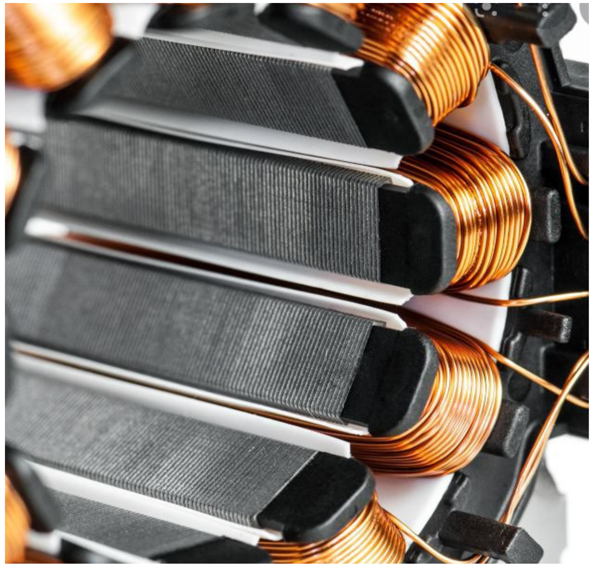
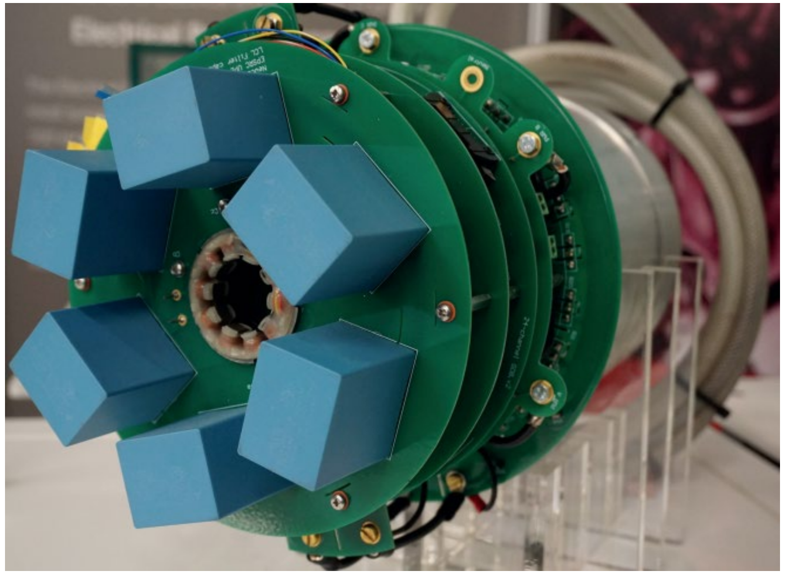
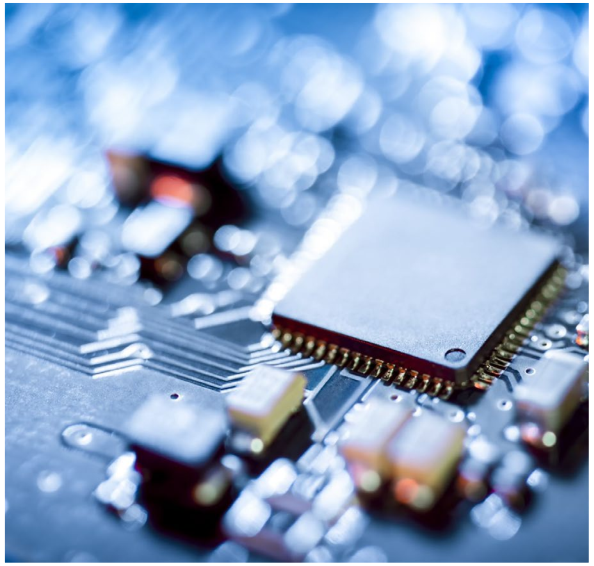

Advanced Electric Drives

Dr Xu (Daisy) Deng

Newcastle University Academic Track (NUAcT) Fellow

Electrical Power Research Group

Newcastle University

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A bit about me

BSc – Electrical Engineering
MEng – Fault-tolerant Bearingless Motor Drives

NUAA, **Nanjing**, **China**

JYPE exchange programme, Tohoku University

TU, **Sendai**, **Japan**

PhD – Drive system for a multi-phase SR Drives
(Electrical Engineering)
Newcastle University

Newcastle, **UK**

Post-Doc:
RA and Senior RA

Newcastle, **UK**

NUAcT Fellowship – Advanced Electric Drives
May. 2021 - present

Electric Motor Drives are ubiquitous

Electric drive in a vacuum cleaner (< 1 kW)

Washing Machines (1-2 kW)

Blender (300 W–1.2 kW)

EVs (50-200kW)

HVAC in commercial buildings

- ***50 billion** electric motors and drives*
- *responsible for about **45%** of the total electric energy consumption*
- *global market of **$18 billion***
- *Most EMDs are cost-driven and less efficient*

My Vision: Future Advanced Electric Motor Drives

Key features

- Higher power density
- Increased sustainability
- More intelligent

Challenges

- Reliance on PM
- Bulky passive components
- Bearing speed limits and lifetime

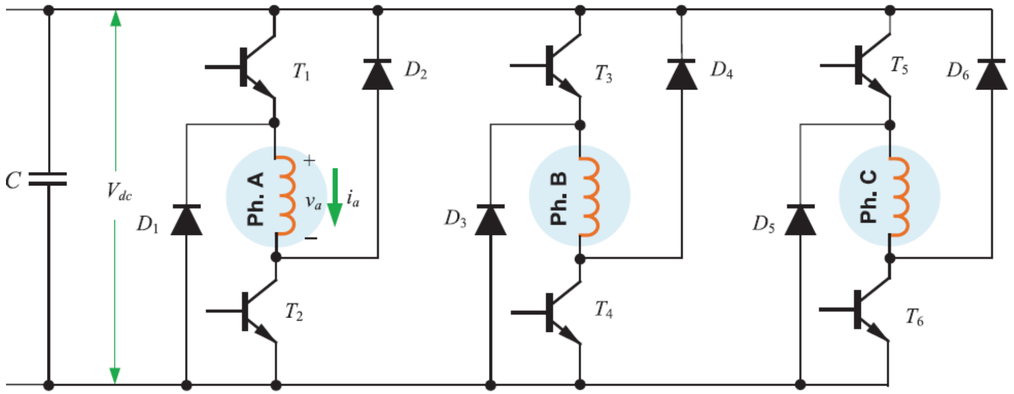
Enablers

- Integration concept
- WBG devices (SiC and GaN)
- Smarter energy control technology
- Levitation technology

My research

- **Rare-earth free Switched Reluctance Motor drives**
- **Integrated Motor Drives**
- **Energy Controller**
- **Bearingless SRMs**
- **High-speed PMSM drives**
- **High frequency power converters**

SRM Drives- Motor

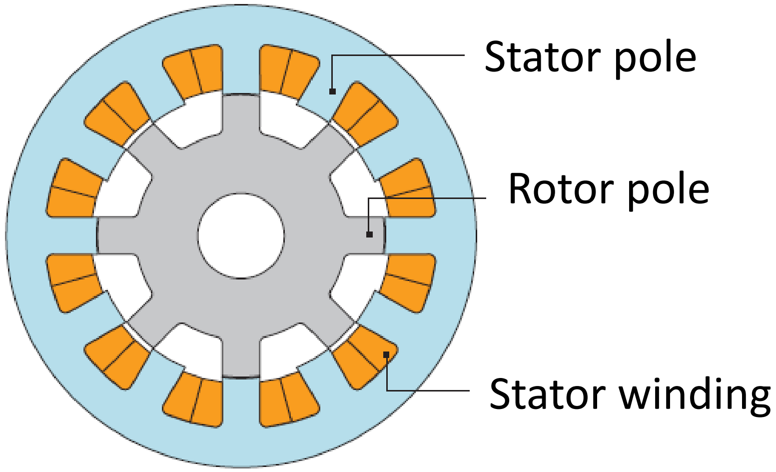


Rotor:

- No winding or permanent magnet

Stator:

- Concentric windings



Advantages:

- Simple structure
- Low manufacturing cost
- High system reliability
- Wide speed range

Application:

- SRMs are contenders for electric vehicle traction drives

Disadvantages:

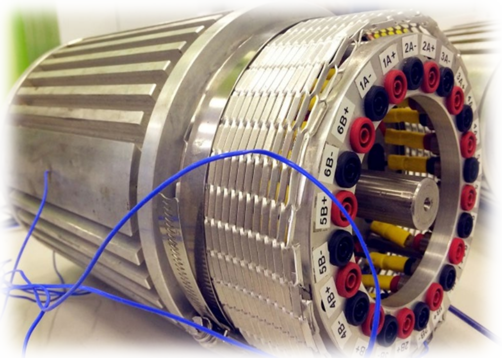
- high torque ripple
- vibration and acoustic noise
- requirement of relatively large DC-link capacitors
- no off-the-shelf inverter module

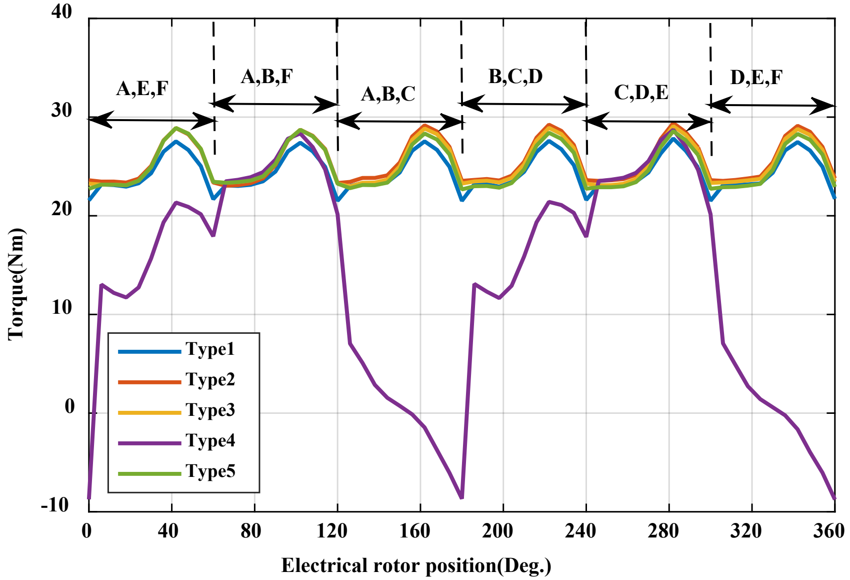
Proven Off-highway Switched Reluctance technology

SRM Drives- Motor

- machines with higher phase numbers
- lower torque ripple
- less phase current for a given power rating
- better fault-tolerant ability
- more overlapping between phases

Why Six-phase 12/10 pole SRM?



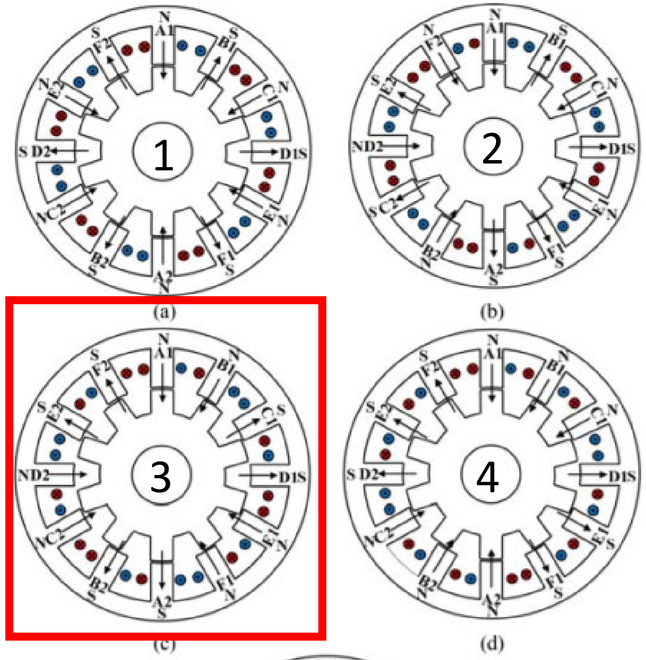


Average Torque and TRR comparison under current control

	Type 1	Type 2	Type 3	Type 4	Type 5
T_{av}(Nm)	24.4	23.9	23.2	14.2	20.4
TRR(%)	27.2	29.2	16.7	243.0	58.8

What's the optimum winding connection?

- high average torque
- low torque ripple
- less coupling between phases



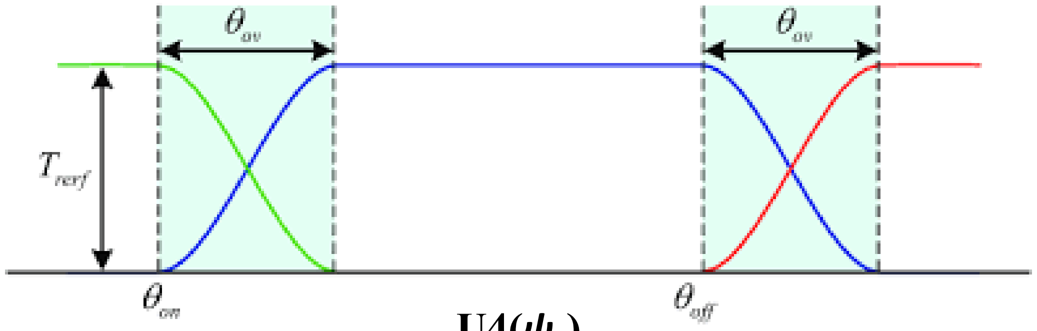
- **Average torque**
- **Low TRR**
- **Lower coupling**

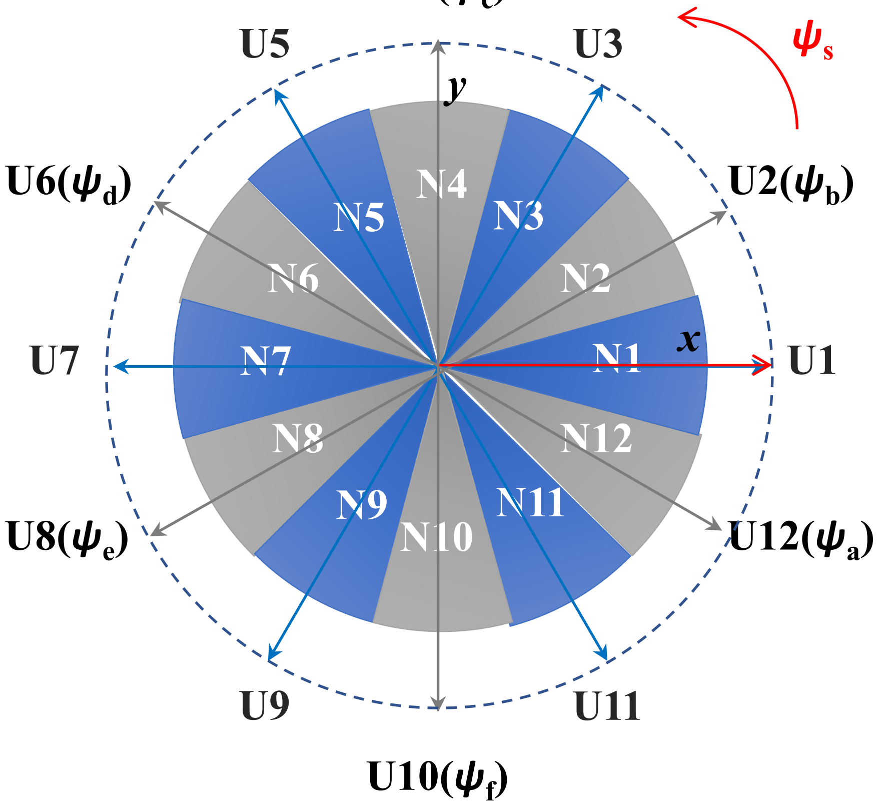
SRM Drives- Control

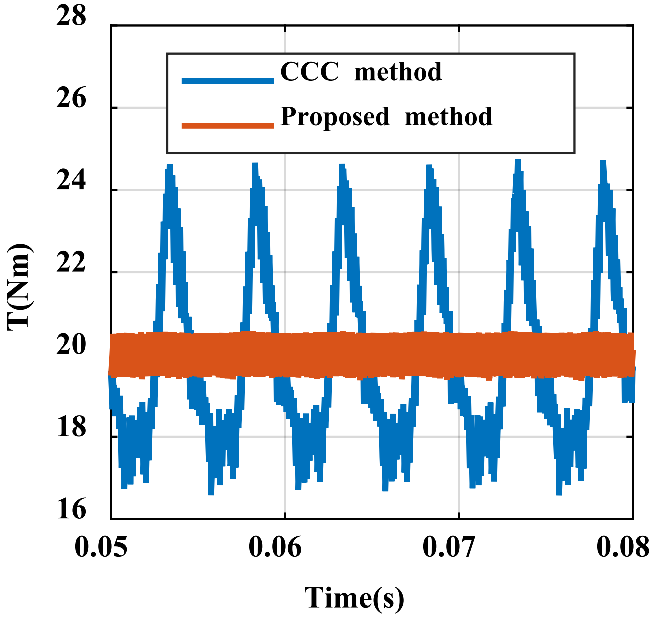
TSF

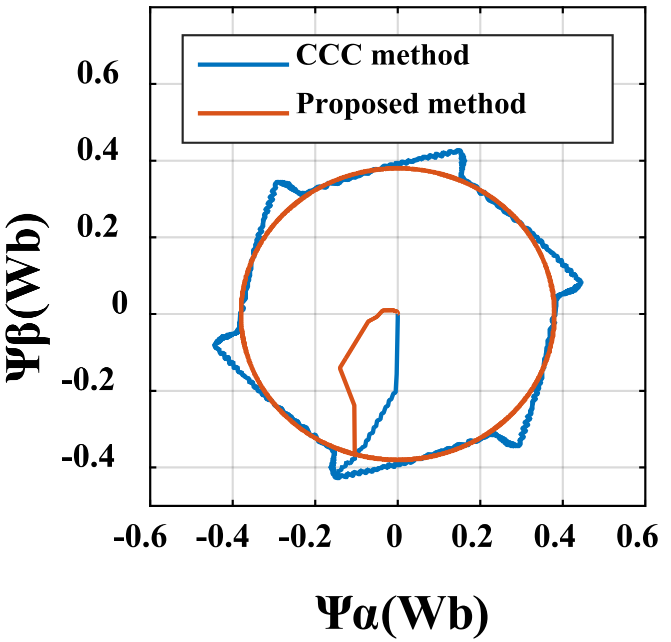
VS

DTC

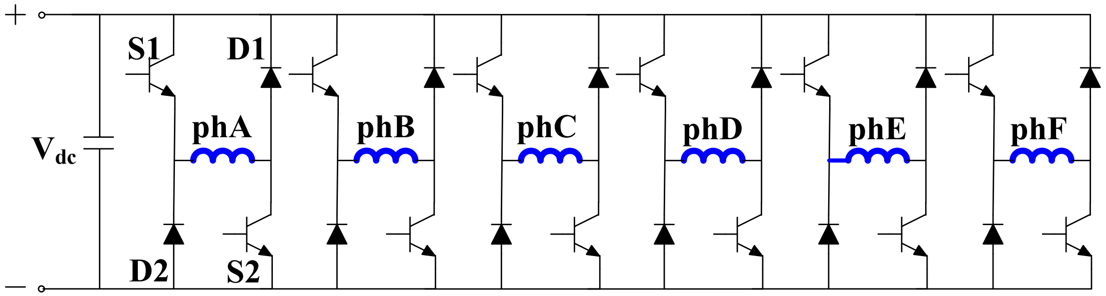








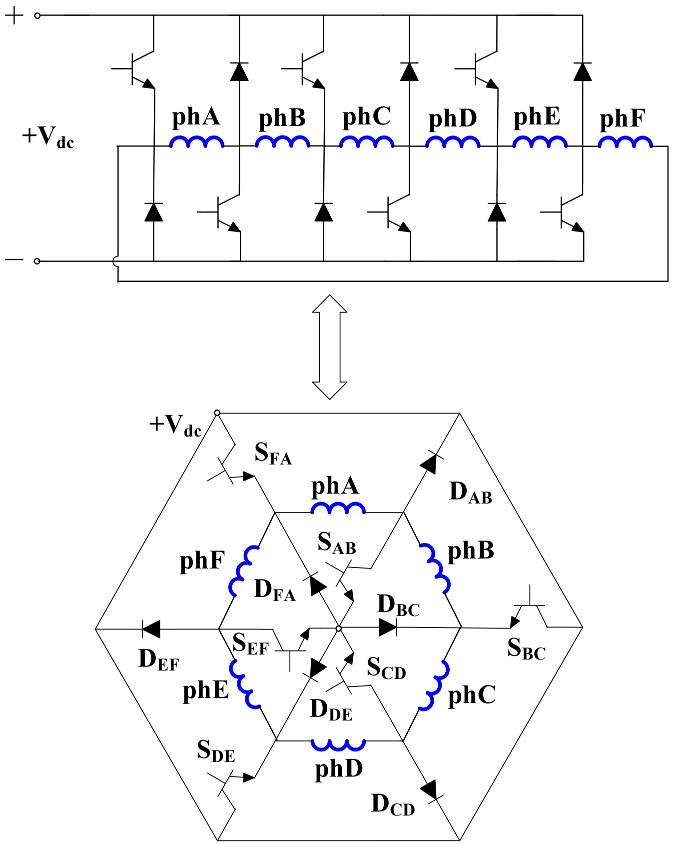
SRM Drives-Converter Topology



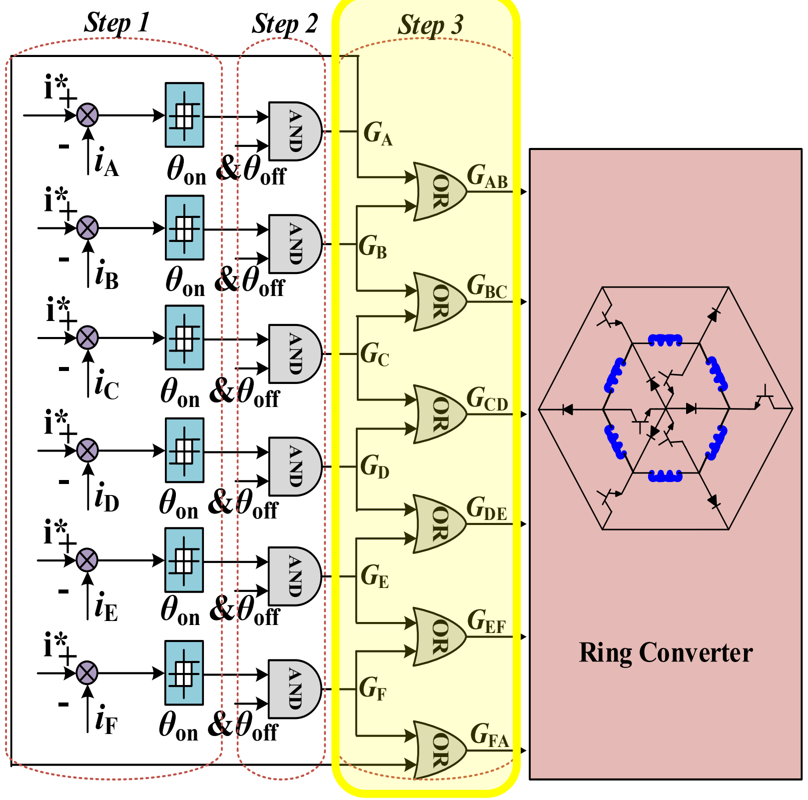
Features of the ideal converter for the multi-phase SRM

- Minimal number of switches;
- Minimal number of diodes;
- Minimal connections between the motor and converter;
- No additional energy storage element;
- Conventional and novel control techniques are applicable.

The proposed ring converter for the six-phase SRM



Modified control method



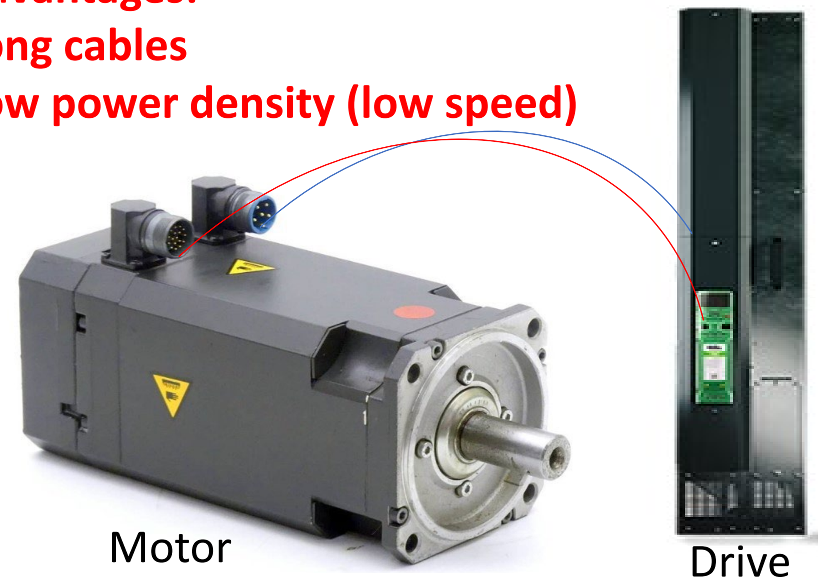
Integrated Motor Drives (IMDs)

By physically integrating power electronic converters and electrical machines we can use common structures and systems to greatly reduce material usage and energy consumption.

Conventional

Disadvantages:

- **Long cables**
- **Low power density (low speed)**



Motor

Drive
(Power Electronics and Controller)

Integration concept

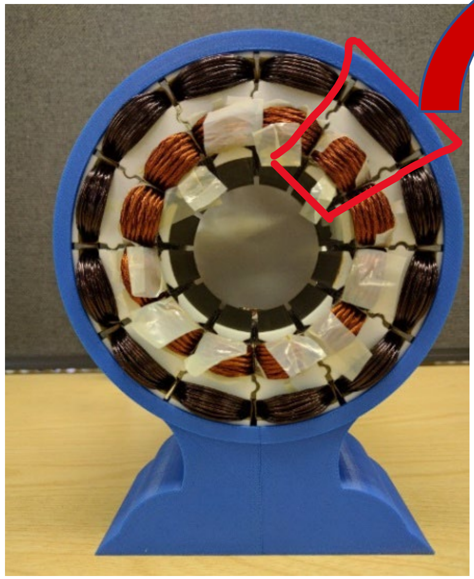
Early Stage Integrated Motor Drive

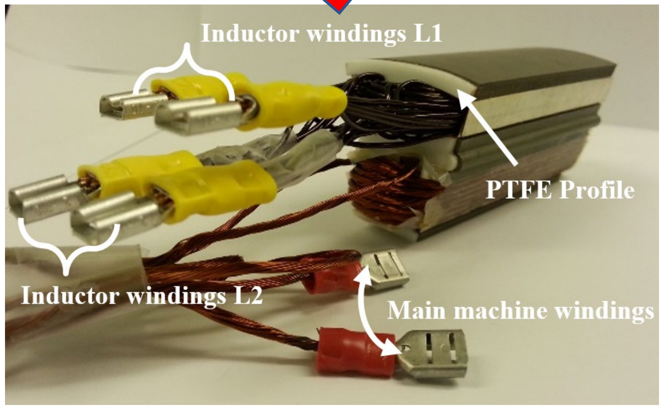
Remaining issues:

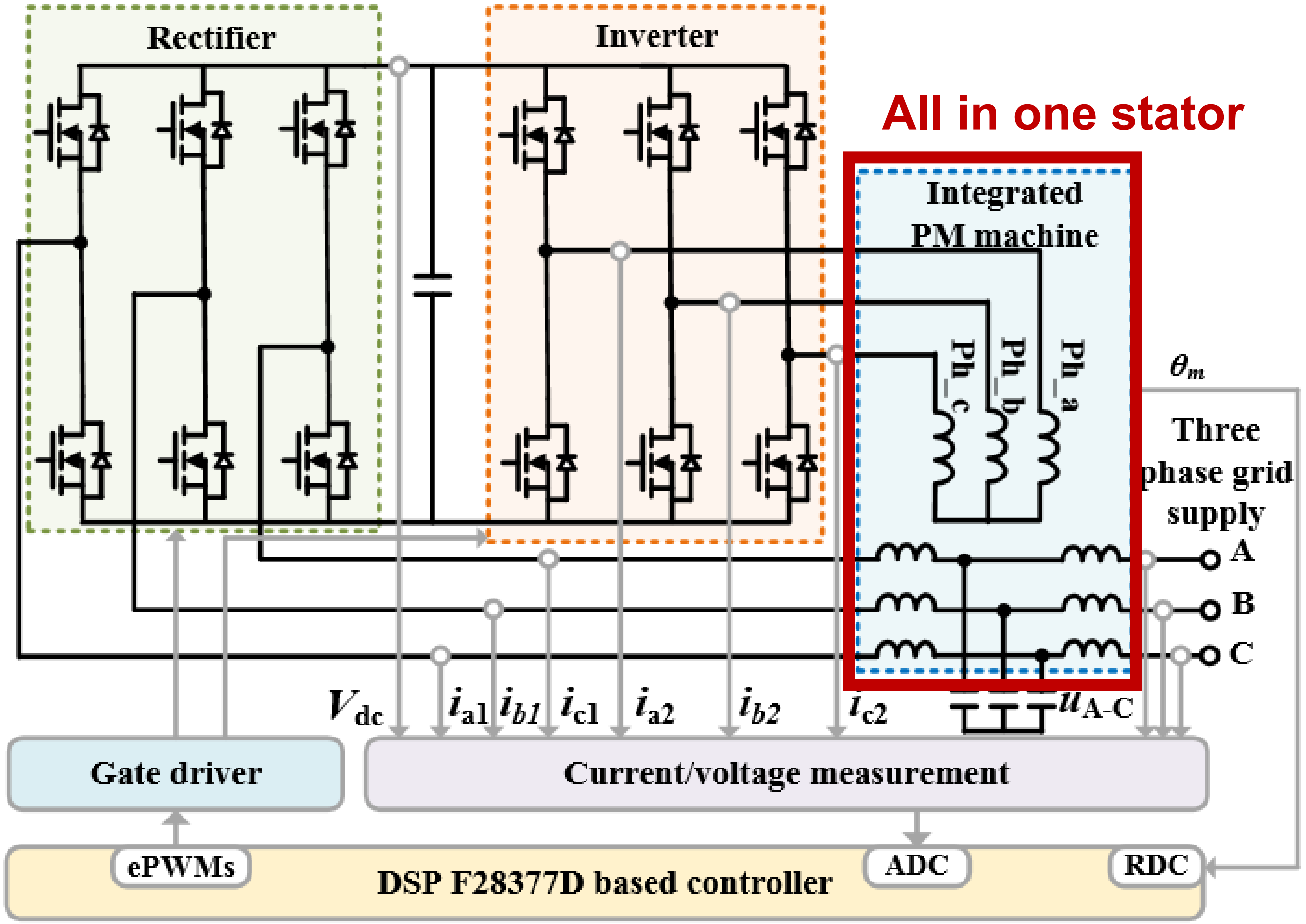
- **Chunky passives**
- **Low power density**

Integrated Motor Drives (IMDs)

Integrating the Magnetics of an LCL Filter into a High-Speed Machine







EPSRC Engineering and Physical Sciences Research Council

POWER ELECTRONICS UK Underpinning Research

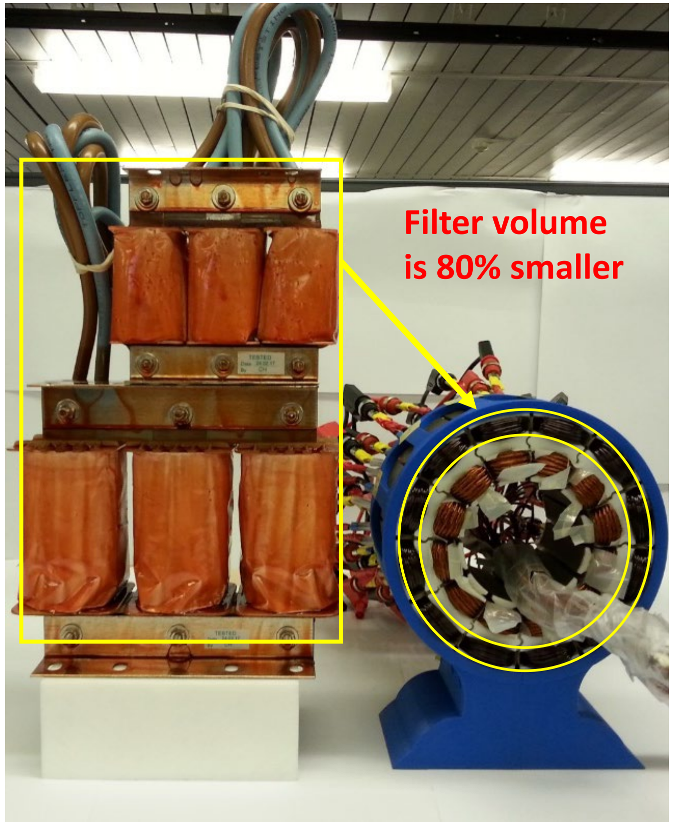
Integrated Motor Drives (IMDs)

Contribution of this research

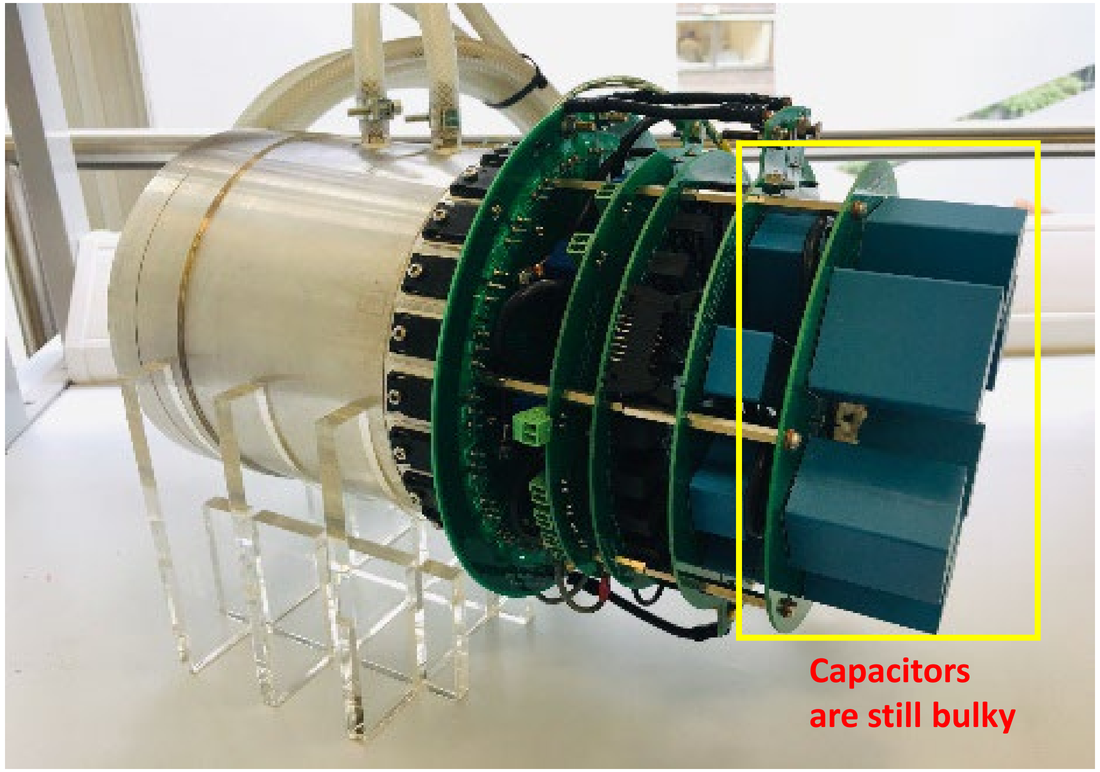
- High speed motor
- High frequency WBG
- Integrated inductive filters
- Thermal management

Perspective on size

Industry filters (left) VS
Full machine stator with integrated filters (right)



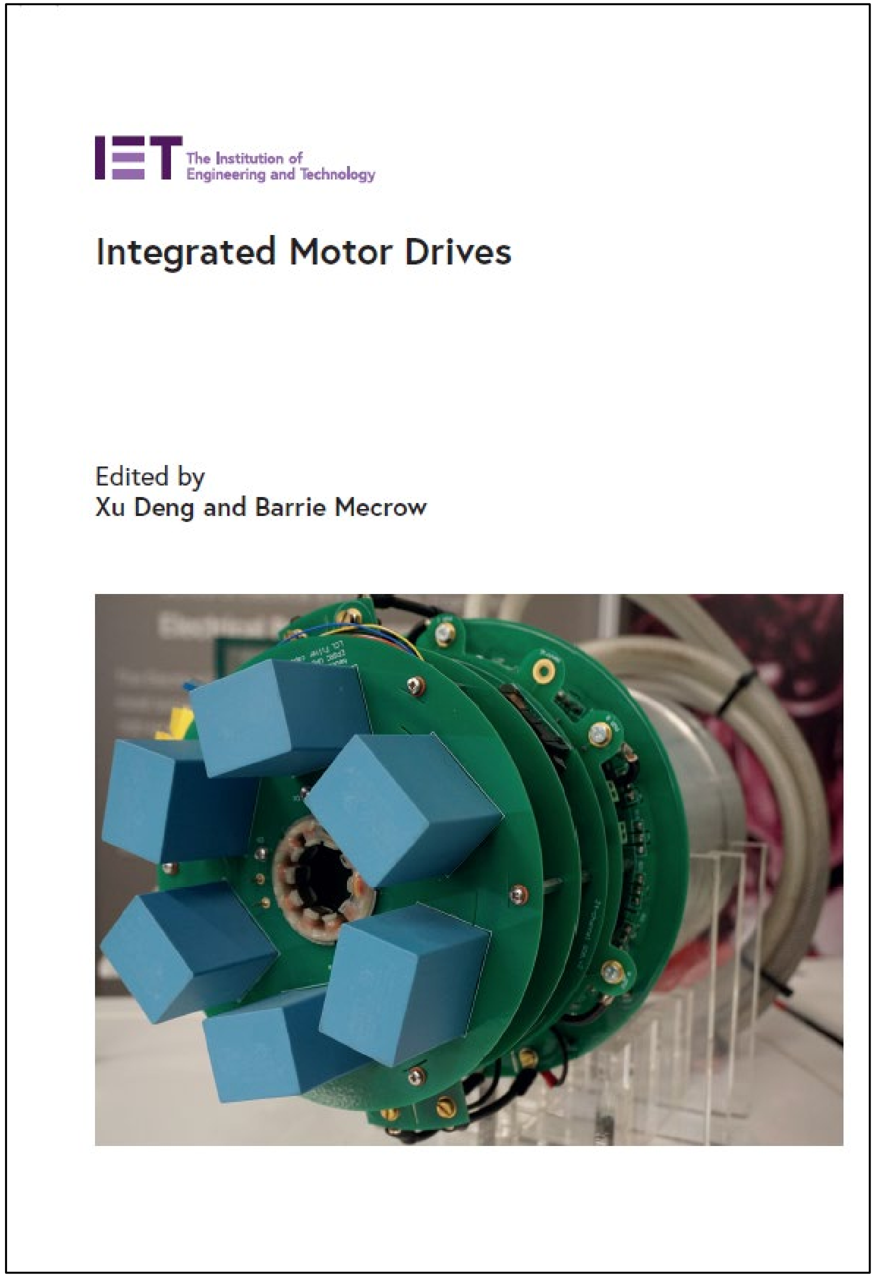
Full Prototype



This work received **the Best Paper Award from the IEEE Transactions on Energy Conversion** for recognition of excellence in the field of electric machines and drives.

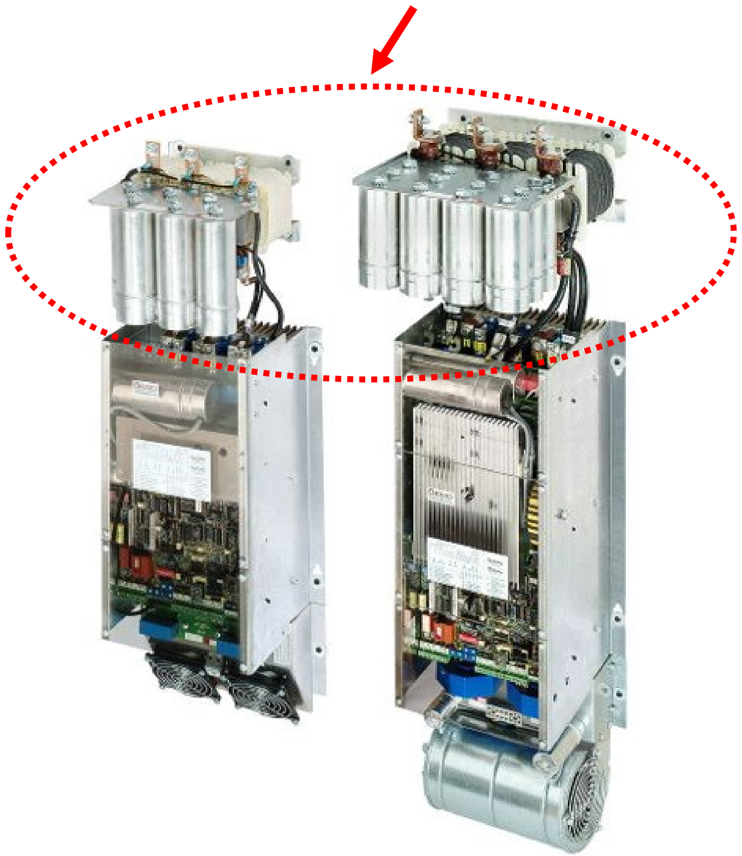
Integrated Motor Drives (IMDs)

Please get a copy if you are also passionate about IMDs!

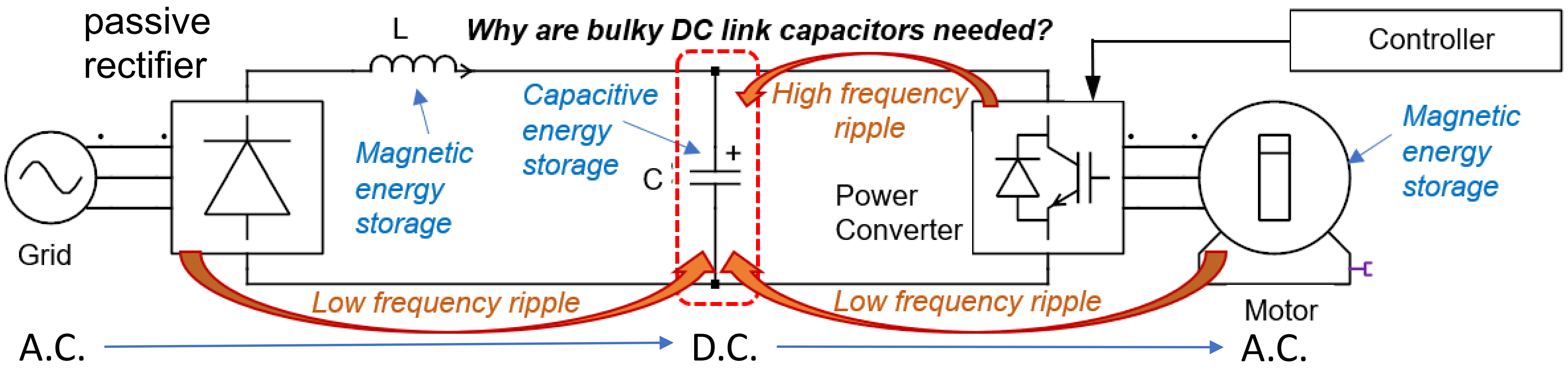


Bulky Energy Storage in Electric Motor Drives

DC link capacitors
in grid connected applications



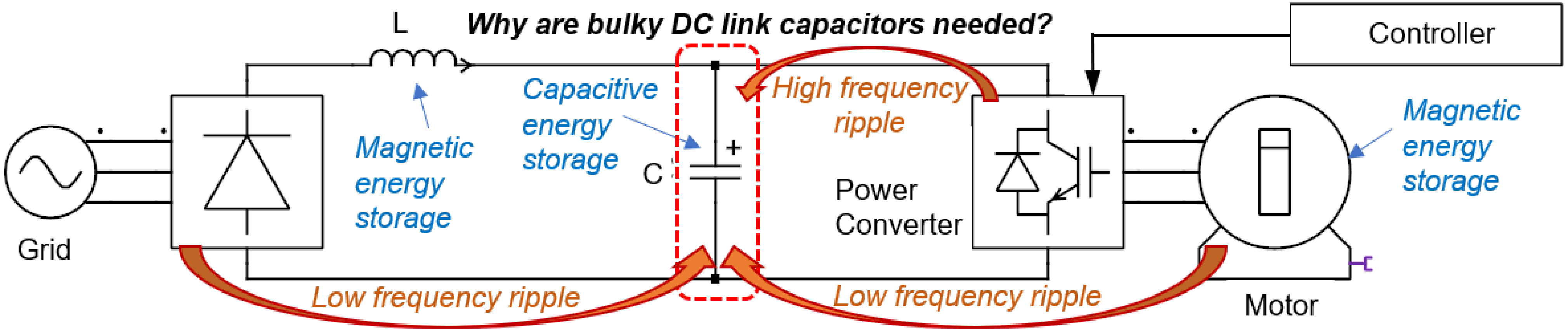
Simplified diagram of a grid connected motor drive system



- DC link capacitor handles **instantaneous mismatch in power**
- **Electrolytic capacitors** are commonly used
- **Ripple current** and **slow evaporation of electrolyte**
- **Short lifetime** and need replacing every 2-3 years

Energy Ripple in Electric Motor Drives

Simplified diagram of a grid connected motor drive system

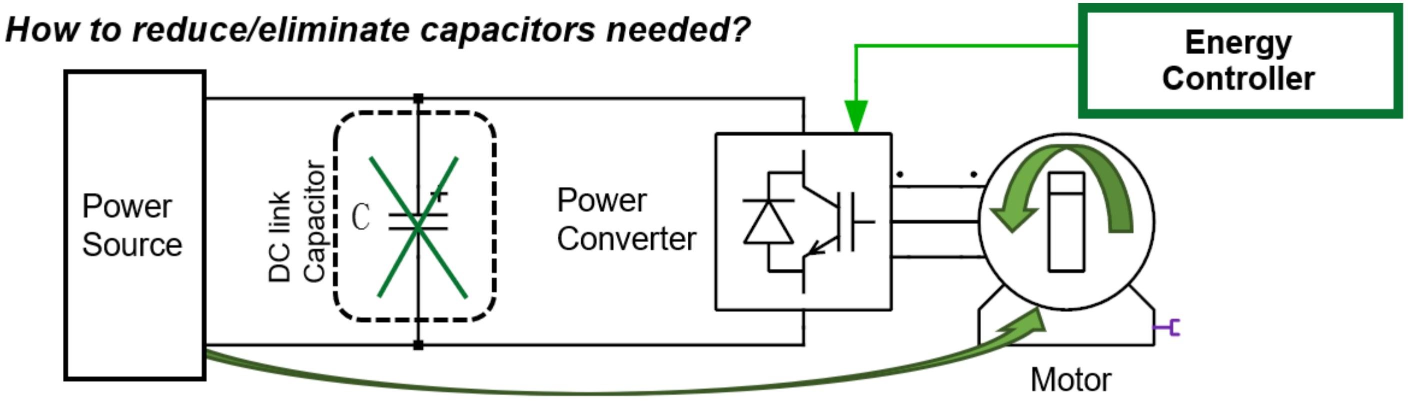


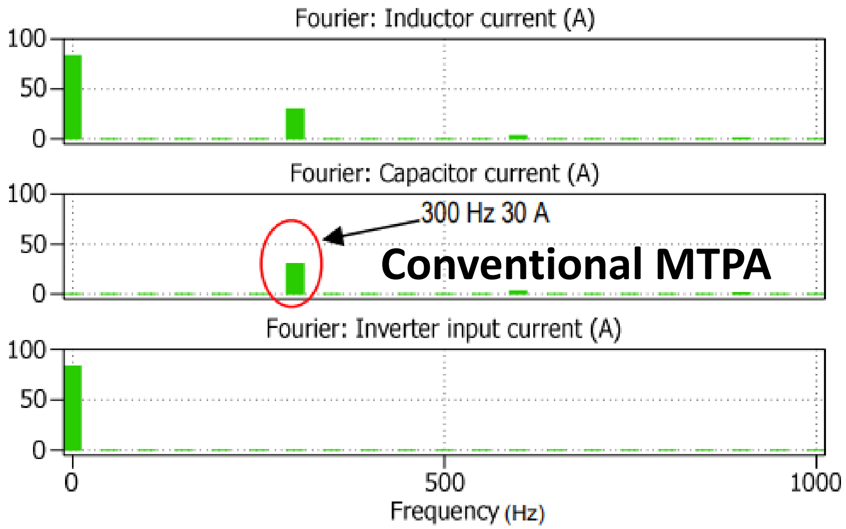
- **Different types of ripple currents**

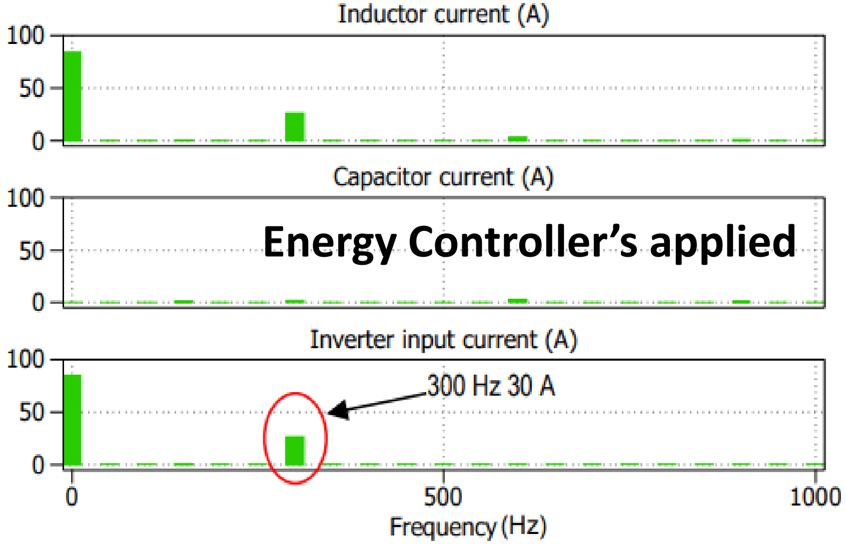
1) switching action of the inverter will produce **high frequency current ripple**;
2) 300 Hz current ripple caused by using a passive rectifier;
3) torque ripple and change of stored energy in the motor would lead to **low frequency current ripple**.

- **Past research** on reducing DC link capacitors in EMDs has **either changed the hardware topology or solely focused on high frequency ripple reduction**

Energy Control Strategy to Reduce DC Link Energy Ripple







Case study: Grid connected PMSM drive with a sinusoidal back-EMF

$$T_m = \frac{3}{2}p\left[(L_d - L_q)i_d i_q + \varphi_m i_q\right]$$

Varying ***Fixed***

$$P_{inv.} = T_m\omega_m + \frac{dW_f}{dt} + P_{loss} = T_m\omega_m + i_d L_d\frac{di_d}{dt} + i_q L_q\frac{di_q}{dt} + P_{loss}$$

- Working with my PhD student (Jack Baines), we developed a **method for reducing the size and increasing the lifetime of DC link capacitors in drives**, resulting in industrial collaboration with **Nidec Control Techniques**.

Nidec Drives

Thank you!