UKES2019
UK Energy Storage Conference

Supercapatteries & Power Electronics

The University of Nottingham

Supercapattery Based Energy Storage System

Dr. Christian Klumpner

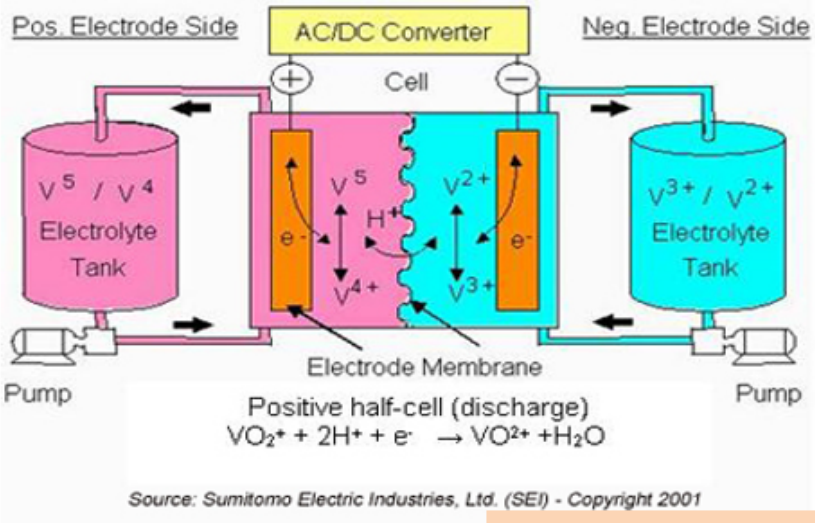
Klumpner@ieee.org

The project this report is based on was funded by E.ON as part of the E.ON International Research Initiative. Responsibility for the content of this publication lies with the author

Energy Storage Systems Generalities

The University of Nottingham

ESS = two components: Energy Store & Energy/Power Converter



Design requirements:
- Required Energy (P vs time) ⇒ Tank size
- **Peak power (v*i)** ⇒ Converter size/surface

Redox flow battery = Electrolyte tanks & Cell (Chemical ⇒Electrical)

Fuel cell = Pressurised H2 tank & Fuel Cell (Chemical ⇒Electrical)

Compressed air= Pressure tank & Turbine (Chemical ⇒Mechanical)

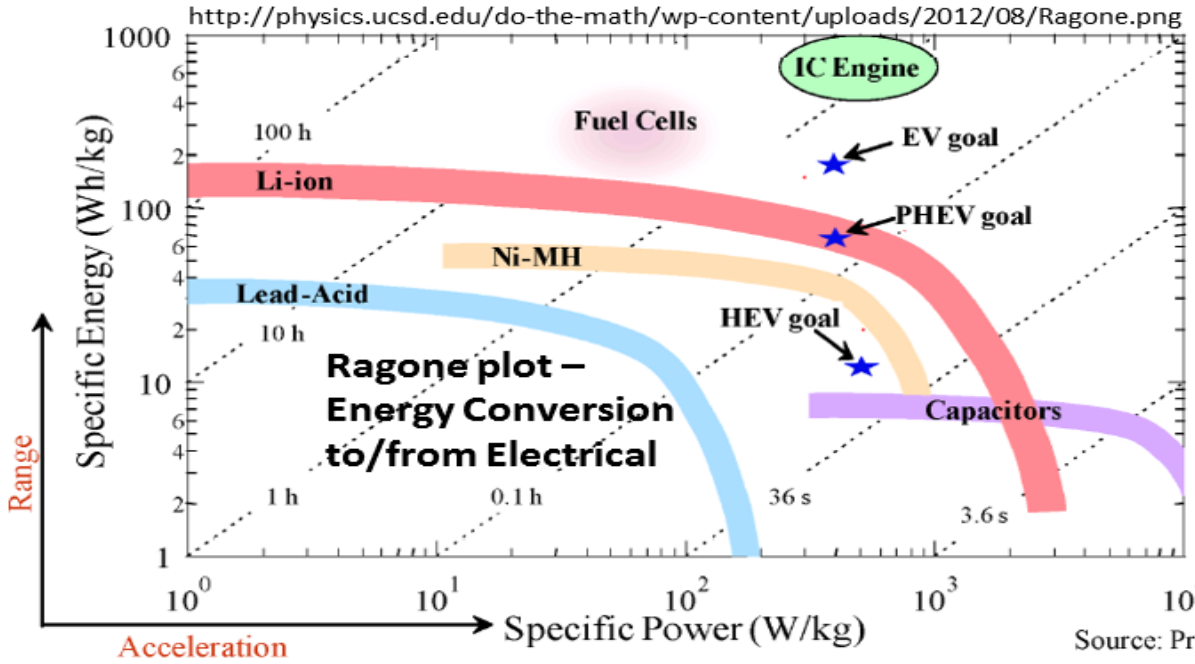
Gasoline sys = Fuel tank & Combustion Engine (Chemical ⇒Mechanical)

Battery&Supercaps = Electrode material (Chemical ⇒ Electrical)

Electrode surface vs thickness of electrode material

Energy Storage Systems Generalities

The University of Nottingham



Source: Product data sheets

$$\text{Specific power} = \frac{\text{Power of engine (converter)}}{\Sigma \text{ weight engine + fuel + tank}}$$

$$\text{Specific energy} = \frac{\text{Total energy in store/tank}}{\Sigma \text{ weight engine + fuel + tank}}$$

Lead acid = 30Wh/kg
NiMH = 50 Wh/kg
Li-ion = 140Wh/kg
Supercapacitors: 5Wh/kg

} rechargeable

but specific power is 10kW/kg (10x larger than Li-ion)

Non-recheargeable batteries have 2x higher specific energy

Internal combustion engine = 800 Wh/kg for petrol (non-rechargeable) to electrical

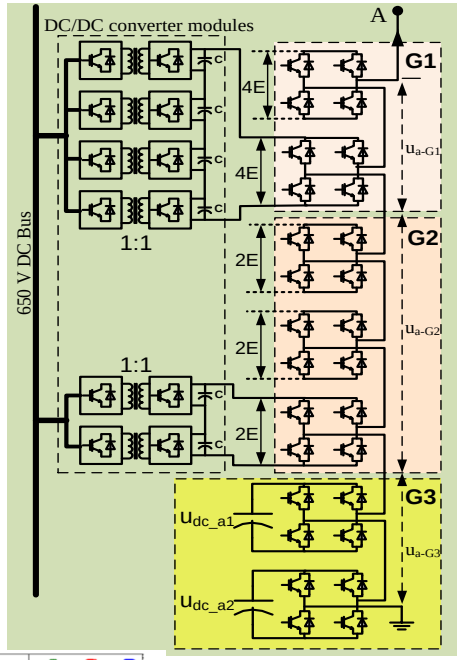
Final use of Energy? If electrical, conversion efficiency needs to be considered
Stationary apps: Round trip efficiency is very important (needs wide power range)
Oversizing the converter will result in poor efficiency at light loading!

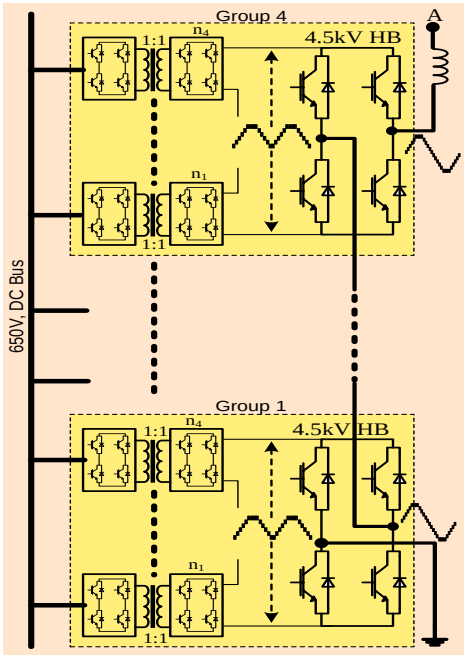
Evaluation of Performance of Candidate Converter Topologies

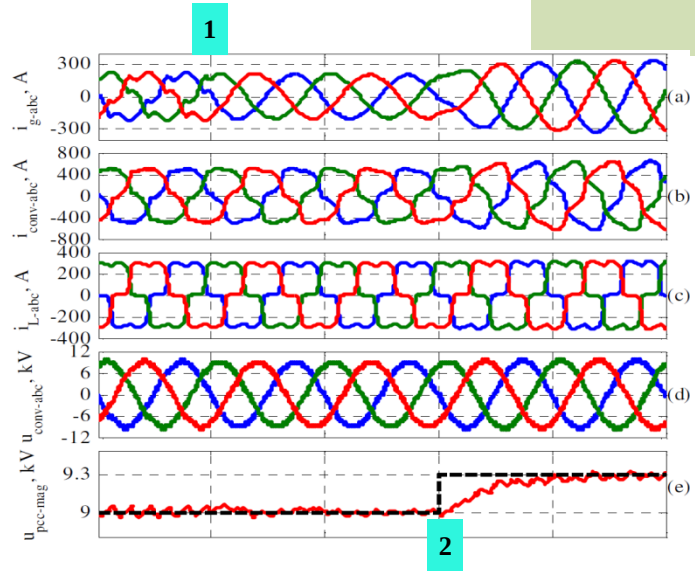
The University of Nottingham

Simulation Based Study

- Identify suitable candidates
- Implement simulation models
- Design/size (L/C, T/D) components
- Develop converter control
- Harmonic Performance
- Evaluate losses/efficiency
- Select best two candidates for prototyping/experimental evaluation

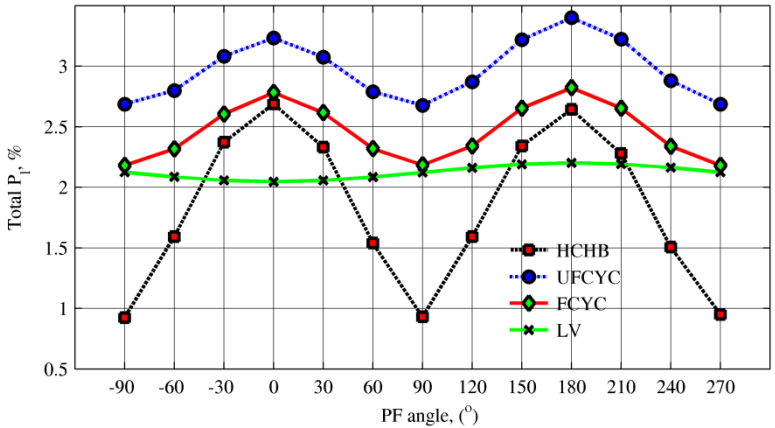






1. Activate harmonic comp.
2. Change PCC voltage

Estimated Power Losses

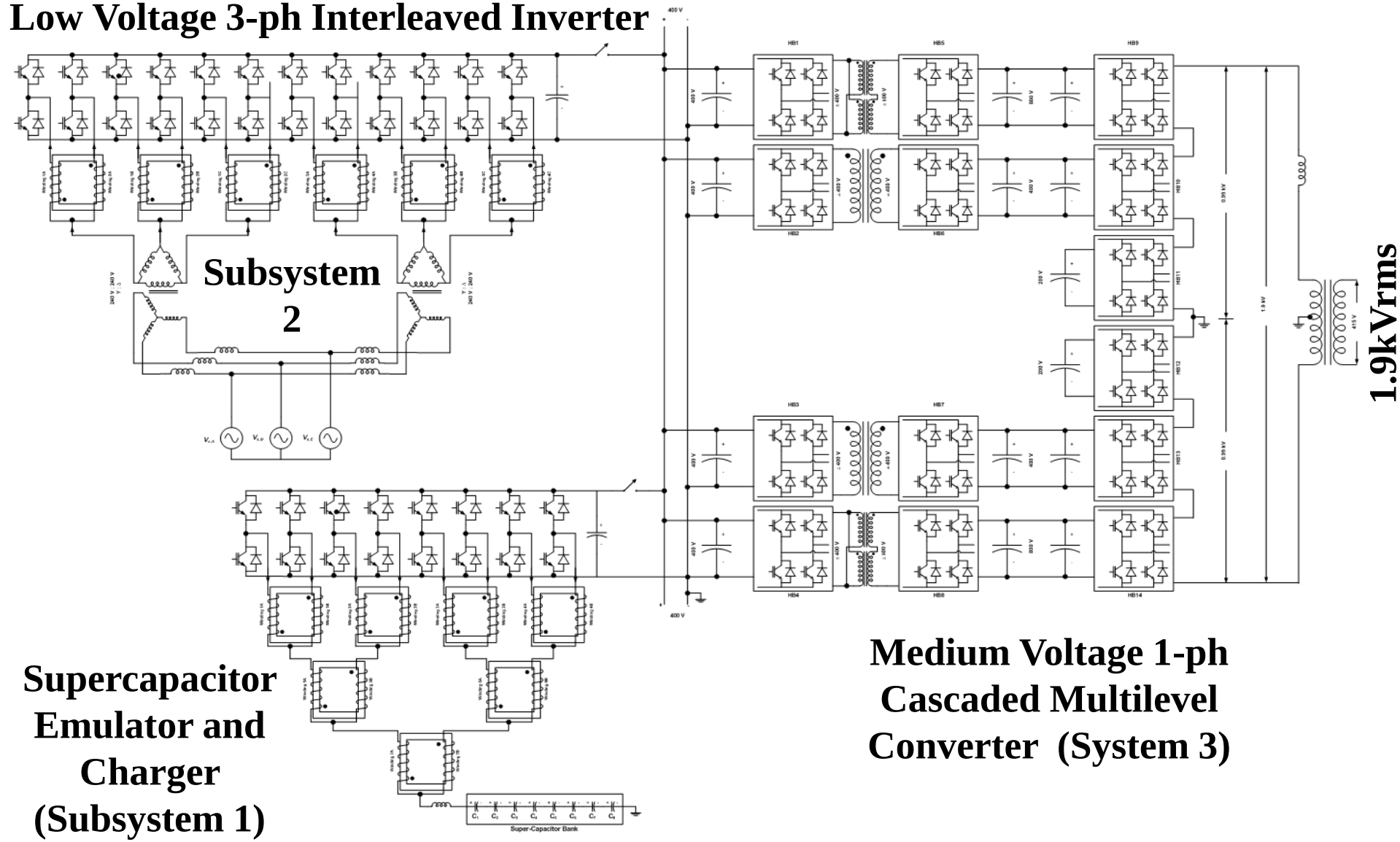


Experimental Evaluation

The configuration of the 25kW test rig

The University of Nottingham

Low Voltage 3-ph Interleaved Inverter



Supercapacitor Emulator and Charger (Subsystem 1)

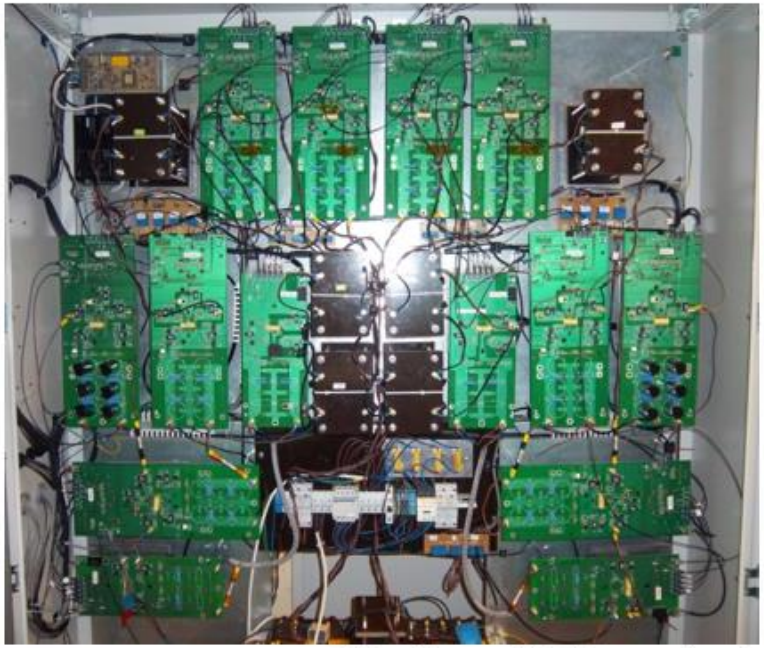
Medium Voltage 1-ph Cascaded Multilevel Converter (System 3)

Experimental Evaluation

The implementation of the 25kW test rig

The University of Nottingham

Subsystem
2



Medium Voltage 1-ph
Cascaded Multilevel
Converter (System 3)

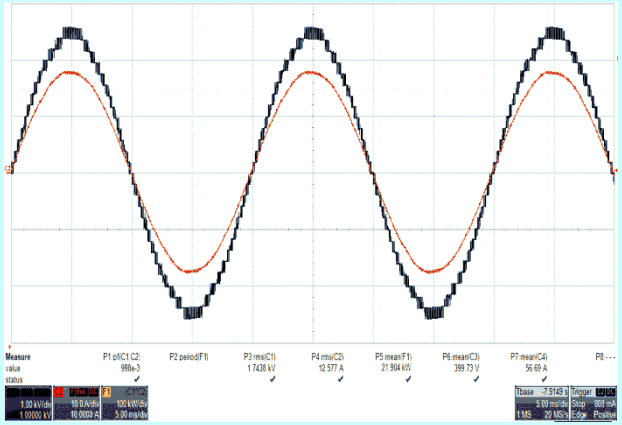
Supercapacitor Charger
(Subsystem 1)

Experimental Evaluation

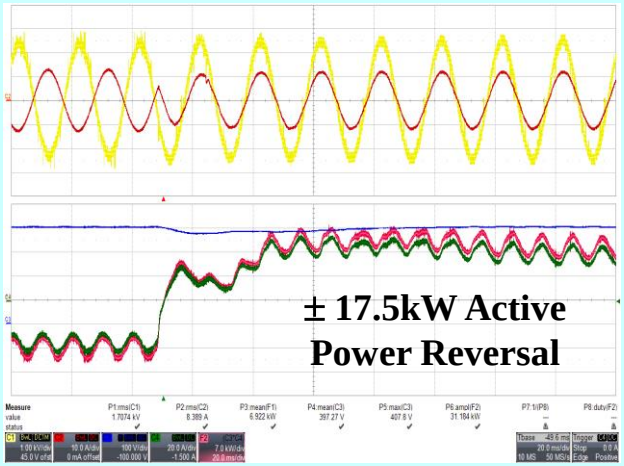
Steady-state and Step transient response

The University of Nottingham

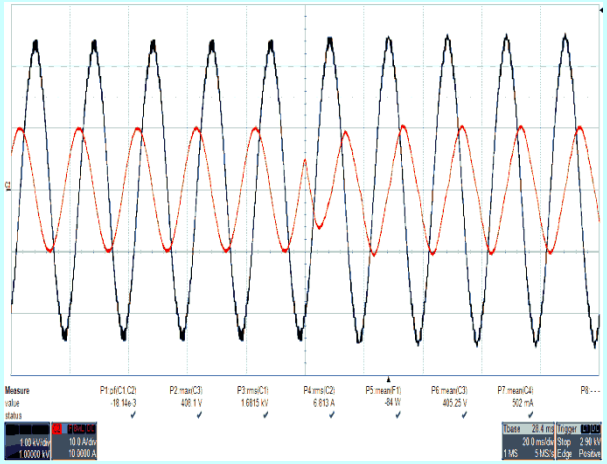
30 voltage levels
1.744 kVrms/22kW



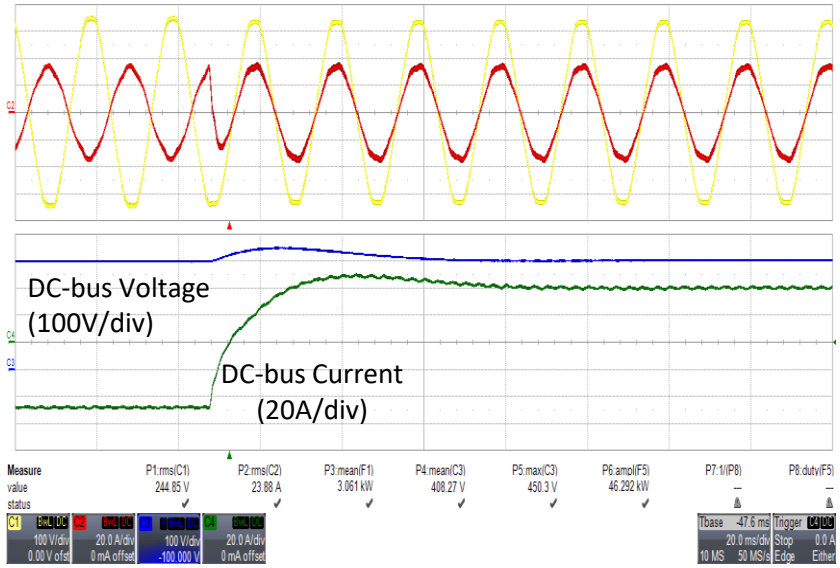
Cascaded Multilevel



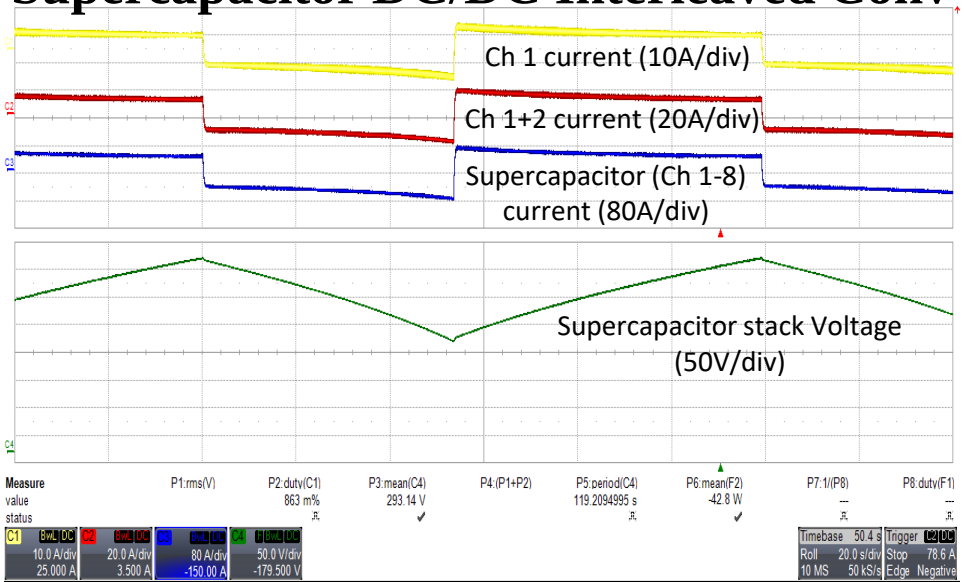
Lead-to-Lag reactive power transient



Interleaved Modular Inverter



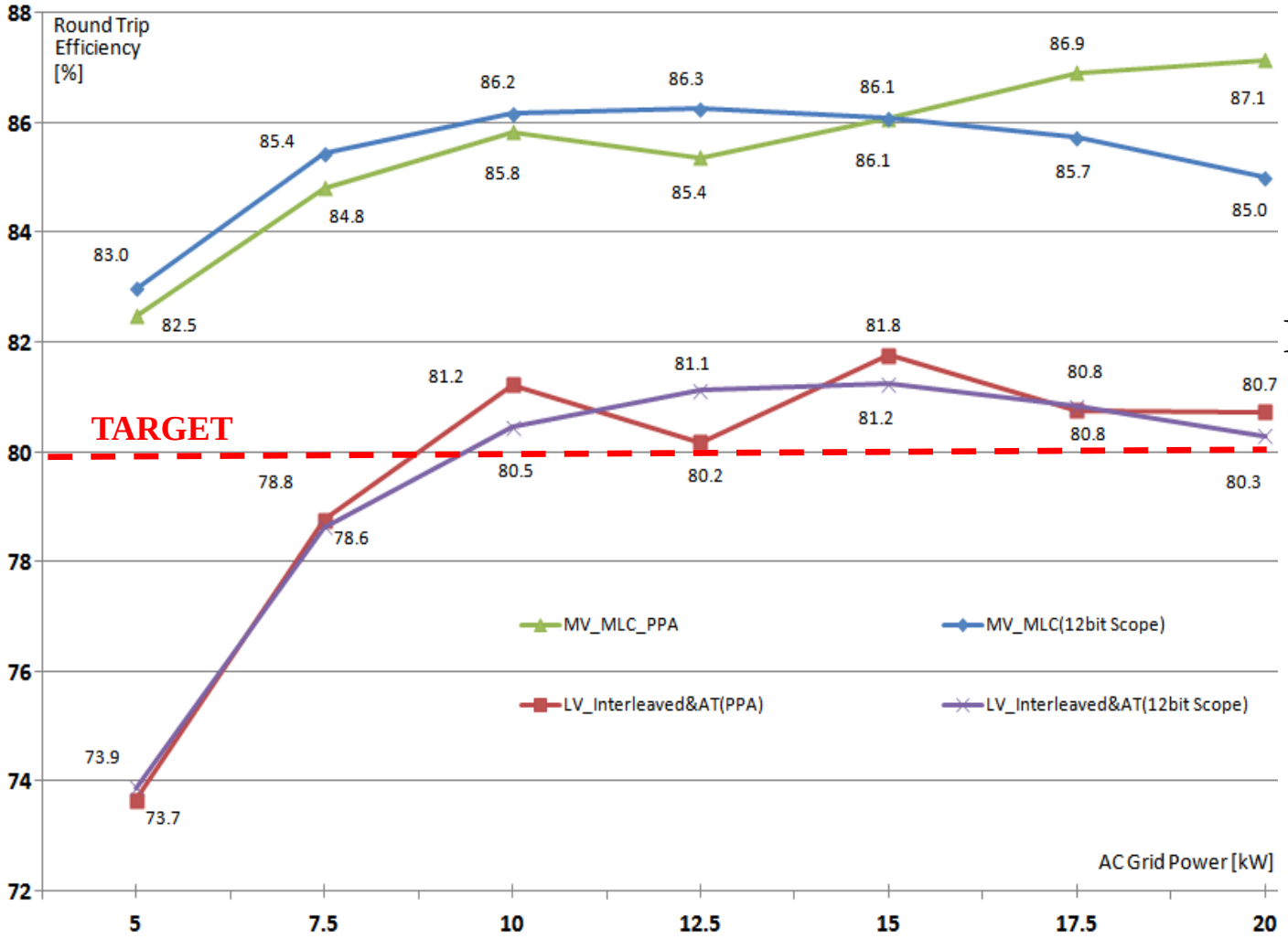
Supercapacitor DC/DC Interleaved Conv



Experimental Evaluation

Round-trip System Efficiency

The University of Nottingham



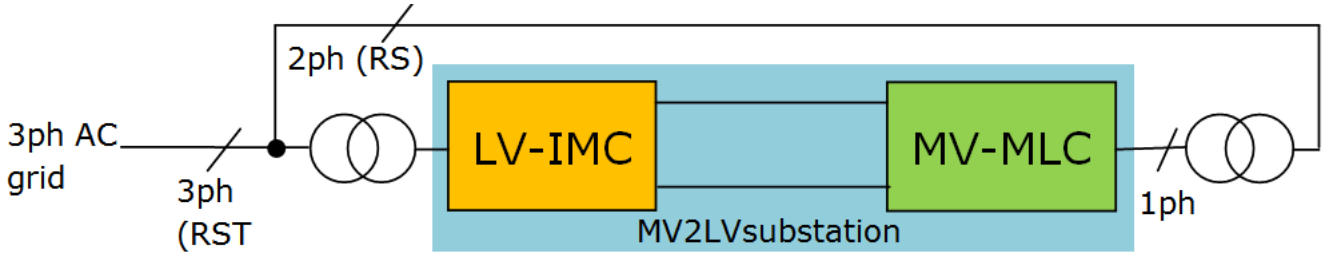
MV Cascaded Multilevel Converter

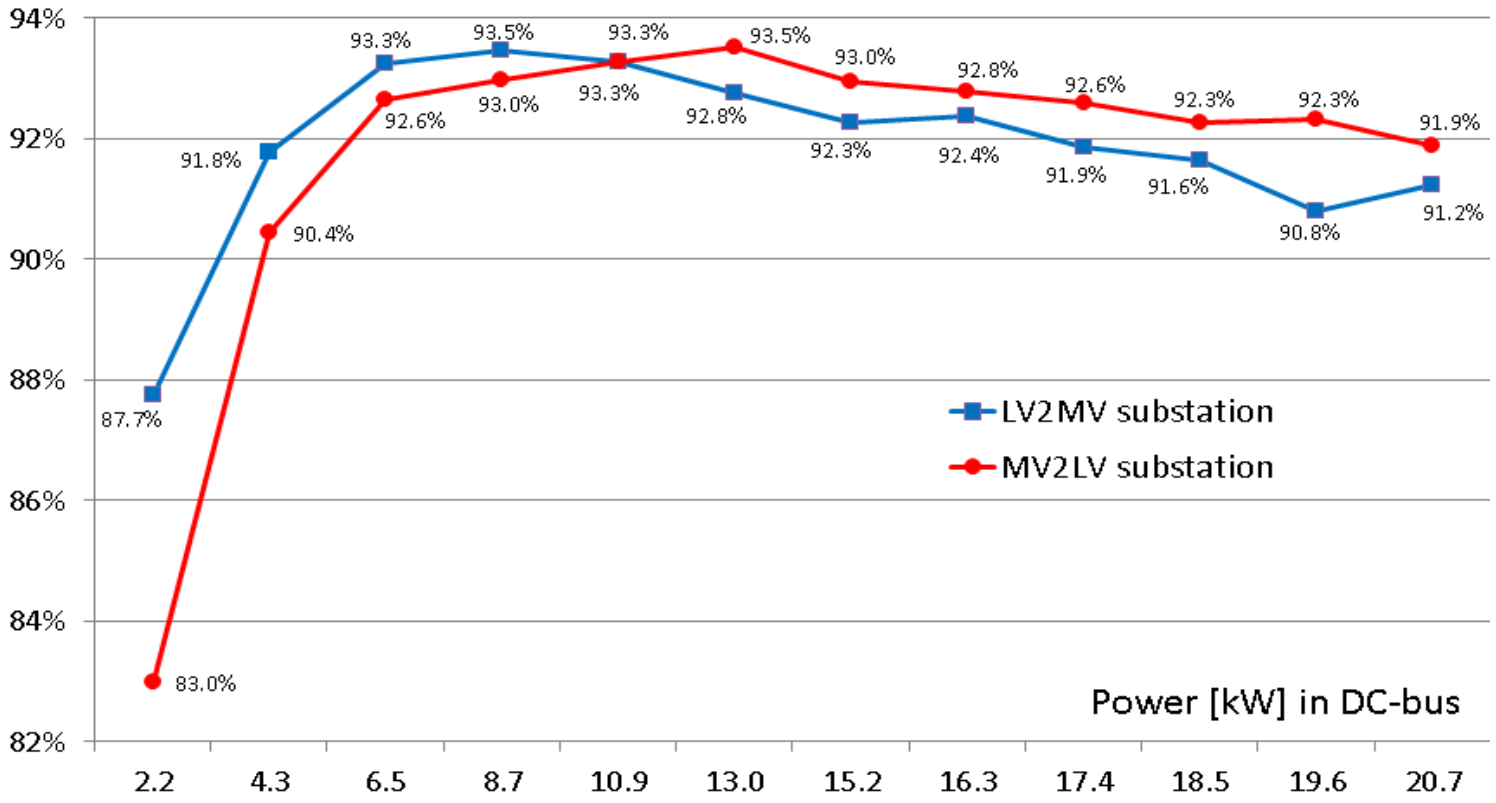
LV Interleaved Modular Converter

Experimental Evaluation

Efficiency in Substation Mode

The University of Nottingham





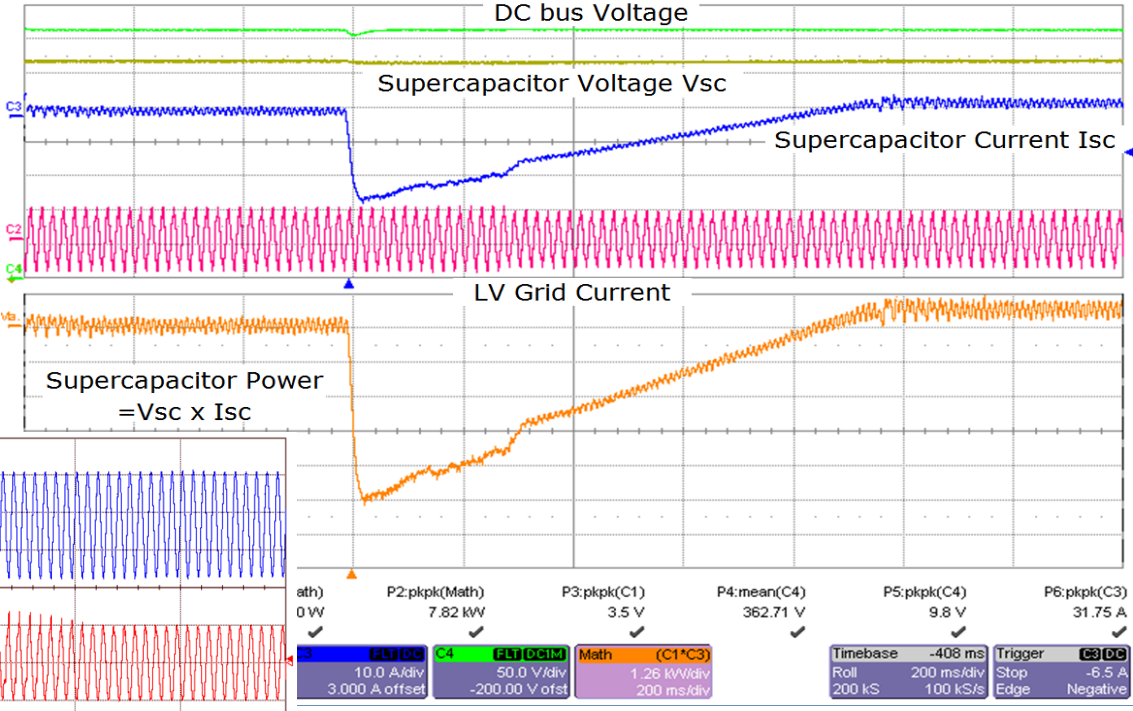
Experimental Evaluation

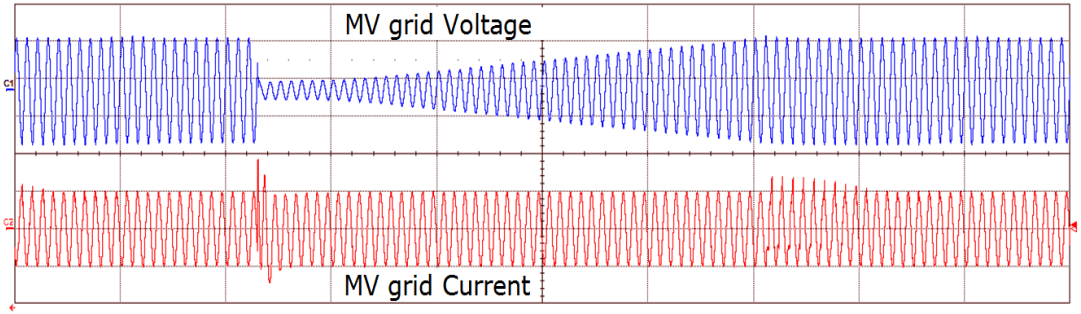
Transient operation during MV Grid Fault

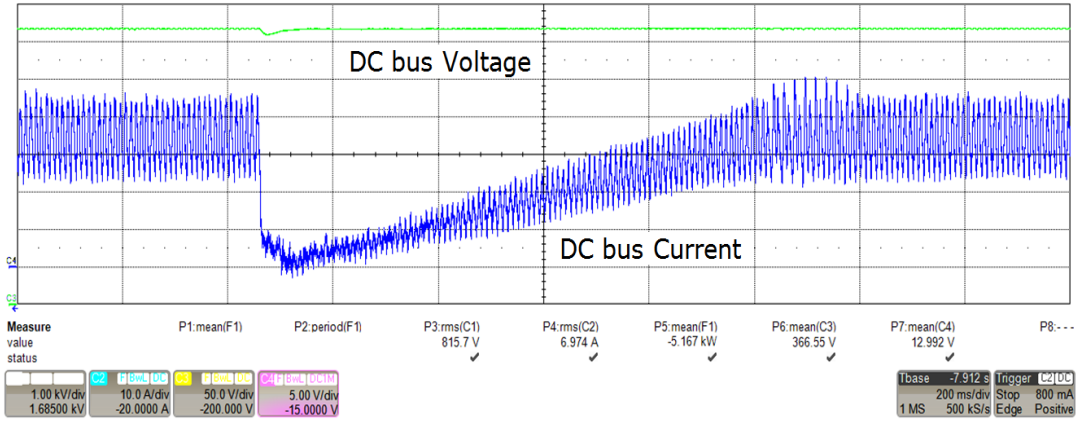
The University of Nottingham

Full System Tests:

MV grid voltage fault ride-through





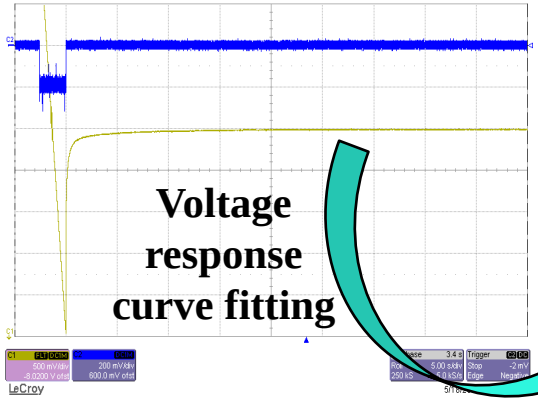


- MV-LV sides full decoupling due to the HF isolating transformer
- The energy storage bridges the load power during short grid failures

The Versatility of Power Electronics - emulating real SCAPs behaviour

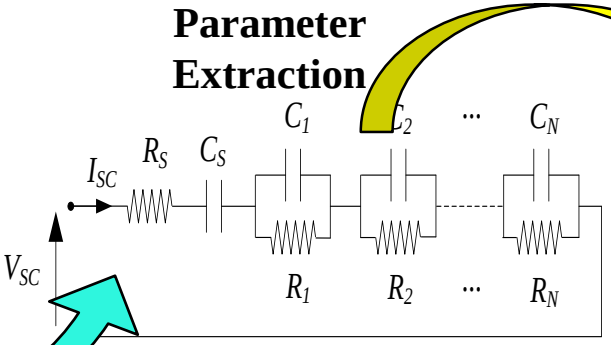
The University of Nottingham

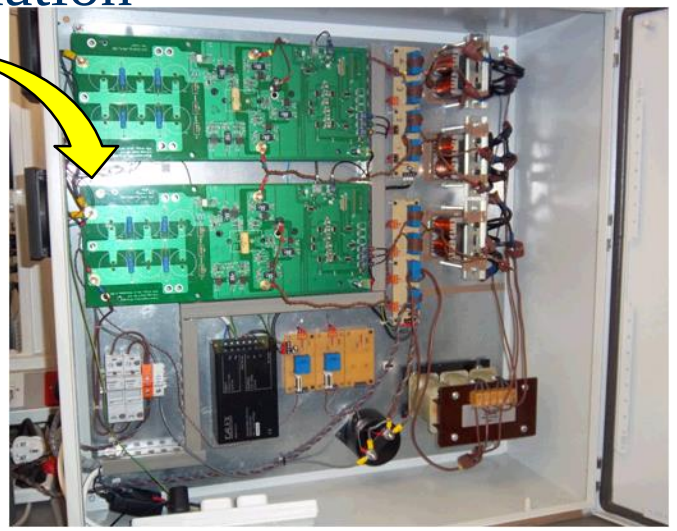
Parameter Extraction & Scale-up Device Emulation



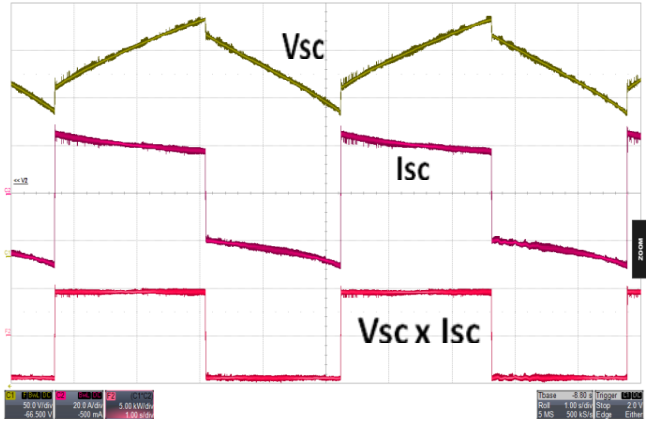
Voltage response curve fitting

Parameter Extraction

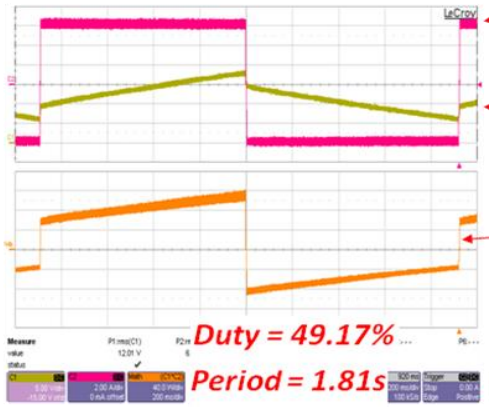




5kW constant power cycle



Real Supercapattery stack



Supercapattery emulator