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BARCELONA
17th-20th November 2013

Safe DRIVE
ADVANCED HYBRID POWERTRAINS

SAFEDRIVE

A Platform Power Management System and Low Voltage drive Train for Hybrid and Electric Vehicles

Tim Crocker — Scimar Engineering Ltd
Cedric De Cauwer — Vrije Universiteit Brussel

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SAFEDRIVE concept

VEHICLE INTEGRATION

Advantages of the SAFEDRIVE modular design around a high torque / low speed electric motor.

SIMPLE MECHANICAL INTEGRATION ⇒

- Compact motor design.
- No gearbox
- Lower DC voltage
- Modular design

EASY ELECTRONIC INTEGRATION ⇒

- Simple user interface
- Multiple configurations
- Friendly diagnosis
- Modular configuration

PROJECT BACKGROUND

QUICK PROTOTYPING : Lower time and effort during the prototype development will end in a reduced Time To Market.

LOW DEVELOPMENT COST : Reducing the cost will reduce the cost and the payback time opening the electrical vehicle to new markets .

BEST ADAPTATION: With modular design and easy parameterization the vehicle will provide the best possible solution for the application .

SIMPLE MECHANICHAL SOLUTION: The maintenance and running cost of the vehicles will increase the profitability.

PROJECT BACKGROUND

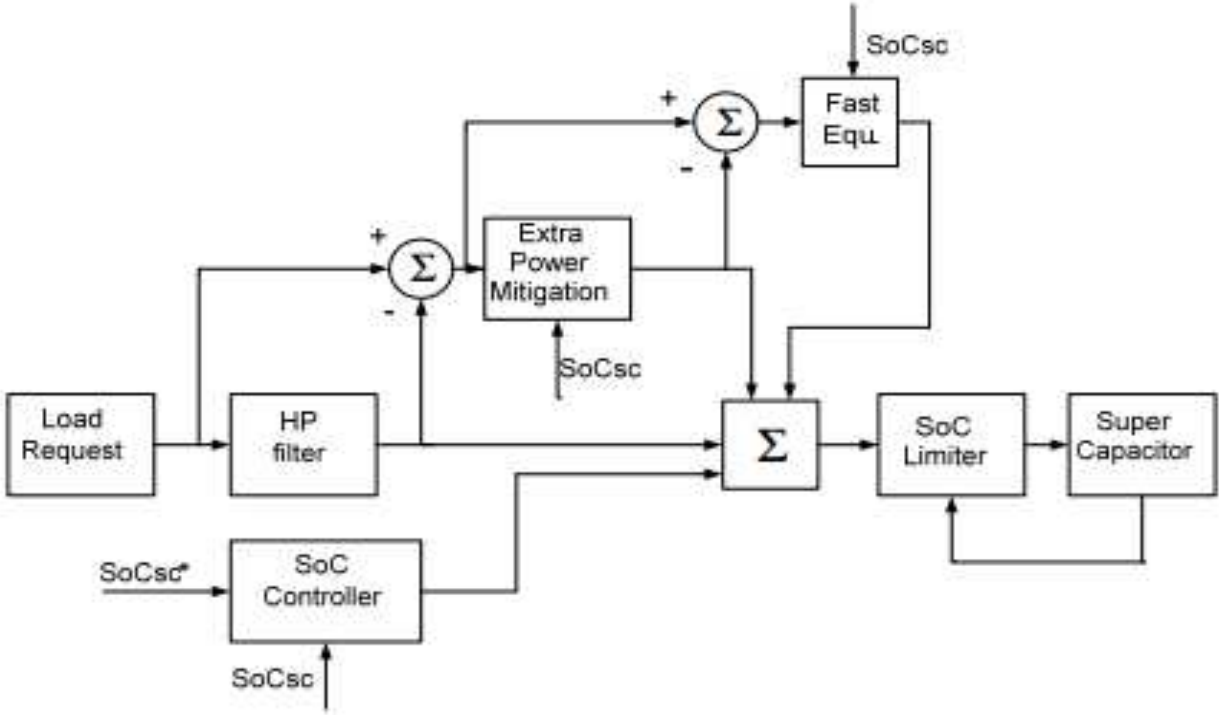
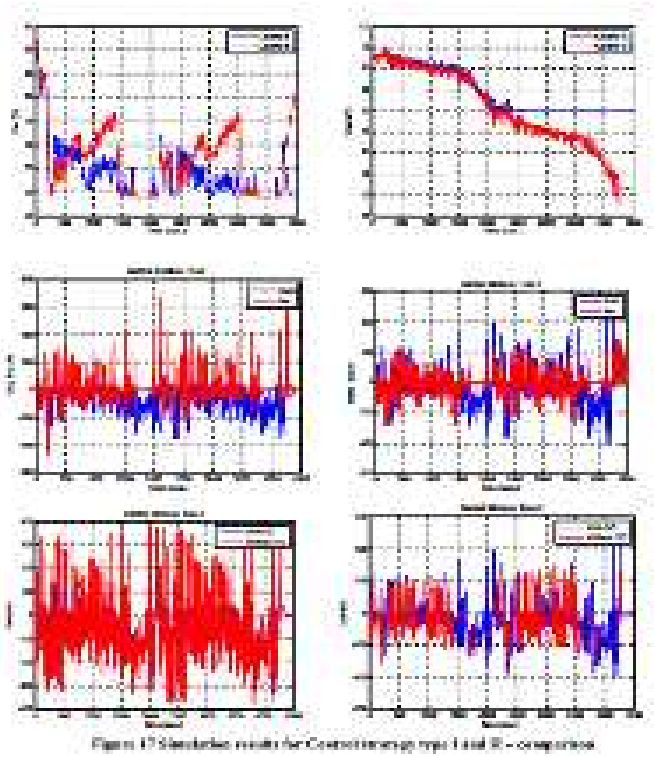


Figure 10. Owerview of the strategies type I

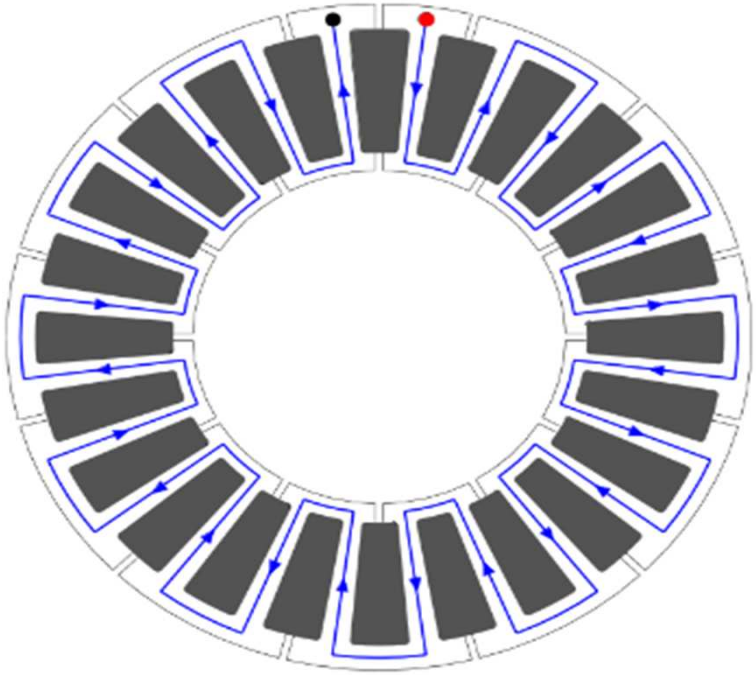


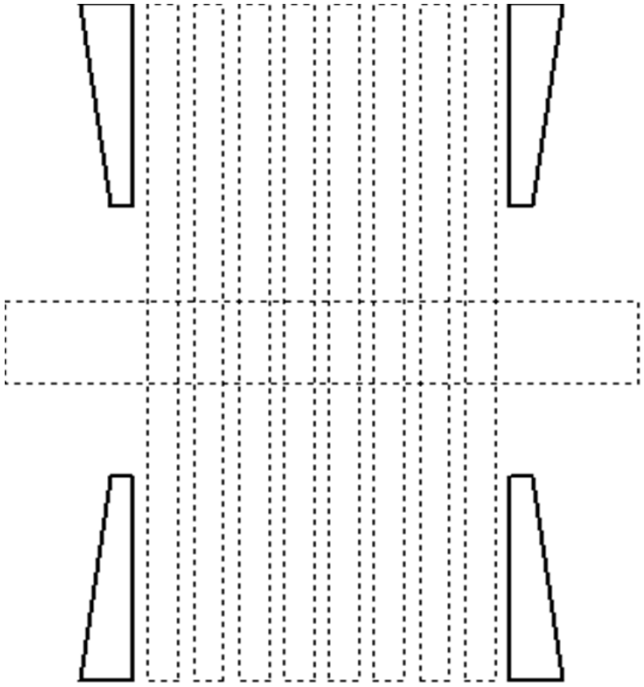
Example of work on control systems
by project partner Novamina (Croatia)

PROJECT BACKGROUND

- **Split-Pi UDIO** — High efficiency low voltage (60V) bidirectional Boost-Buck DC-DC Converters
- **Electrochemistry** — Cell voltages of batteries and ultra-capacitors are a few volts
- **Energy Density** — High voltage packs have a higher percentage of packing material
- **Reliability** — Fewer elements in the chain to fail
- **SAFETY** — "48V" electric vehicles have excellent safety and reliability record
- **Cost of Safety** — High voltage systems have a high cost of safety implementation
  High current copper and aluminium conductors not so expensive
- **'HV MYTH'** — Electric motors do not need high voltages: only $\mathbf{B_{pk}}$ and $\mathbf{J_{pk}}$ matter
- **'MC' MOTOR** — Mutually Coupled motors as paper concept
  Alternative for permanent magnet motors for direct drive

MUTUALLY COUPLED MOTOR





Rotor or stator disc

Dark is soft magnetic composite
Light is aluminium, structure and conductor
Blue is current path through aluminium

Motor stack

Interleaved rotor and stator discs
Flux return rings at ends

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MUTUALLY COUPLED MOTOR

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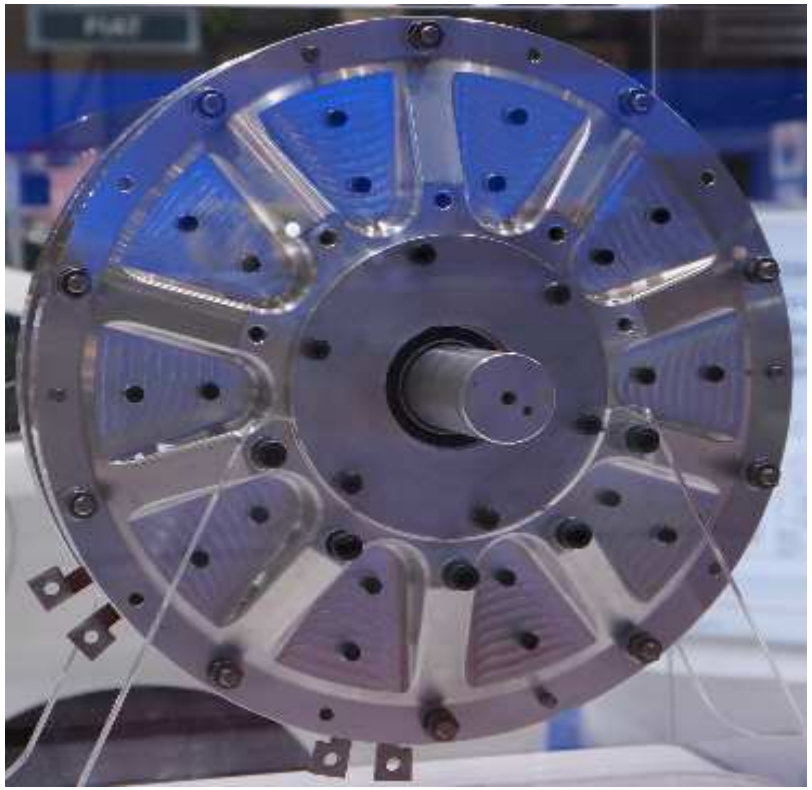

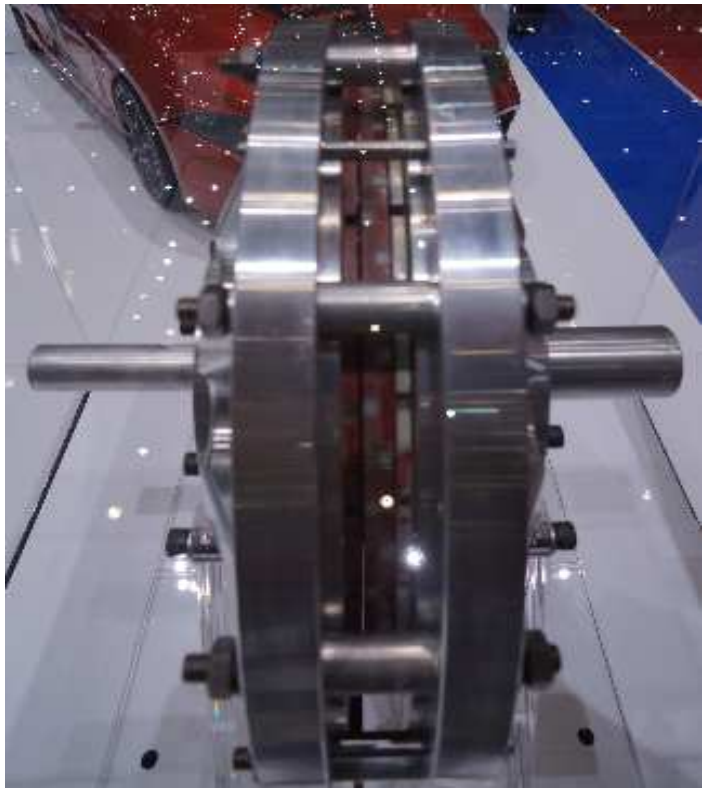

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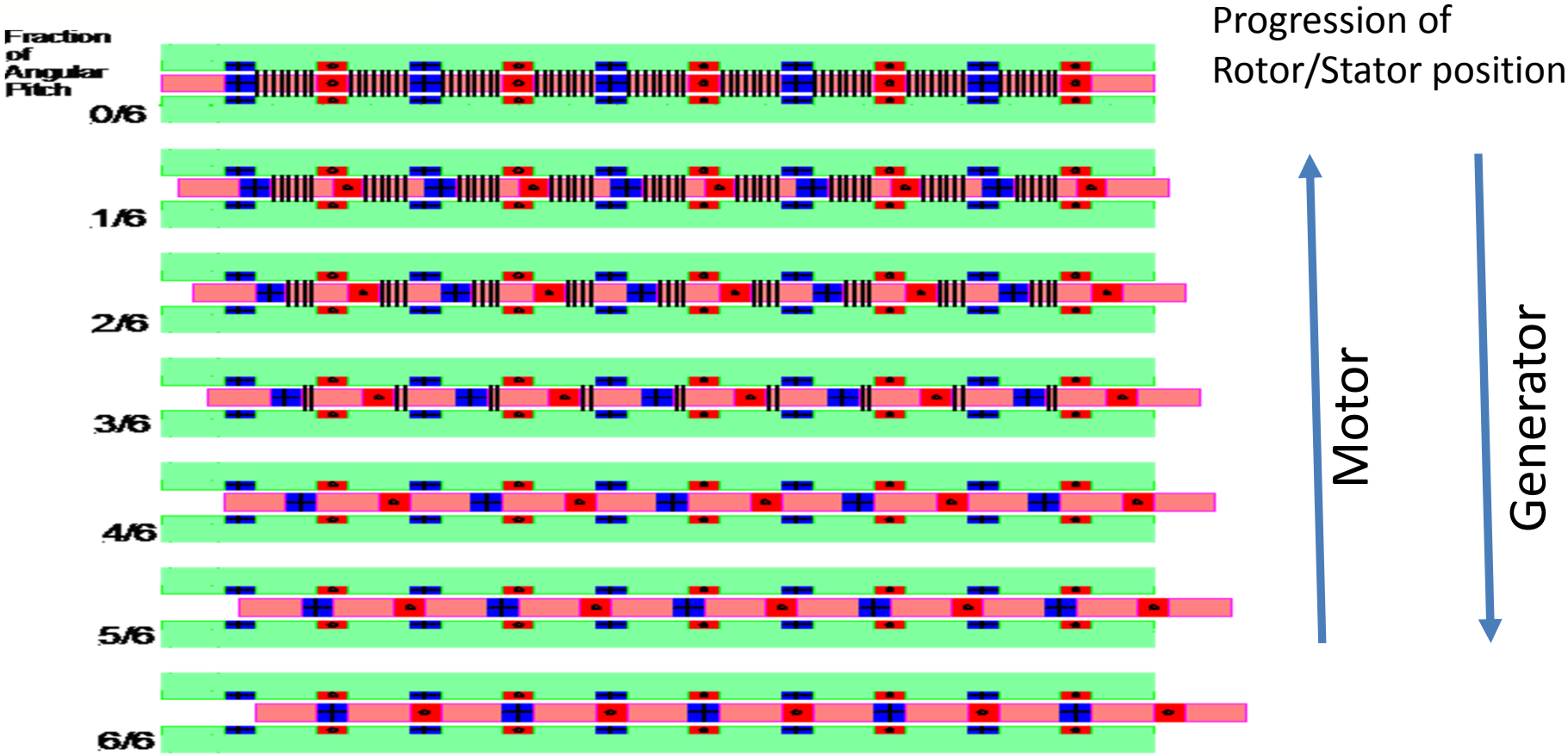
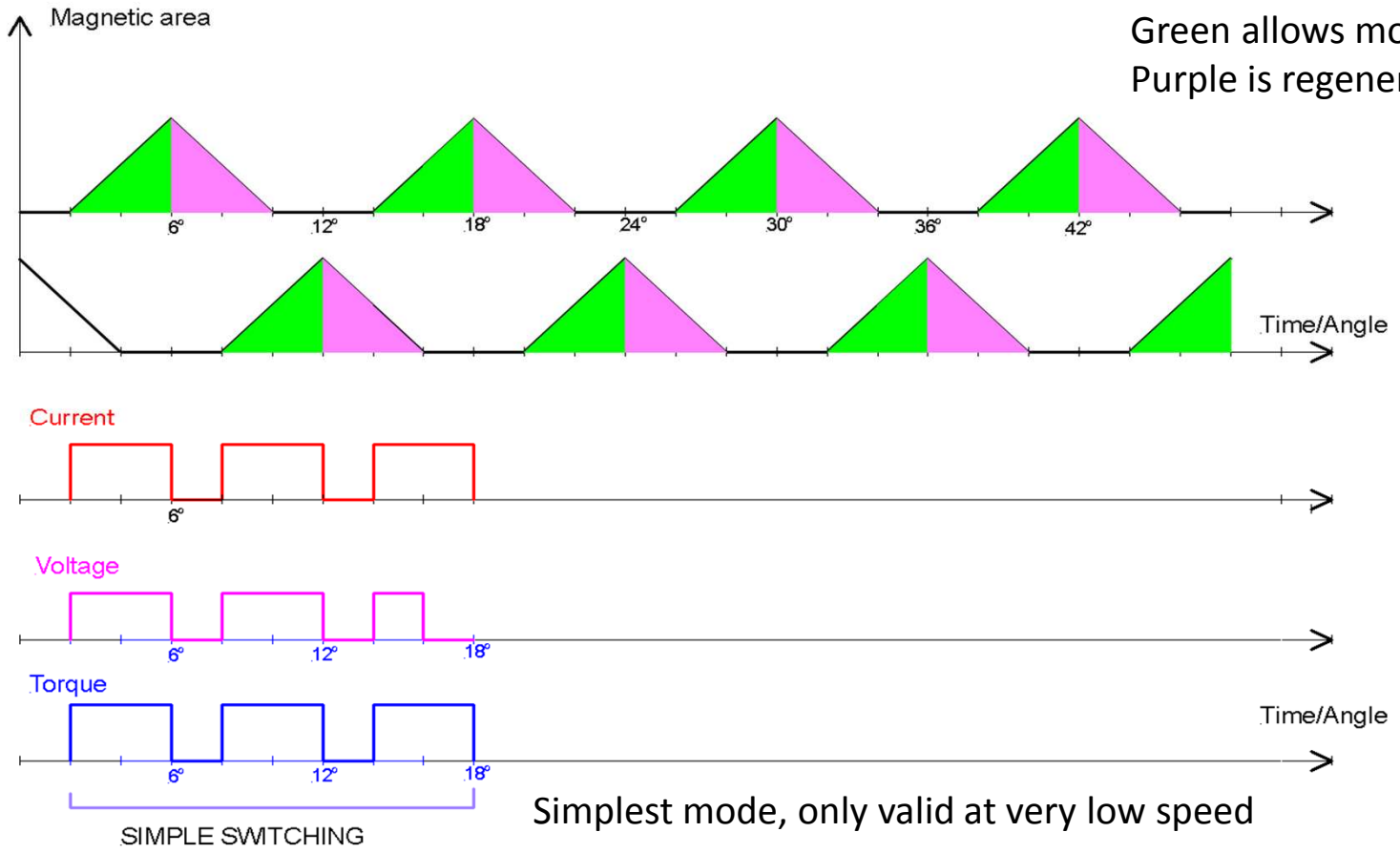
MUTUALLY COUPLED MOTOR



MUTUALLY COUPLED MOTOR



Green allows motor mode
Purple is regeneration

Simplest mode, only valid at very low speed

MUTUALLY COUPLED: MOTOR THEORETICAL PROPERTIES

- $Torque \propto Current^2$
- $Motor\ voltage \propto Current\ .\ Speed$
- $\frac{Torque}{Mass} = B_{pk}\ .J_{pk}\ .R/(8\ .(\rho_{Fe}.\rho_{Al}))$
- $\frac{Torque}{Mass} \cong 28\ Nm/kg$

for R=147mm, Bpk = 1.7 T

Jpk = 14.8A

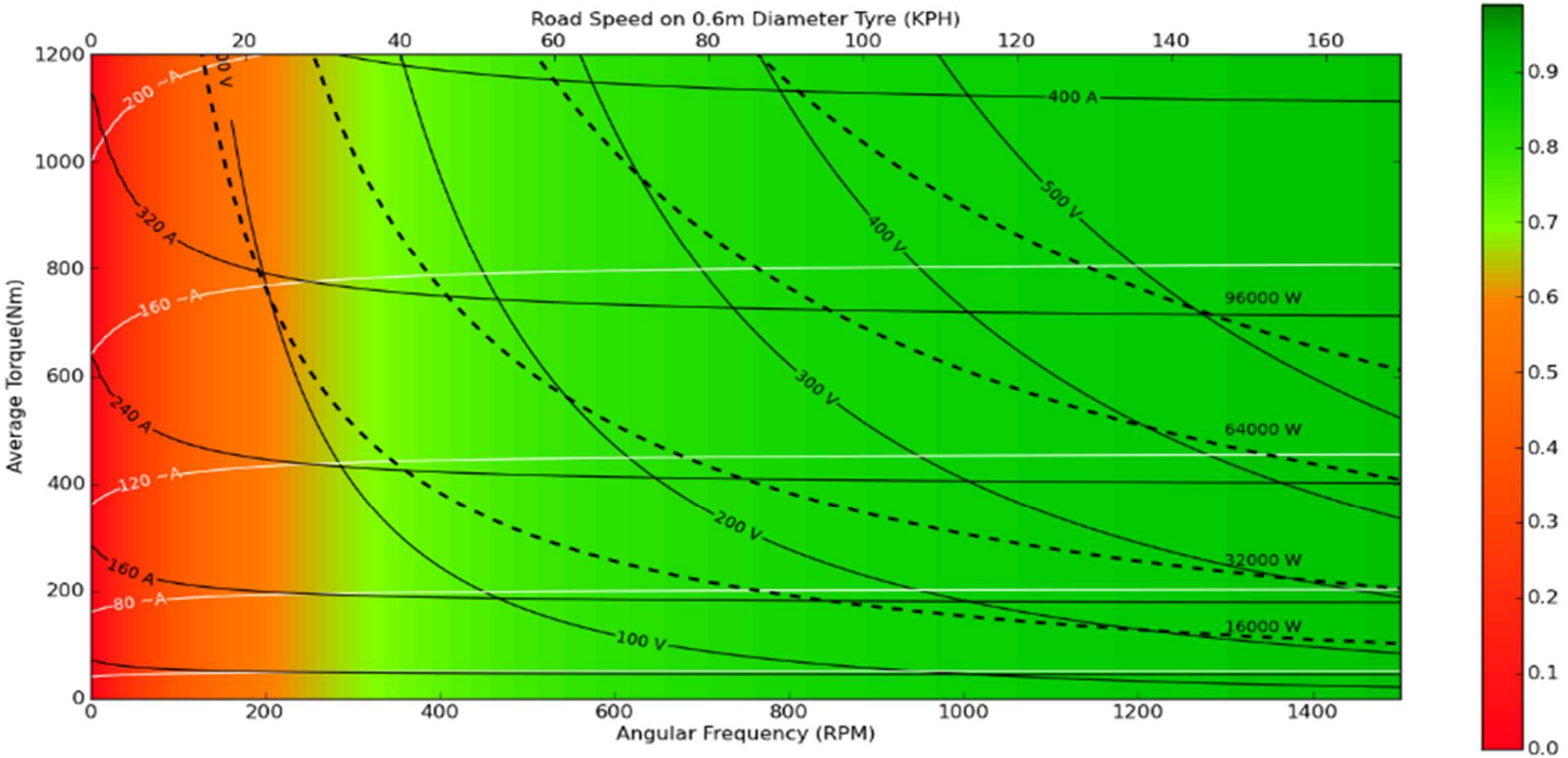
MUTUALLY COUPLED MOTOR PRACTICAL IMPLEMENTATION

- Air cooled — Duty cycle limitation
- Slip rings — HF inductive coupler for production
- External commutation — MOSFET Switches integrated into motor for production
- Triple ‘4 gap’ design — 2 of 3 producing torque
  - Equivalent to 3 cylinder IC engine
  - Simplest for early work
  - Other variants possible
- Built as test bed motor — Mechanically overbuilt
- 1200 Nm peak target torque

MUTUALLY COUPLED MOTOR DESIGN PARAMETERS

• Outside Diameter	384mm
• Sectors	60 (6^o)
• Radius of action	147mm
• Radial active length	60mm
• Conductor arc width	2^o
• Magnetic arc width	4^o
• Disc thickness	10.5mm
• Gap (axial air-gap)	0.25mm
• J_{pk}	14.8 A/mm2
• B_{pk}	1.7T
• Torque $_{pk}$	300 Nm/gap

Mutually Coupled motor: loadmap



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Test results

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Testing of developed components

- SplitPI DC/DC converter
- Mutually coupled motor
- Demonstration vehicle

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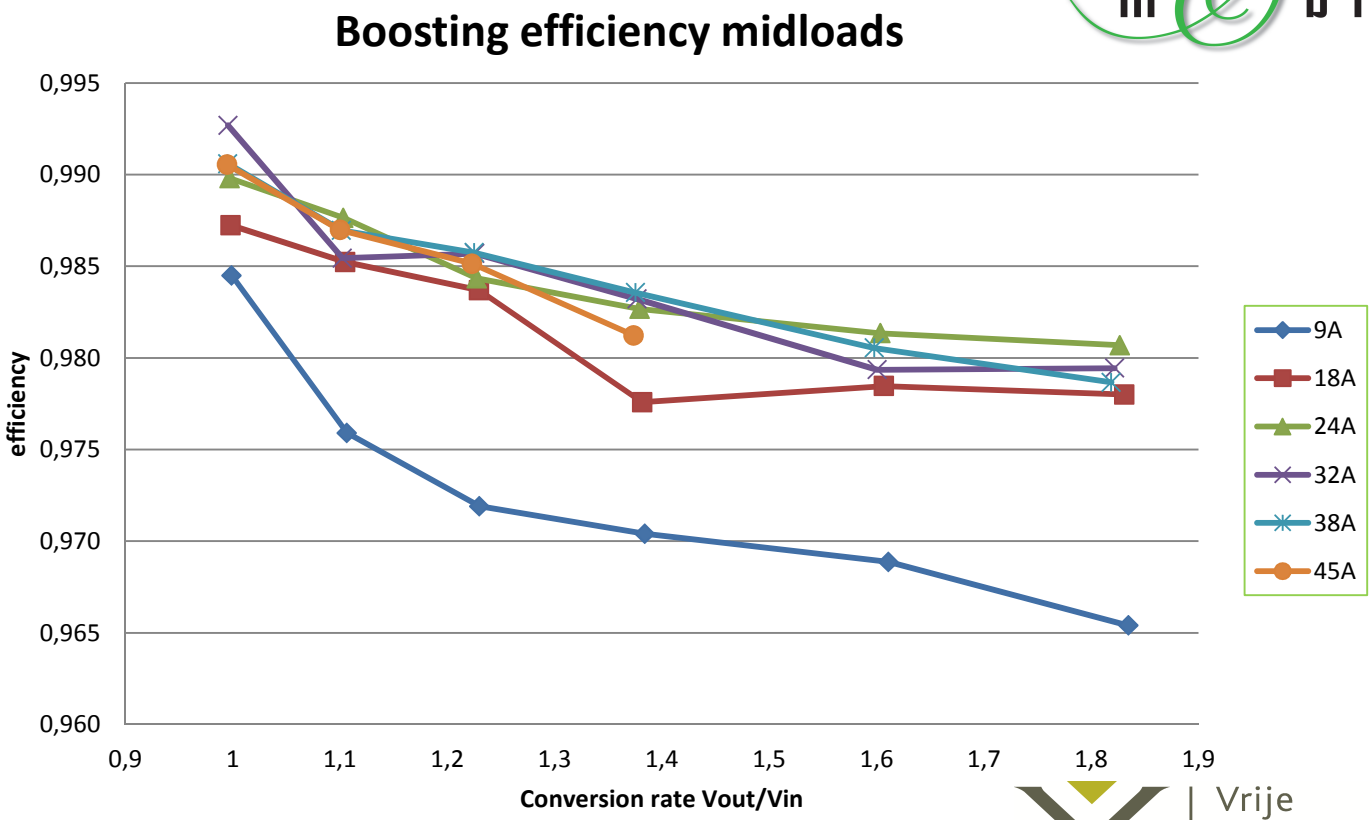
Split-PI DC/DC converter

Boosting:

- High efficiency
- Conversion rate dependent
- Load dependent



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Split-PI DC/DC converter

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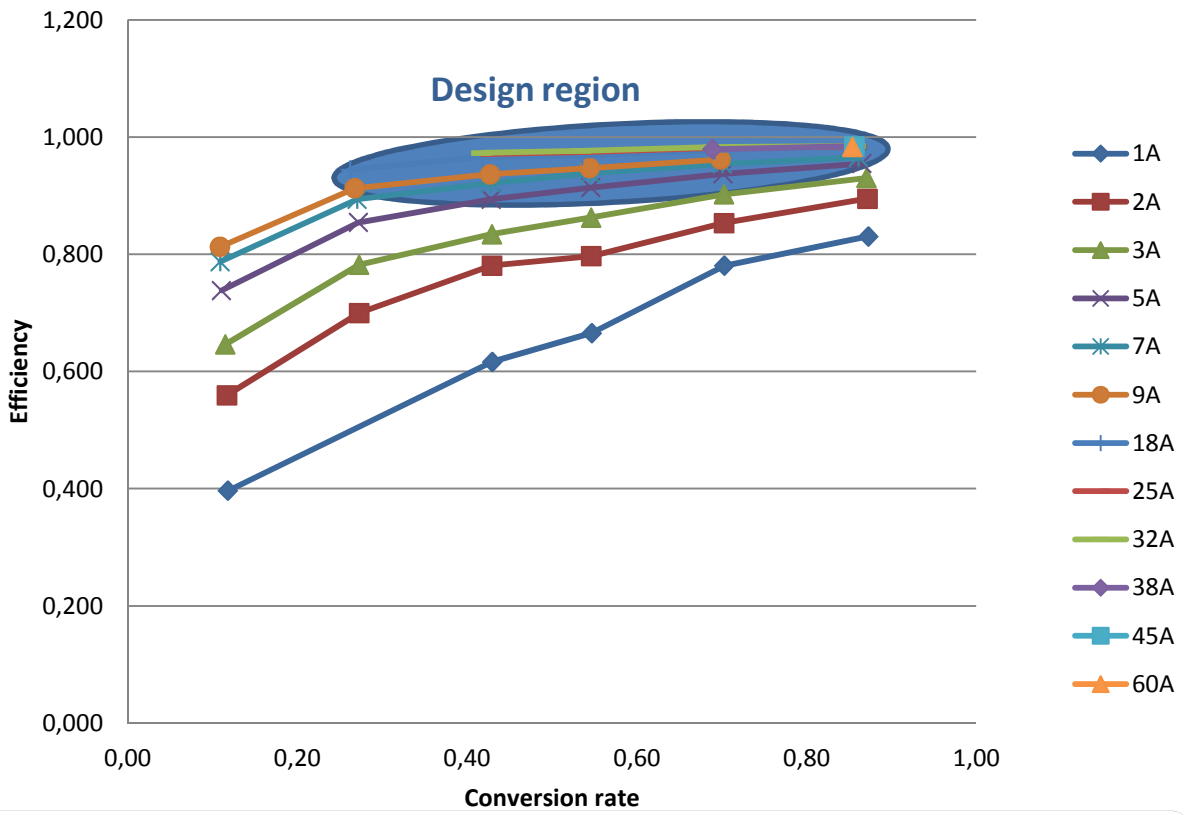
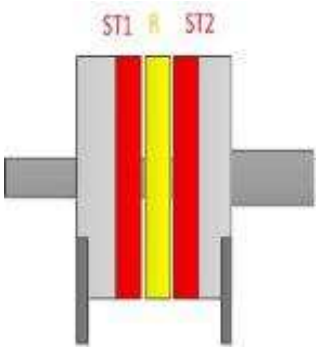
Bucking:

- High efficiency in design region
- Conversion rate dependent
- Load dependent

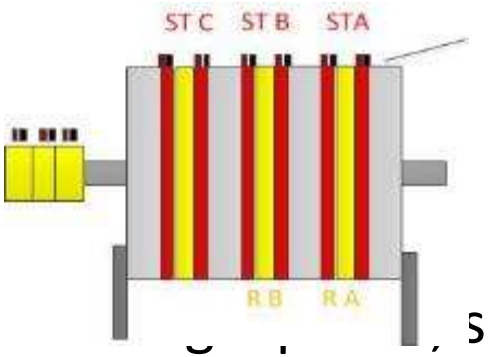


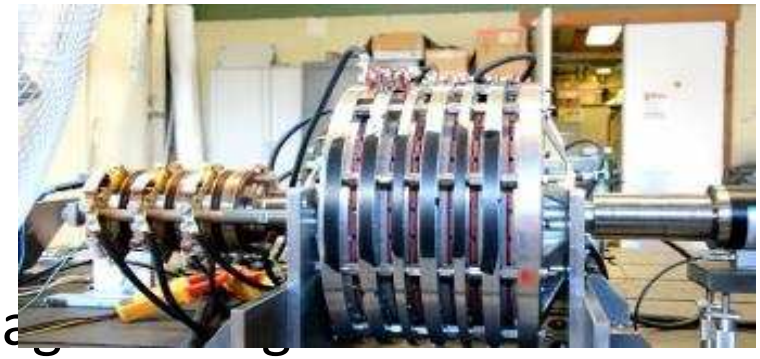
Mutually coupled motor

- 4 implementation stages:
  1. Single phase steel segments



  2. Triple phase, steel segments
  3. Triple phase, steel segments, improved motor control software





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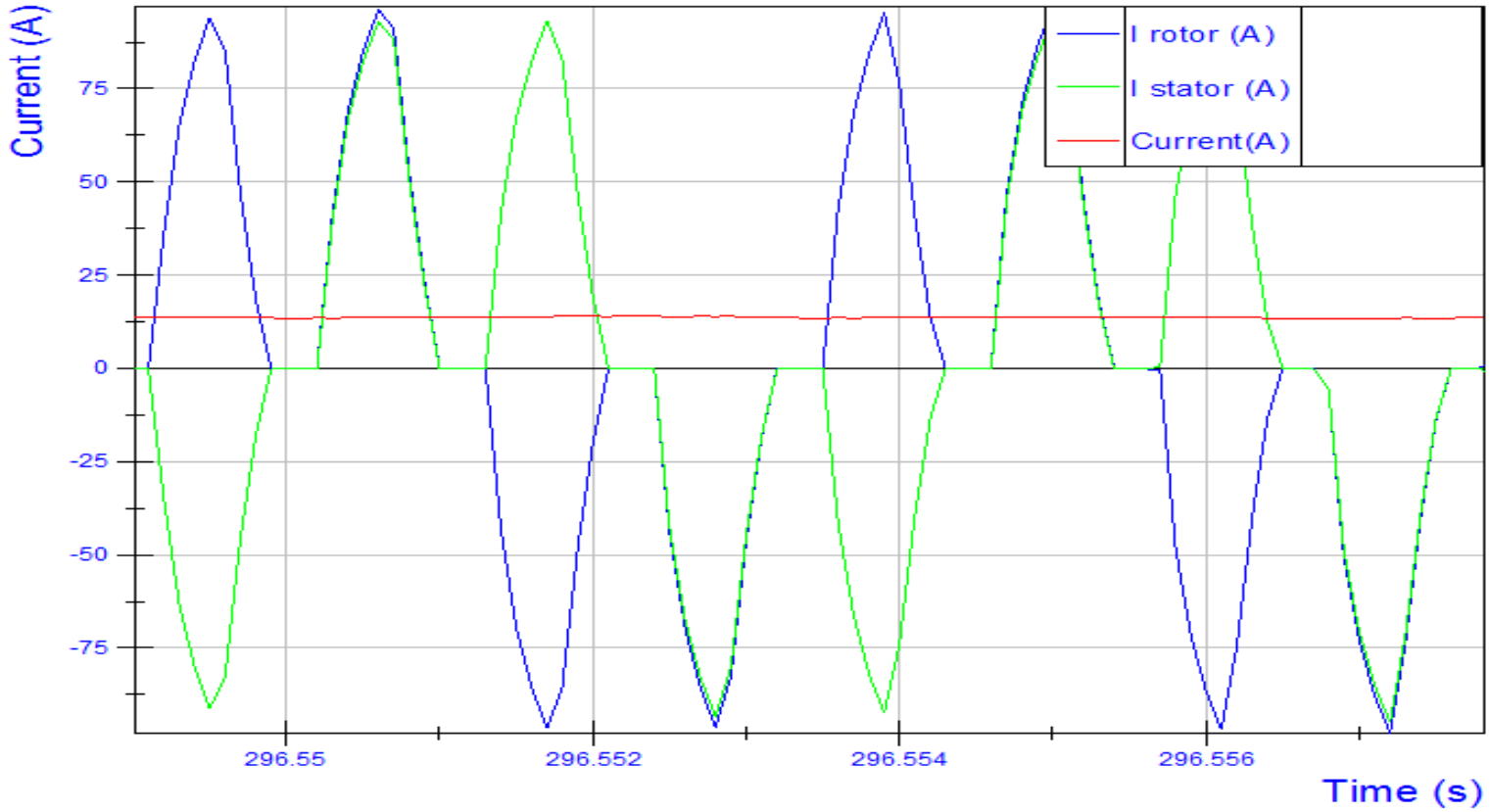
Mutually coupled motor

- Static testing for characterization

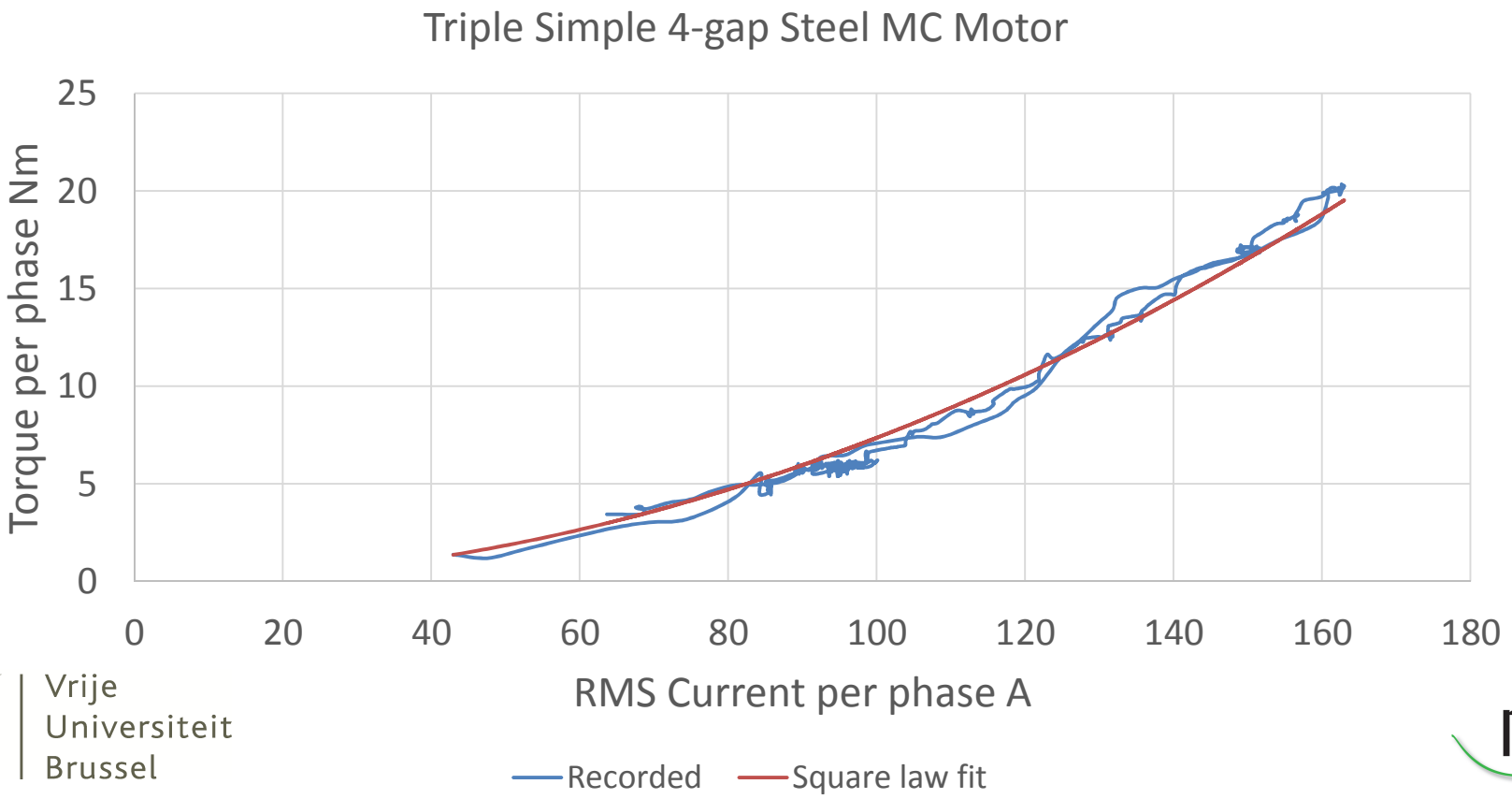
- Dynamic testing:
  - Efficiency
  - Performance
  - Vibration
  - Thermal monitoring
  - Synchronized measurements using data-acquisi system

Mutually coupled motor: cu waveforms

- Single phase during free-run



Mutually coupled motor: Torque results



Mutually coupled motor: Important results

- Proof of concept: running motor capable of producing torque
- The importance of the soft magnetic material for the efficiency of the motor
- First validation of theory
  - Square law appears
  - Projections possible

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Mutually coupled motor: proof of concept

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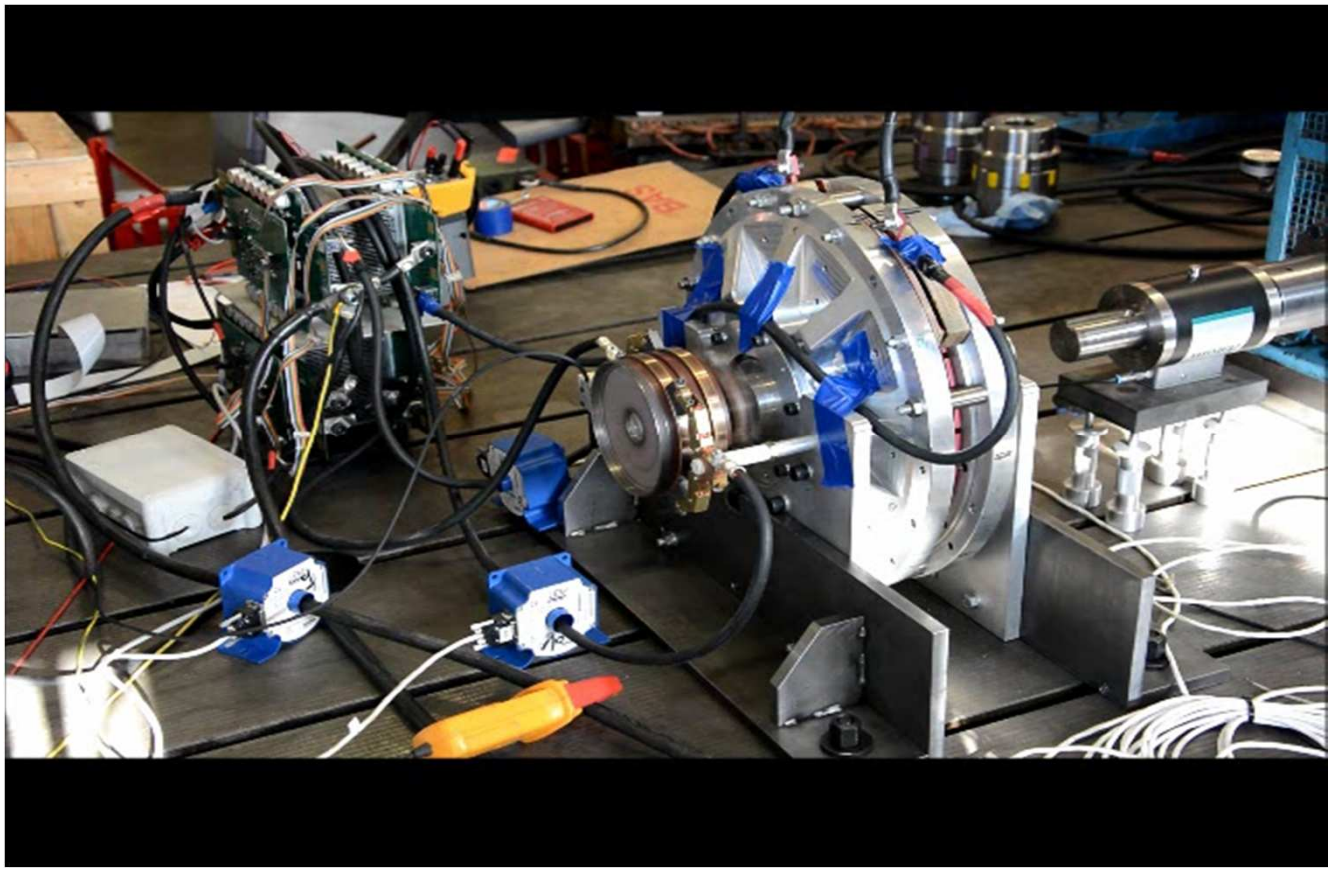

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Mutually coupled motc
Future work

- Improve mechanical design (need for higher flexural strength)
- Improve mechanical built (obtain design tolerances)
- Improve motor control software (robustness, timing)

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Demonstration

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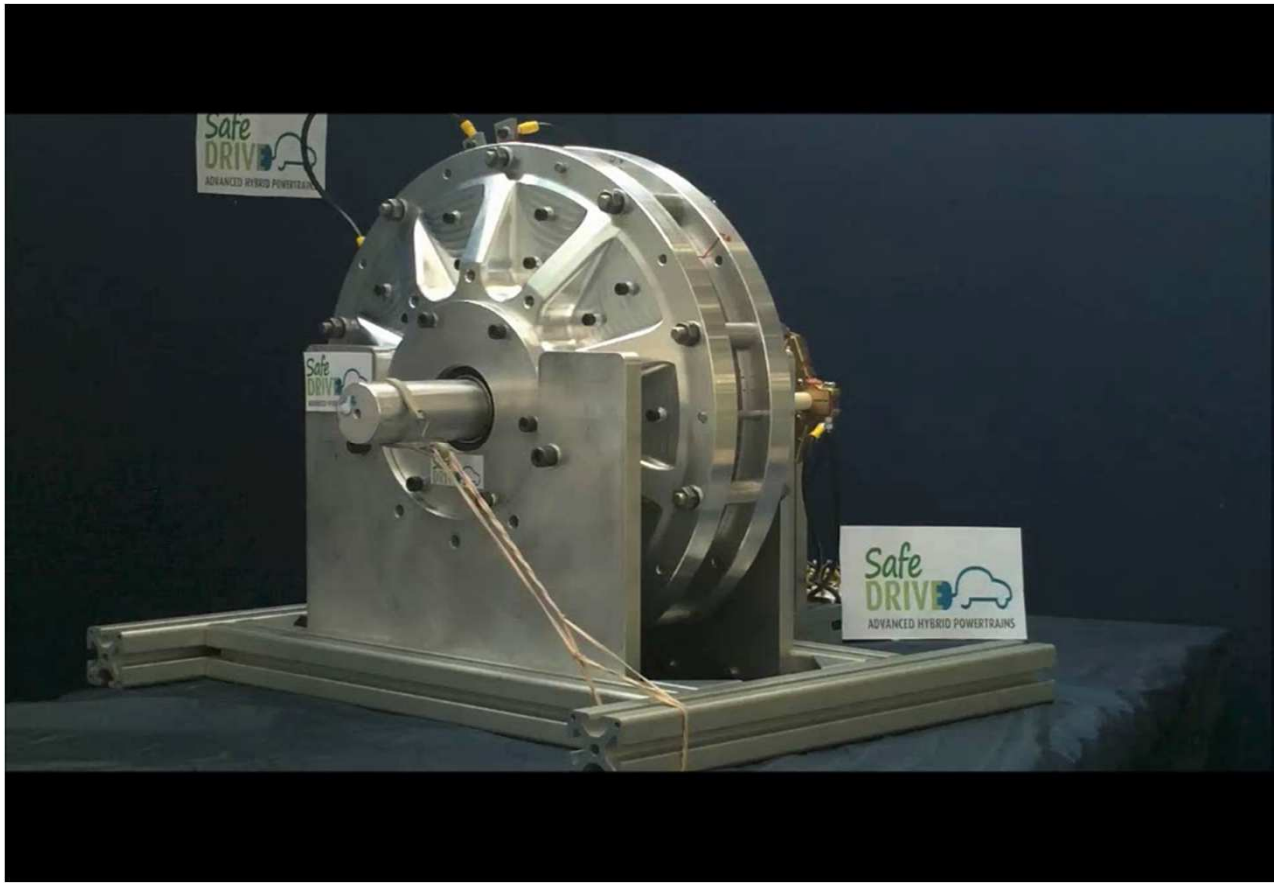

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Conclusions

- DC/DC converter with a high efficiency
- New topology of motor “Mutually coupled motor” has been developed
  - = Alternative for high torque direct drive without permanent magnets (PM)
- Proof of concept for Mutually Coupled motor
  - Running motor
  - Validation of theory
  - Demonstration vehicle

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Thank you

Questions?

http://safedrive-fp7.eu

timc@scimar.co.uk

cedric.de.cauwer@vub.ac.be

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