csa.catapult.org.uk

Catapult Compound Semiconductor Applications

Power electronics device modelling using ANNs and initial steps towards design automation

Dr Ingo Lüdtke, Head of Power Electronics

AESIN 2024

11th July 2024

We work with Innovate UK

UKRI Innovate UK

CSA Catapult

£110 million
Funding over 10 years

Established
April 2018

100+
Staff and growing

Our vision is for the **UK to become a global leader** in developing and commercialising new applications for compound semiconductors.

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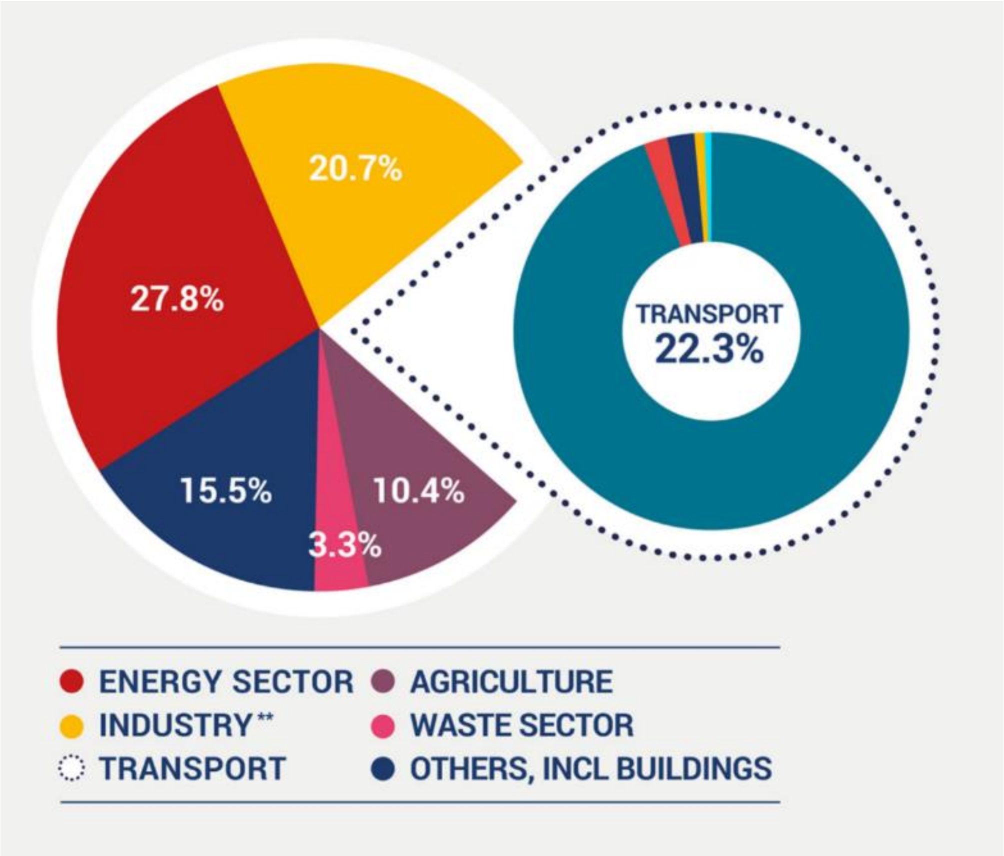
Power Electronics - key to Net Zero

CO2 emissions contributors



Renewable energy and electrification drive the

power converter

market toward

$146b by 2028

Converters

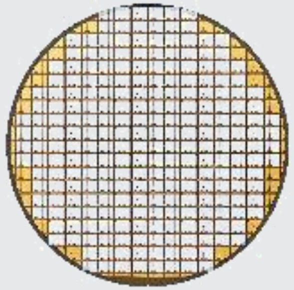
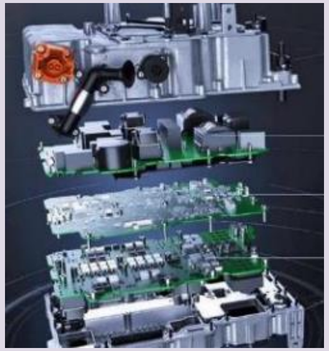
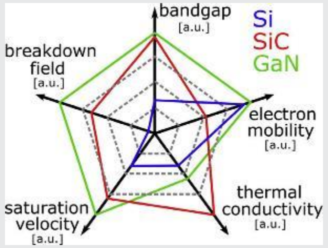
Inverters

Switches

Chargers

Source: https://www.acea.auto/files/ACEA_preliminary_CO2_baseline_heavy-duty_vehicles.pdf

Power electronic semiconductors – SiC / GaN vs Si

<table>
<tr><th>Semiconductor material</th><th>Power module</th><th>Power converter</th><th>Application</th></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>
</td><td>✓ Low on-resistance
✓ High switching speed
✓ Smaller chip size
✓ High operating temperature</td><td>✓ High (system) efficiency
✓ High power density
✓ Thermal management
✓ High switching frequency</td><td>✓ More range
✓ Smaller battery
✓ Lower cost
✓ Faster charging
✓ Lower weight</td></tr>
<tr><td>? Costs
? Wafer size
? SiC process steps
? GaN voltage rating</td><td>? Parasitics
? Temperature
? Gate drivers / sensors
? High heat flux
? Qualification standards</td><td>? Parasitics
? Circuit topology
? Thermal management
? High-frequency magnetics</td><td>? Supply chain
? Technology track record
? Motor design</td></tr>
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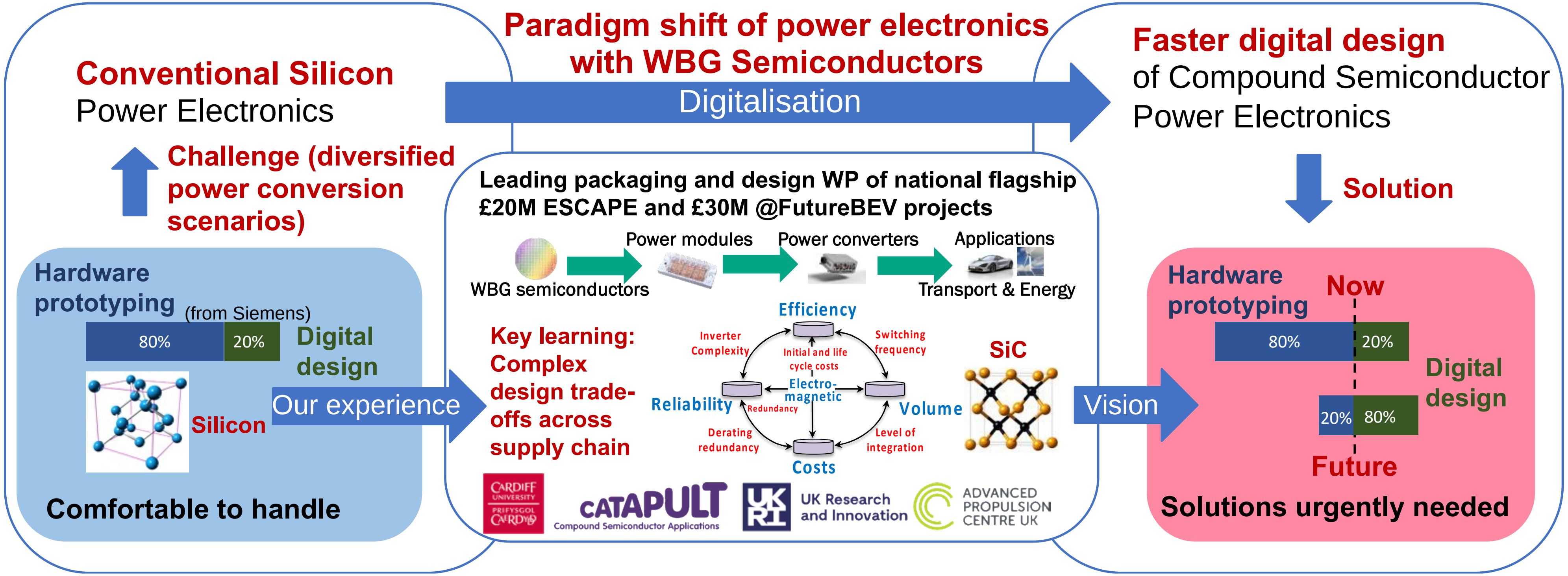
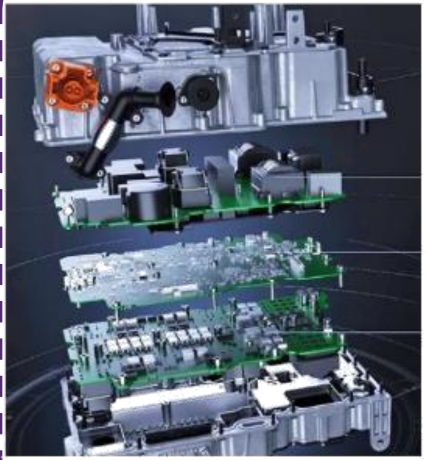
Background and motivation



- Traditional design tools are segmented and may lead to sub-optimal system performance
- Highly human-intensive workflow of building, testing, prototyping, and refining
- Traditional design tools are not enough to handle compound semiconductor electronics

But it is not straightforward!

Converter



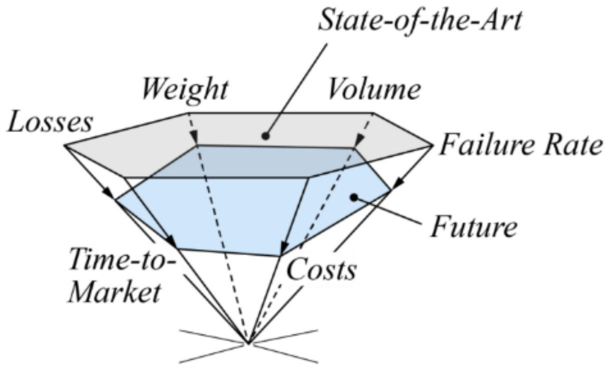
Power board
- Inductors
- Capacitors
- Resistors
- Power modules/discrete semiconductors
- Current sensors
- Power management IC
- Fuses, overvoltage protections
- Etc.

Thermal management
- Thermal Interface material (TIM)
- Cooling systems

Control board
- Communication interface
- Microcontroller
- Sensing

Mechanical Design
- Busbar
- Connector
- Housing

High level of complexity



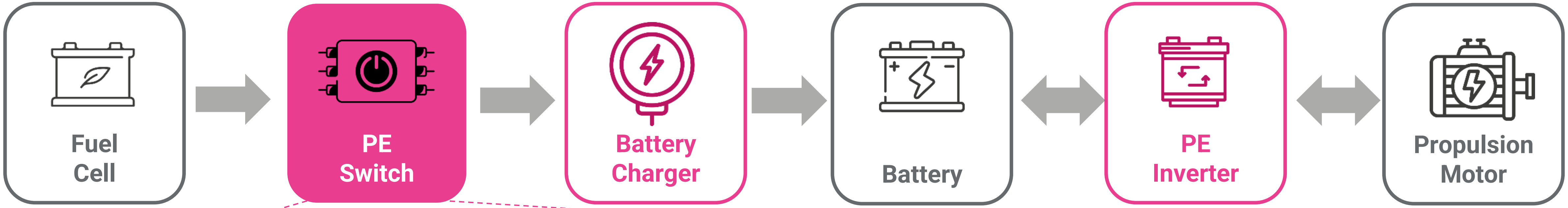
Multiple objective requirements

Power Electronics designs

Too slow and too effort intensive

Modelling and simulation
are the key to solving this

But it takes too long to simulate!



Simulation models challenges

Computing time

- for 7 out of 37 candidate components
- **25 million design permutations**
- 2 seconds per simulation

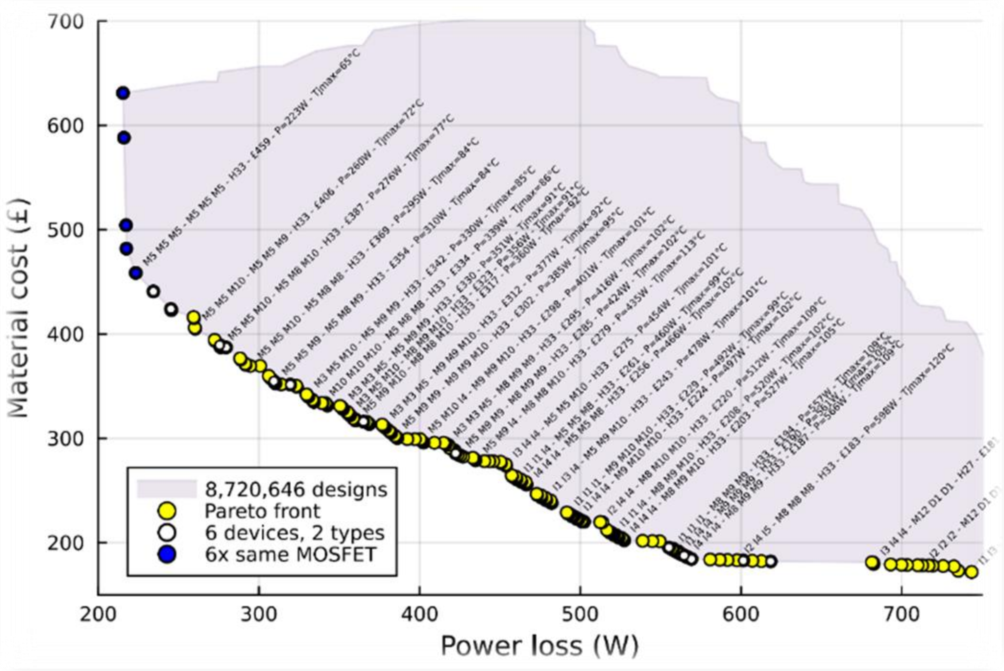
580 days
simulation time

- Limited availability
- Non-compatible
- Inconsistent results
- Inaccurate results

Introducing AI-Optimised Power Electronics

580 days
simulation time

99.83%
simulation time reduction
Using Artificial Neural Network (ANN) modelling of circuit topology training data



Circuit topology, components, operating conditions

1 day
simulation time

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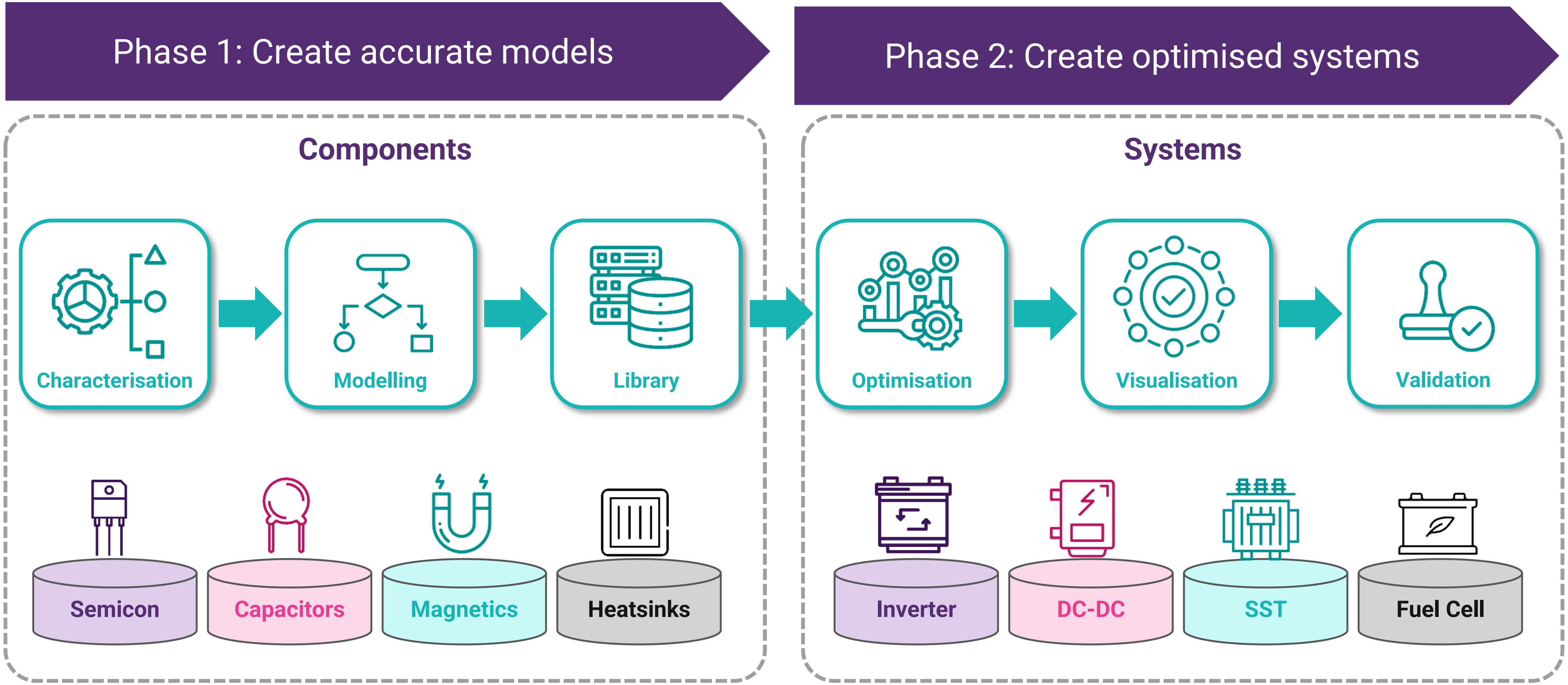
Development methodology



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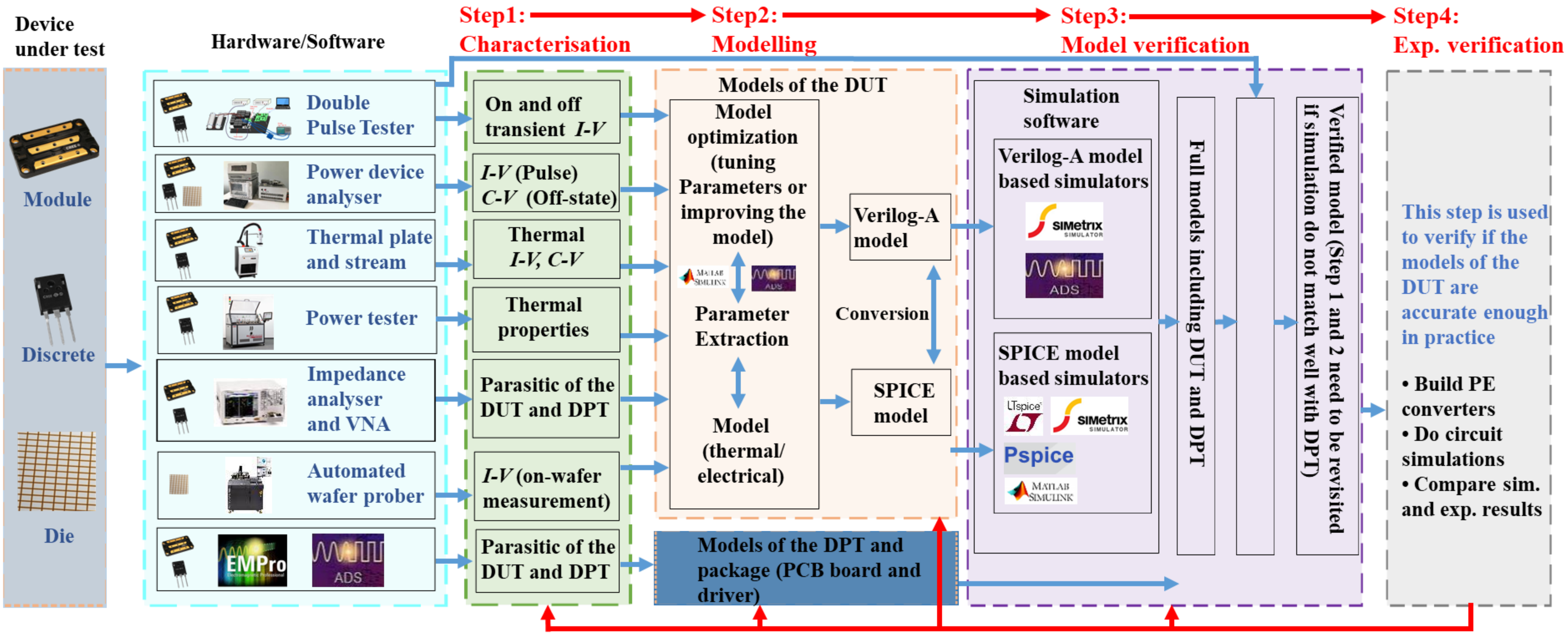
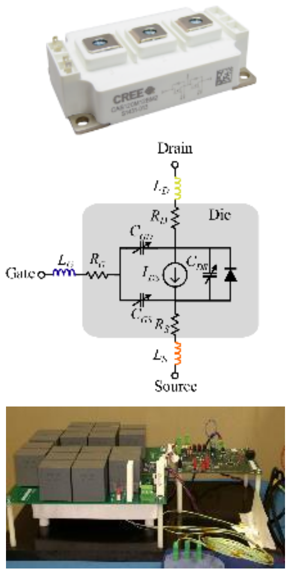
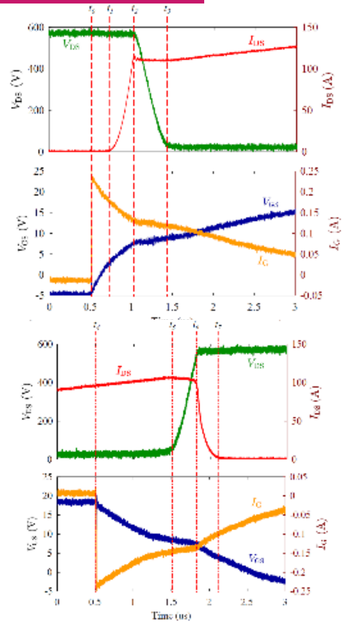
AI-enabled digital design: Accurate modelling of compound semiconductors

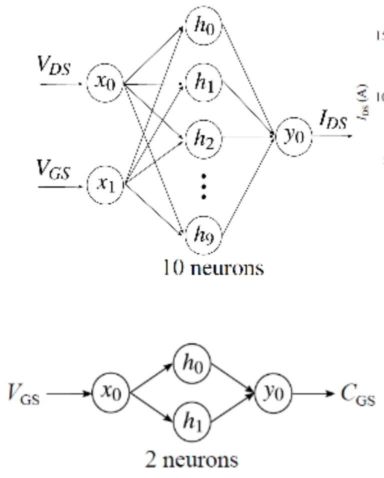


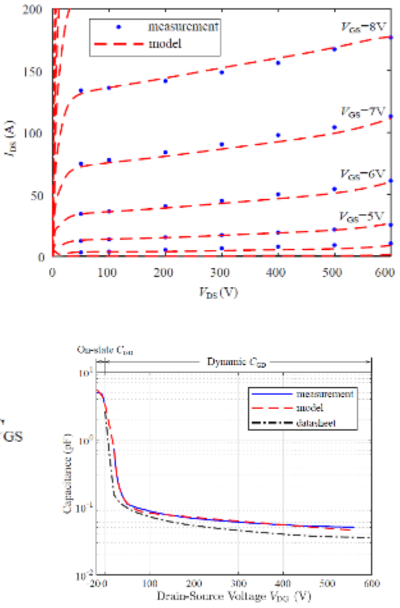
AI-enabled digital design: Accurate modelling of compound semiconductors

Characterisation → Modelling → Verification → Simulation vs Experiments

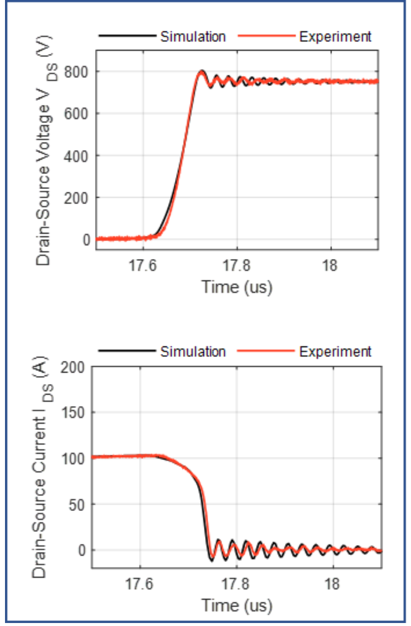




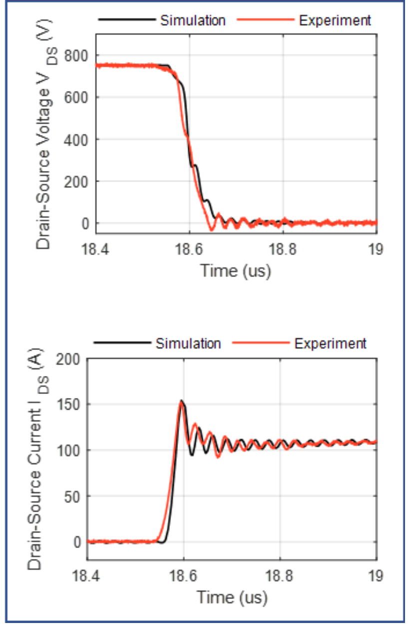




Turn-off transients



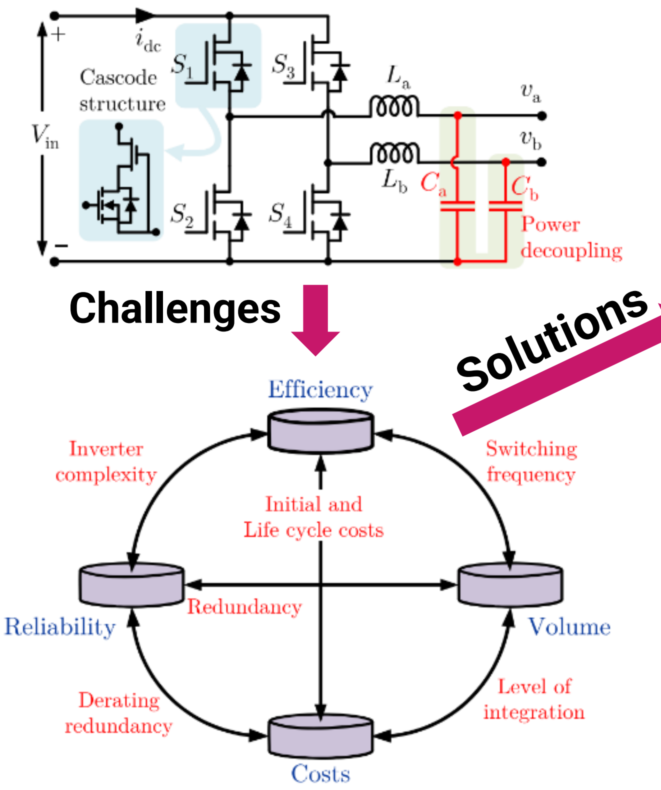
Turn-on transients

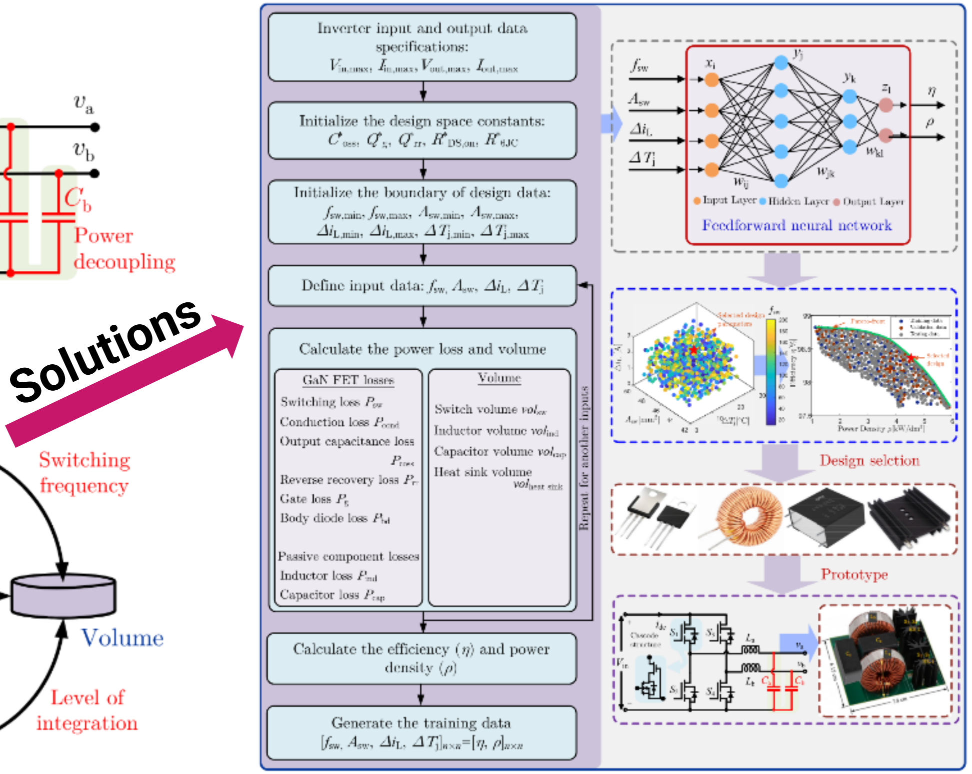


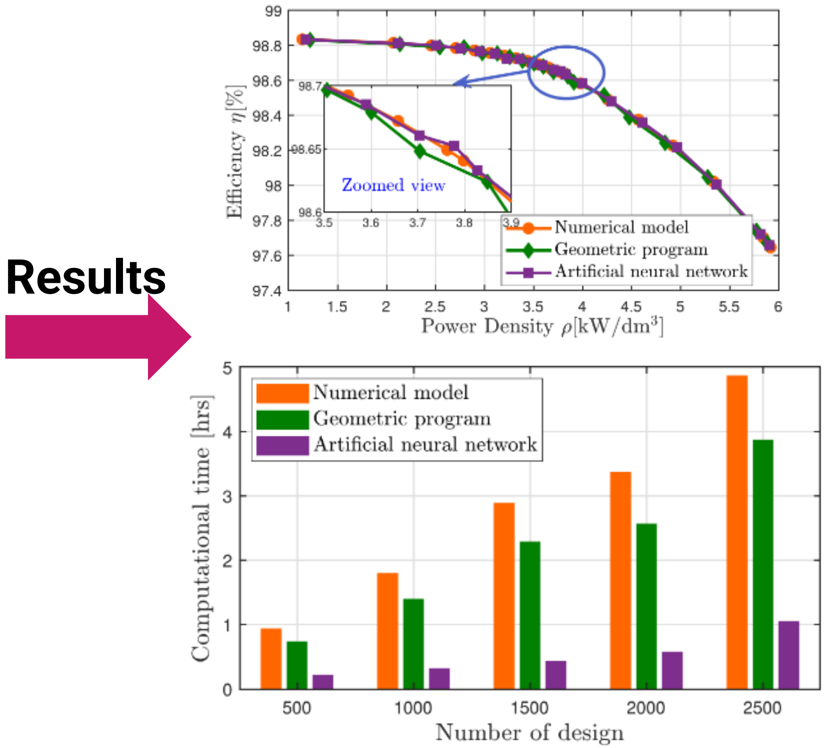
- Nonlinear characteristics of voltages/currents are well modelled by ANN (only 10 neurons!)
- Parameter extraction is the key for accurate modelling so domain knowledge is essential
- RMS errors of transient voltage/current are below 5%

P. Yang, W. Ming, J. Liang, I. Lüdtke, S. Berry and K. Floros, "Hybrid Data-Driven Modeling Methodology for Fast and Accurate Transient Simulation of SiC MOSFETs," in IEEE Transactions on Power Electronics, vol. 37, no. 1, pp. 440-451, Jan. 2022, doi: 10.1109/TPEL.2021.3101713.

AI-enabled digital design: Multi-objective optimisation







- ANN is used to generate a surrogate model of the DC/AC inverter to speed up the optimisation
- Reduction of computation time by 80%

R. Rajamony, S. Wang, G. Calderon-Lopez, I. Ludtke and W. Ming, "Artificial Neural Networks-Based Multi-Objective Design Methodology for Wide-Bandgap Power Electronics Converters," in *IEEE Open Journal of Power Electronics*, vol. 3, pp. 599-610, 2022, doi: 10.1109/OJPEL.2022.3204630.

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Vision: Automated power electronics converter design optimisation

Benefits	Implementation
✓ **Faster design cycles** Reduce iteration time from months to days, fostering innovation ✓ **Enhanced efficiency, reliability and power density** Multi-objective optimisation of power electronics converters ✓ **Cost reduction** Minimise development time and costs through optimised design	✓ **Power device modelling** AI/ML data-driven model generation from characterisation data, digitised datasheets and manufacturer models ✓ **Power converter modelling and optimisation** AI/ML mapping of design to performance space based on a limited number of simulations. Automatic selection of circuit topology, power devices and operating conditions ✓ **Learning loop** Feedback physical prototype validation data to continuously improve design model accuracy

Thank you!

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