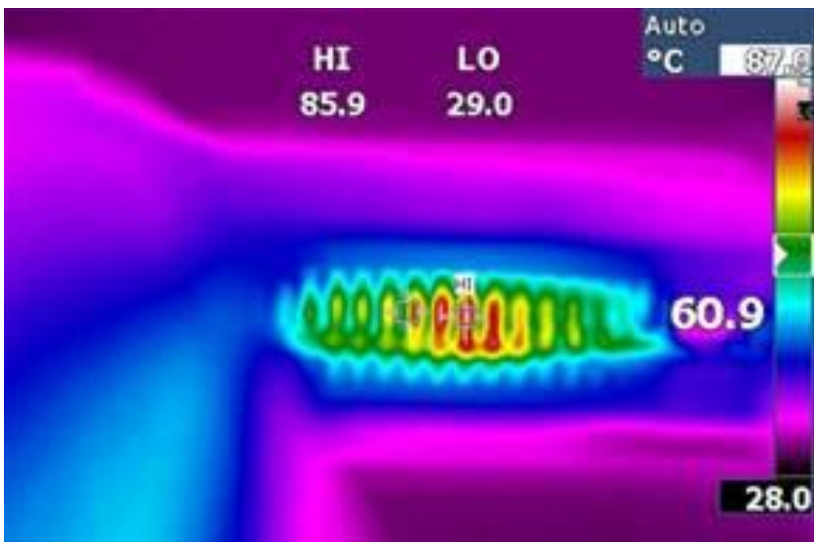
Red – chip temp. cycle new module
Blue – chip temp. cycle traditional module

Theme 3: Packaging



High energy density inductors

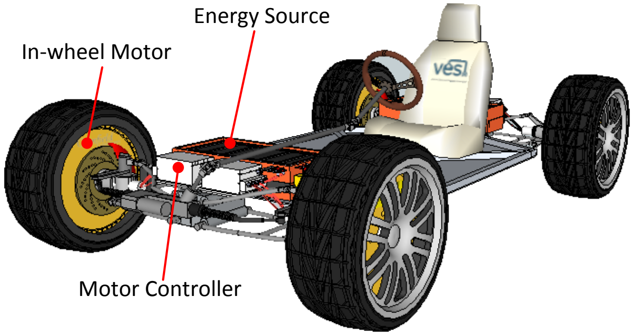
1200V, 80A integrated switching cell



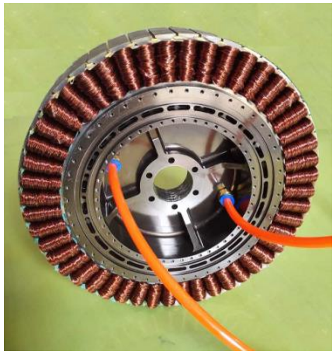
Thermal image of integrated inductor under test at 100A/mm^2

DC-DC power converter, 300V In, 0-250V out, 52kW max rated power (12.8 x 16.3 x 3.3 cm)

Theme 4: Motors



- **In-wheel direct-drive permanent magnet synchronous machine (PMSM) based on rare-earth PM (<1 krpm)**
  - Pros: No gearbox or transmission system, so **space** for battery.
  - Cons: high-temperature demagnetization; expensive; restricted supply.



Stator for in-wheel rare-earth PM motor

Medium-speed ferrite rotor

- **Medium-speed high-performance PMSM using ferrite PM (5 krpm)**
  - Pros: Working temperature 100^{0}C higher than rare-earth PM, excellent corrosion resistance, low cost
  - Cons: low-temperature demagnetization; fragility; energy density (BH)max only 1/10 of rare earth).

- **High-speed switched reluctance machine (50 krpm)**
  - Mechanical integrity design and analysis to ensure rotor safety and to improve the overall power density of the machine.

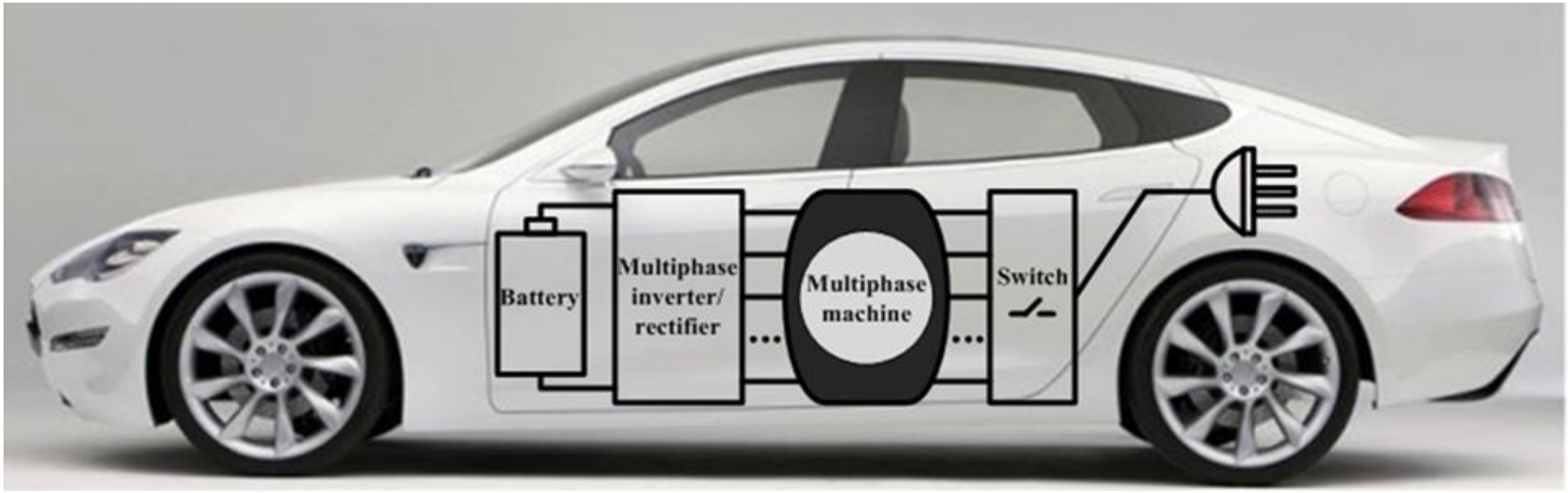
High-speed SRM stator

Theme 5: Converters

- Investigate integrated **on-board charger with bidirectional power flow** for battery charging and V2G operation.
- Can use single-phase (slow), 3-phase, and multiphase charging (fast).
- No separate charger, instead **RE-USE** the pre-existing magnetic components and inverter installed for driving mode.
- No torque produced while charging.

Advantages:

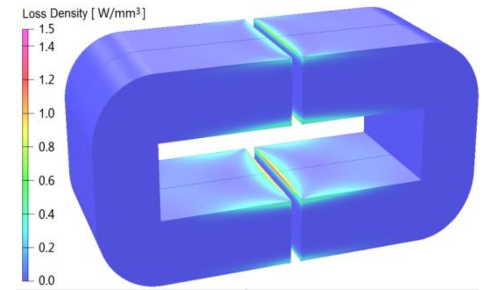
- Fewer new elements → lower cost
- Lower weight → faster vehicle
- Less space needed → smaller vehicle
- Can use any type of power socket
- V2G operation → helps with providing stored electricity to the grid

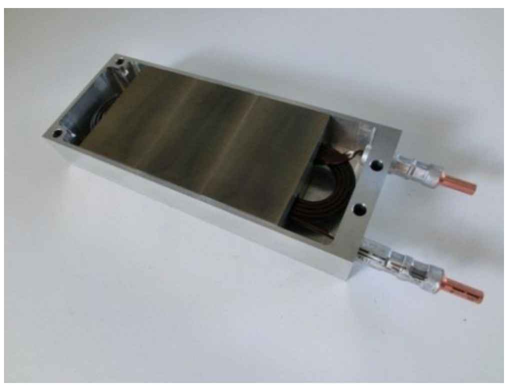


Theme 6: Passives

Achieved:

- Developed a thermo-electric design optimisation tool to demonstrate energy-dense wound components.
- Established high fidelity models to accurately analyse parasitic loss effects due to gap fringing and AC winding losses.
- Investigated alternative methods of cooling and heat extraction within wound components, including alternative encapsulates and heat spreaders.



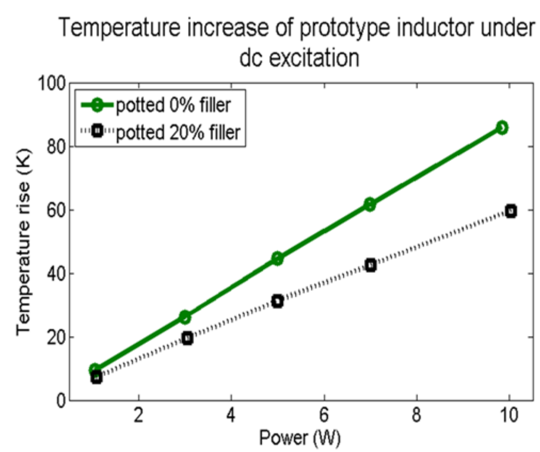


VESI filter inductor prototype:

- 80 μH inductance
- 200 A rated current
- 400 Hz operating frequency
- SiFe core
- Aluminium conductors
- 2.5 kg weight

Interleaved DC-DC converter inductor incorporating gap loss mitigation

Inductor Design	Energy density
Commercial	0.1-0.2 J/kg
Publications	0.2-0.8 J/kg
VESI	1.2 J/kg

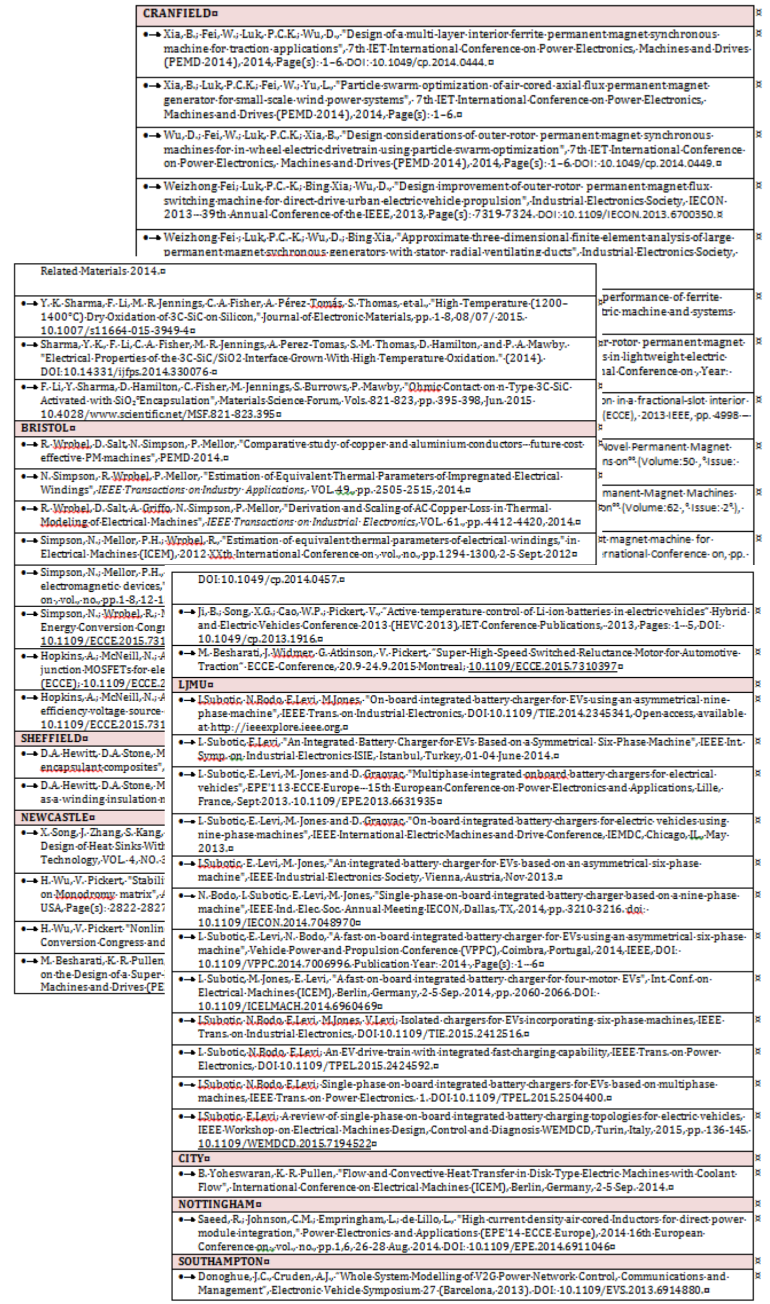


Encapsulated component

Conclusions

1. Completed the research into the underpinning technology.
2. 55 publications.
3. Investigated ways to reduce cost, increase power density, improve reliability of electrical power systems.
4. Applied the research to creating three demonstrators.
5. Desire to take the three demonstrators to higher TRLs.

www.warwick.ac.uk/vesi



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- Potting compounds ….………….. d.a.stone@sheffield.ac.uk
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