Energy management for high capacitance devices to support EV

E-mobility NSR

30 March 2012
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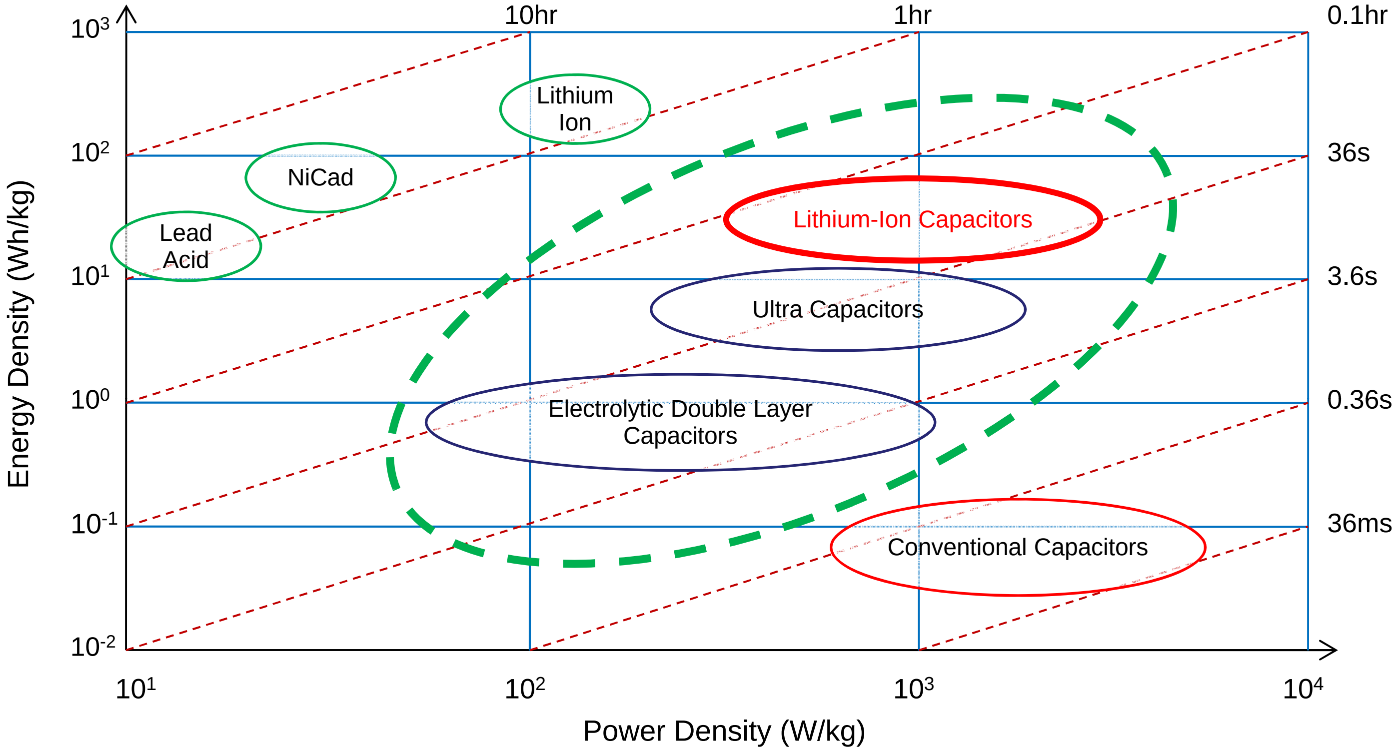
Newcastle University

Ragone plot



10hr
1hr
0.1hr
36s
3.6s
0.36s
36ms
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
Energy Density (Wh/kg)
Lithium Ion
NiCad
Lead Acid
Lithium-Ion Capacitors
Ultra Capacitors
Electrolytic Double Layer Capacitors
Conventional Capacitors
10^1
10^2
10^3
10^4
Power Density (W/kg)

Devices

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- Capacitance: 5F – 3000F
- Cell voltage: 2.5V – 3.8V
- ESR: <1mΩ
- Volume 500cm^3 – 20cm^3
- Chemistry Organic electrolyte, Li-ion electrode…
- Peak continuous current 300A-700A

Maxwell 2700F

JSR micro 2200F Li-ion capacitor

Automotive Applications

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- Short time constant energy cycling
  - Acceleration
  - Regenerative braking
  - Smart grid filter to protect bulk battery from wear out
  - Power steering
  - Starter motor for turbine

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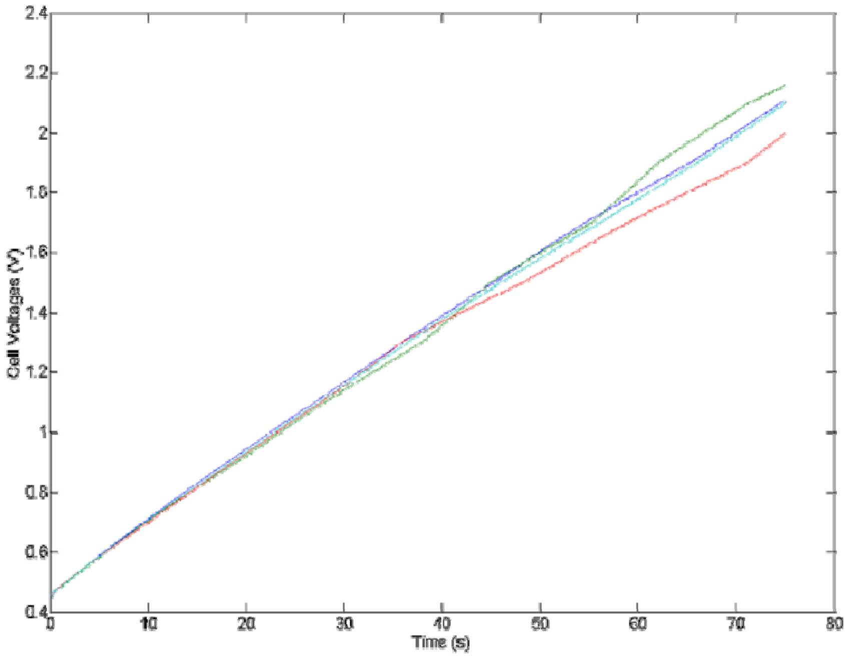
Capacitor Cell Voltage Equalisation Schemes

- Individual cell voltage is low, cells must be connected in series to attain a system level voltage
- Manufacturing tolerances result in mismatched values for nominal capacitance, series resistance and self discharge
- The result under series connected charging is a mismatch in individual cell voltages
- Over voltage on a supercapacitor cell will cause the cell to fail and can result in explosion
- **Voltage equalisation negates this risk increasing reliability and allows maximum energy storage potential to be realised**



Cell voltages of four series connected supercapacitors over 75s of charging at 60A

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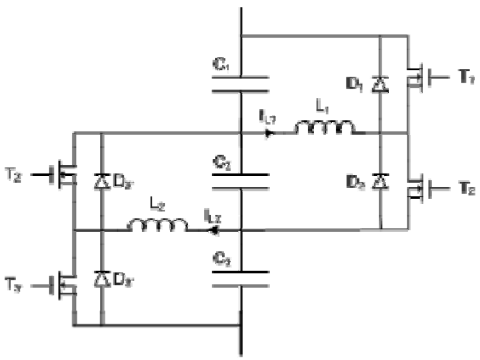
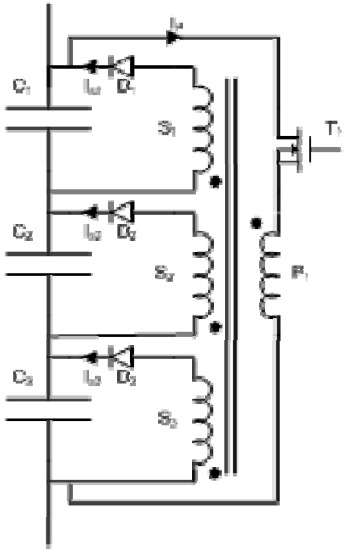
Existing Equalisation Schemes

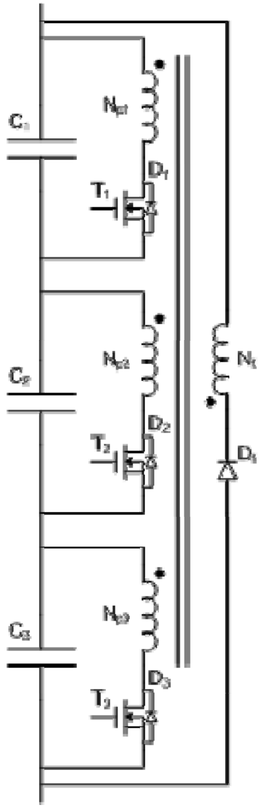
- Numerous schemes for equalisation of battery and supercapacitor systems have been published



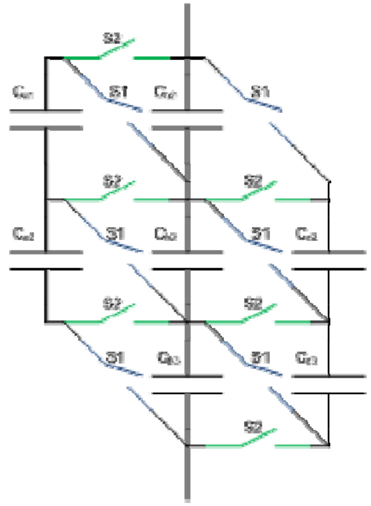
Buck-boost converter



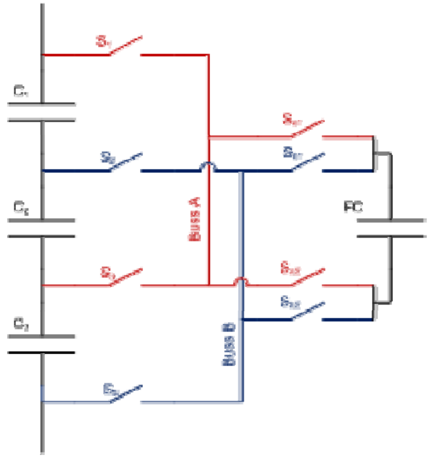
Flyback converter with distributed secondary



Fwd converter with distributed primary



Series/parallel connection



Flying capacitor

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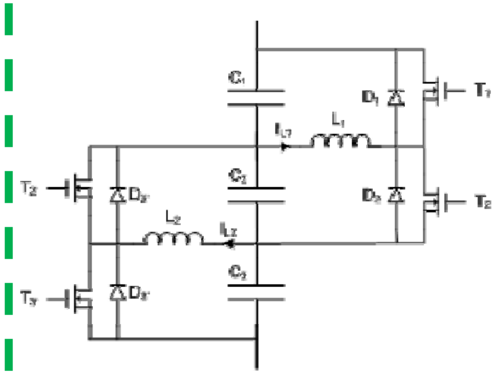
Existing Equalisation Schemes

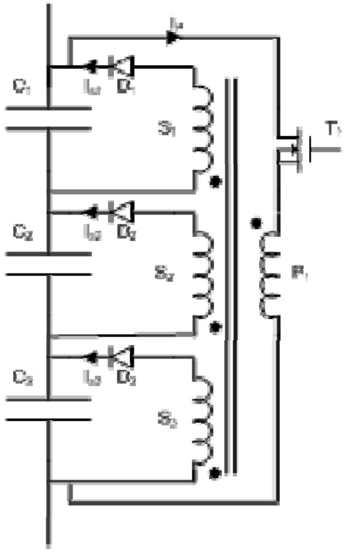
- Numerous schemes for equalisation of battery and supercapacitor systems have been published

Transformer-less

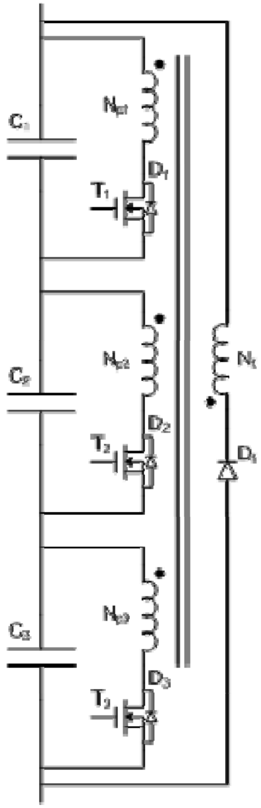


Buck-boost converter

Multi-winding transformer

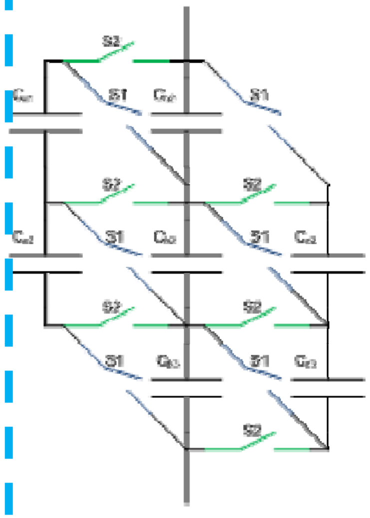


Flyback converter with distributed primary

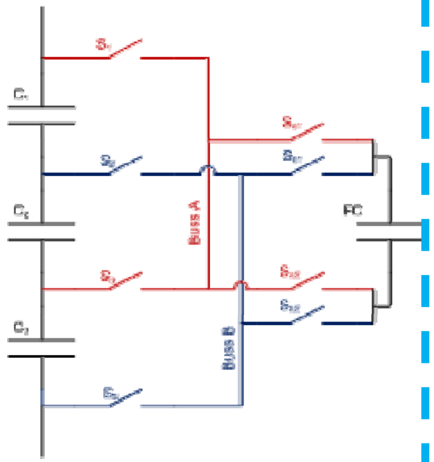


Fwd converter with distributed primary

Inductor-less



Series/parallel connection



Flying capacitor

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Evaluation of Existing Equalisation Schemes

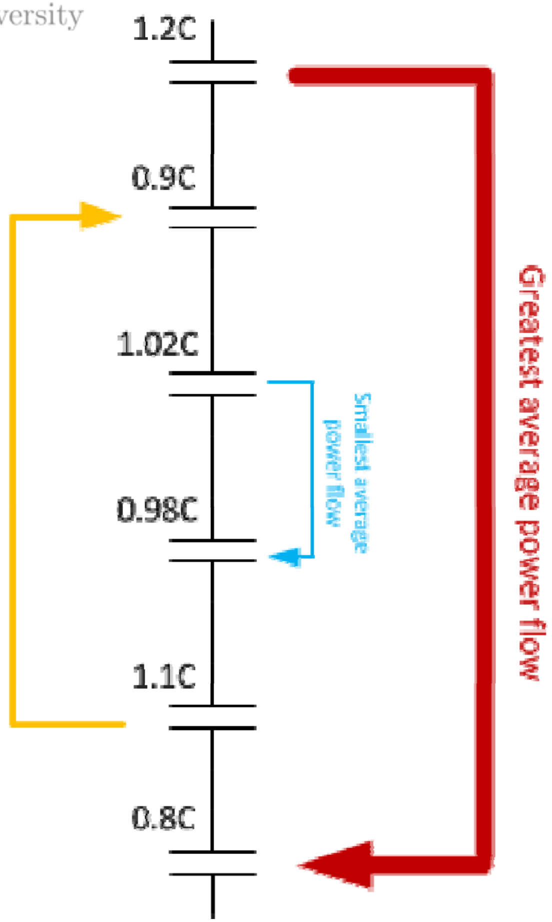
Scheme	Advantages	Disadvantages
Buck-Boost	Greatest number of independent energy paths No complicated magnetic components Modular	No direct energy paths between non-adjacent cells Lots of discrete magnetic components
Flyback	Only one active component Self regulating energy paths	Inefficient equalisation paths Complicated multi-winding transformer Not modular
Forward	More efficient than flyback	Greater number of active components Complicated multi-winding transformer Not modular
Inductor-less schemes	Smaller, lighter	Very slow equalisation rate More modular than transformer schemes

[1] Lambert, S.; Pickert, V.; Holden, J.; Wuhua Li; Xiangning He; , "Overview of supercapacitor voltage equalisation circuits for an electric vehicle charging application,"
URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5729226&isnumber=5728974

A new methodology in equalisation scheme design

- Previously published equalisation schemes have been designed with various engineering goals in mind; modular systems, compact systems, faster systems etc.
- However, all of the systems have something in common; they all treat the individual capacitors identically
- Individual capacitors in a stack are not identical – otherwise there would be no need for an equalisation device!
- Instead of looking at energy flow paths, power flow paths may be considered.

A new methodology in equalisation scheme design



- Consider a stack of six capacitors with a bell curve distribution over 20% of nominal capacitance
- The stack is being charged, discharged or both over a given time period
- For equalisation to occur the greatest average power flow over a given period is between the most dispersed capacitances
- Therefore it is not required to give equal capacity to each energy flow path
- Reducing overall capacity in the equalisation scheme reduces mass, size and component count

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Practical realisation

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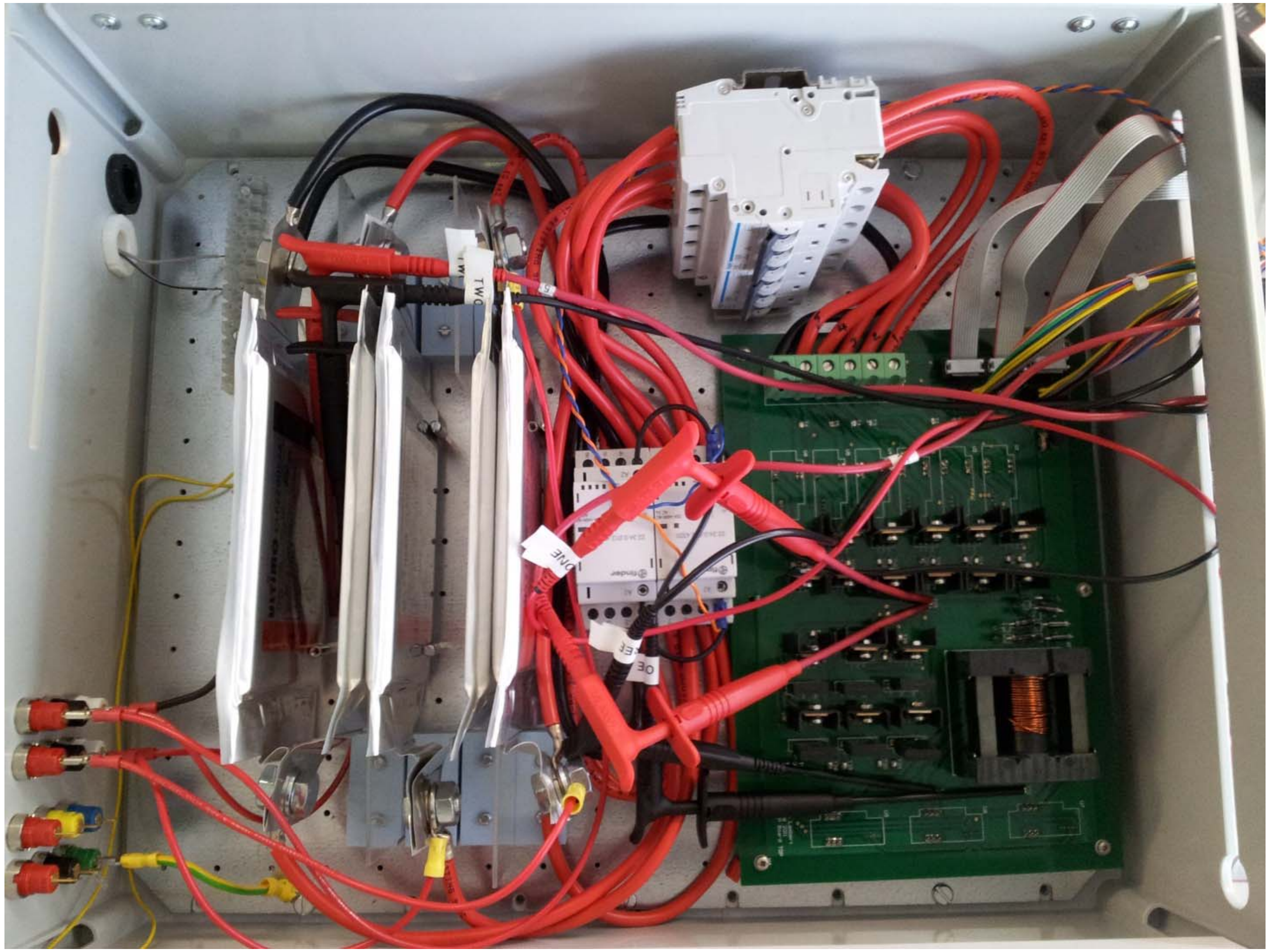
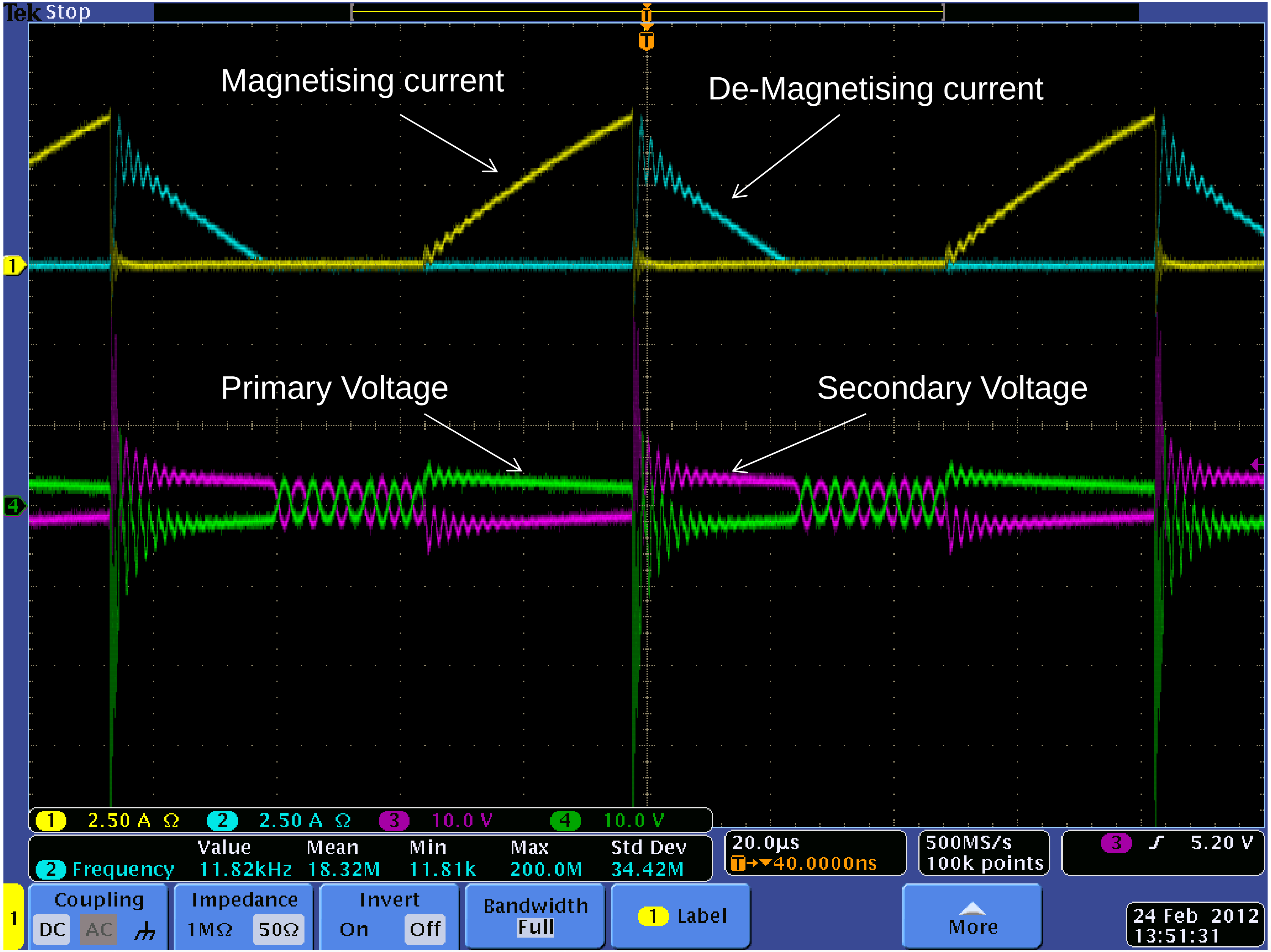
Practical realisation



Results

f = 11kHz
I_{pk} = 5A
Q = 0.1mC



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Conclusions

- High capacitance devices are ideal for short time constant energy storage applications such as regenerative braking, acceleration and fast charging
- As with battery technology there are considerable design considerations regarding protection and energy management of the cells
- A number of voltage equalisation schemes have been proposed but all have significant power level headroom
- An equalisation scheme which is based upon power flow considerations has been proposed and tested and shown to be a good candidate for lowering power headroom for equalisation

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