Towards compact integrated electric drives for automotive traction applications

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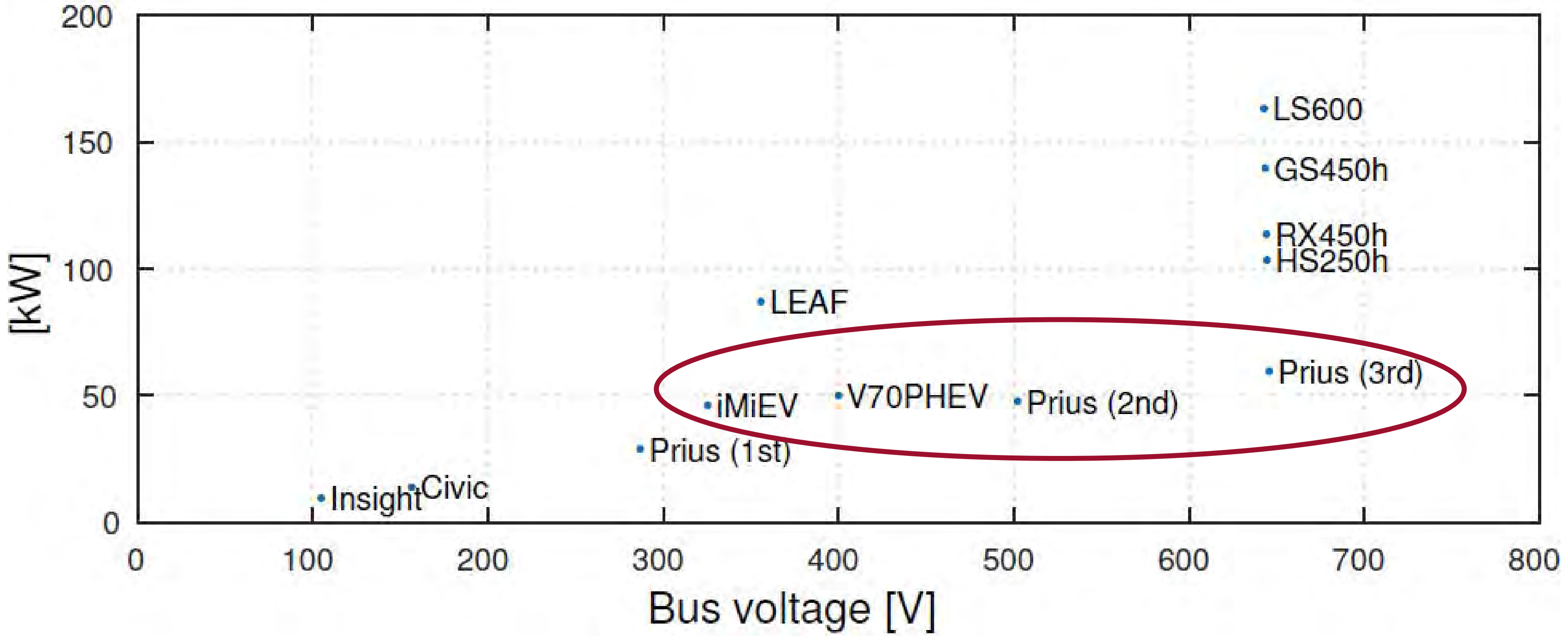
Background


2016 Volvo XC90 Plug-in hybrid
(www.thecarconnection.com)

- Integration of electric motor and converter (potentially) enables:
  - Reduction of cabling, EMI, and weight
  - Packaging advantages (single unit)

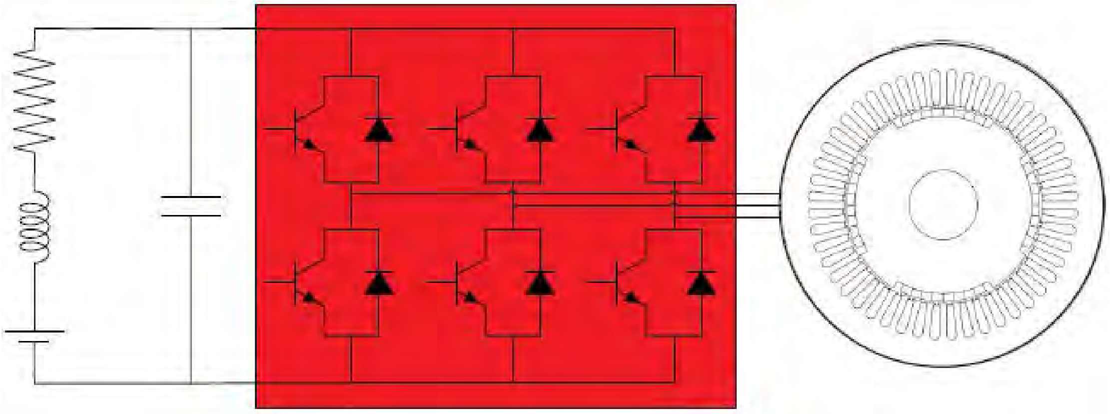
Background



- 300-700 V “suitable” at 50 kW

Data from K. Nishikawa, “GaN for automotive applications," in Proc. IEEE Bipolar/BiCMOS Circuits and Technology Meeting (IEEE-BCTM), 2013.

Conventional solution



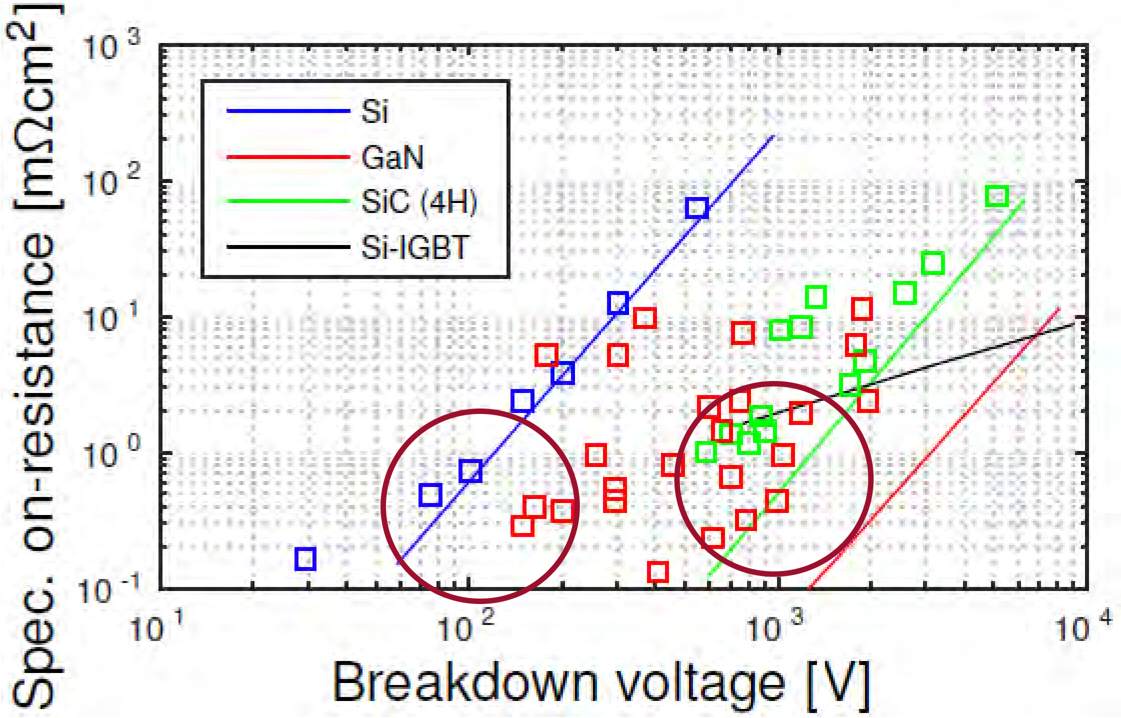
- 600, 1200 V Si-IGBT switching at 10-30 kHz
- 7-10 uF per kVA required at 400 V (when switching at 10-30 kHz)
  - This means 1000-2000 uF in a vehicle
  - Al electrolytic capacitors have the highest energy density (bulk material ≈ 1 J/cm^3, capacitor pack assembly ≈ 0.3 J/cm^3 [1])

[1] T. Hosking, "Comparative evaluation and analysis of the 2008 Toyota Lexus, Camry and 2004 Prius DC link capacitor assembly vs. the SBE power ring DC link capacitor," in Proc. 5th IEEE Vehicle Power and Propulsion Conf. 2009.

Conventional solution

- 600 V, 1 mF @ 0.3 J/cm^3 capacitor volume approximately 2 soda cans
- Al electrolyte → Temperature limited below ≈ 105 degC and reliability concerns

New power devices



- ≥400 V: Sic- and GaN-based components promise significant improvements compared to Si-IGBTs
- ≤100 V: Si-based FETs provide low conductive losses today with GaN offering potential future improvements

Data from: www.irf.com/product-info/ganpowir/gangeneral.pdf

A. Nakagawa et al., "Silicon limit elect. chars. power devices and ICs," in Proc. ISPS'08.

K. Nishikawa, "GaN for automotive applications," in Proc. IEEE-BCTM'13.

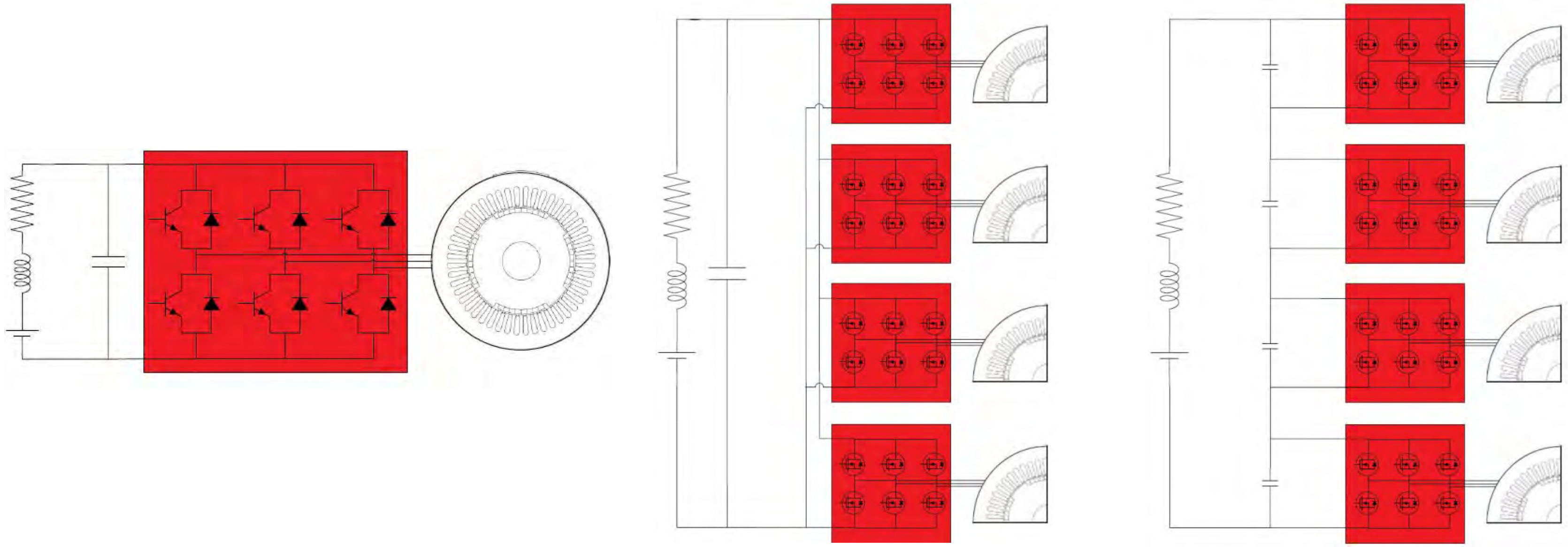
New power devices

a)

b)

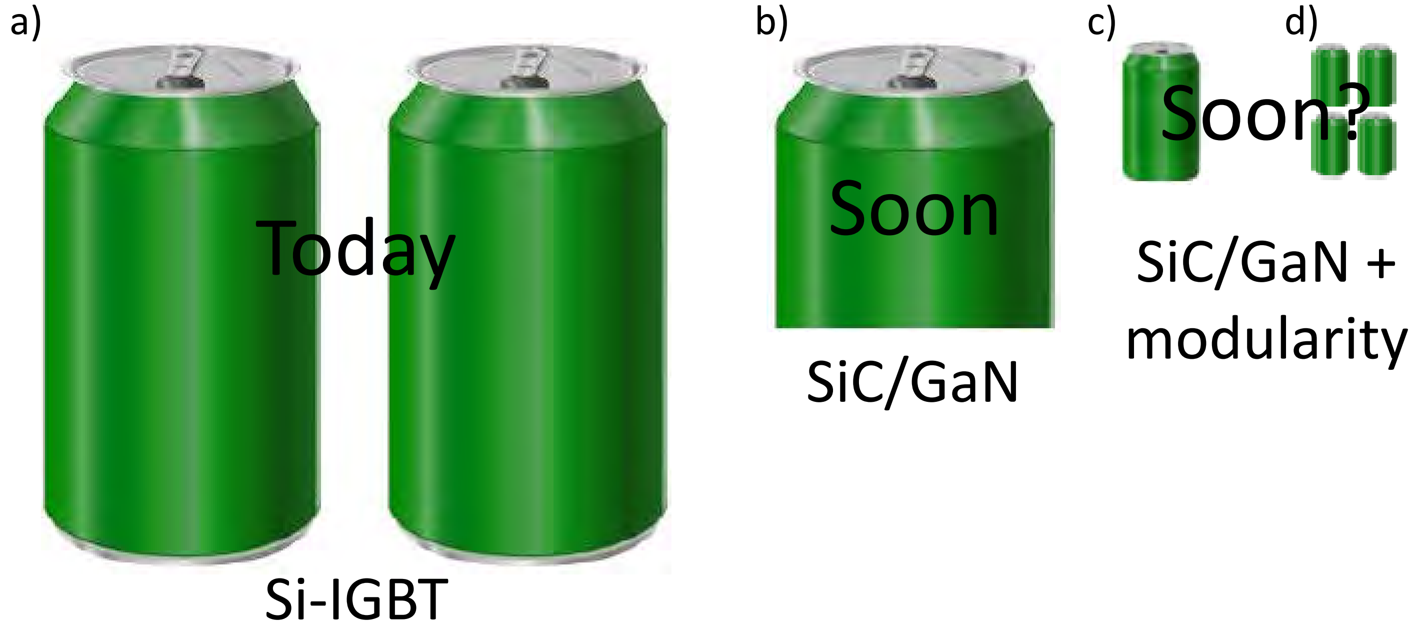
a) 600 V, 10 kHz, 1 mF, 2 soda cans (Al electrolytic type, 0.3 J/cm^3)
b) 600 V, 100 kHz, 25 µF, 1/2 soda cans (polyester type, 0.03 J/cm^3)

Modular converters



- Left: Conventional three-phase converter (Si-IGBT, SiC or GaN)
- Middle: Modular converter (parallel-connected submodules) (SiC or GaN)
- Right: Modular converter (series-connected submodules) (Si or GaN)

New power devices and modular concepts

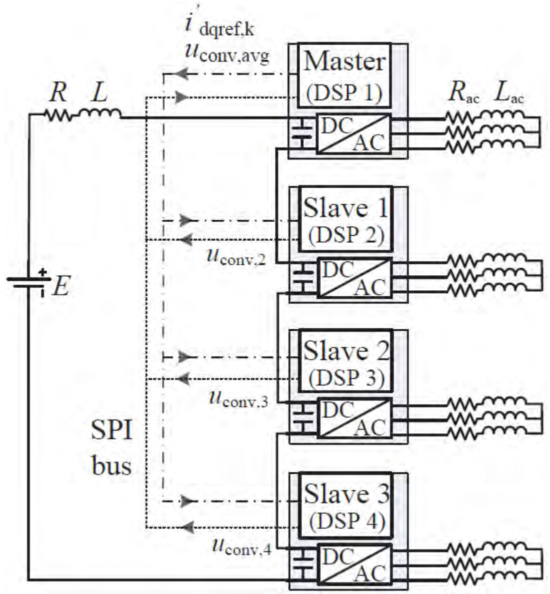


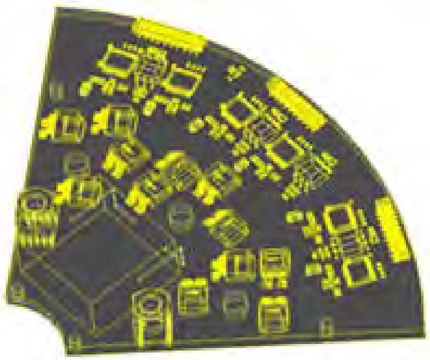
a) 600 V, 10 kHz, 1 mF, 2 soda cans (Al electrolytic type, 0.3 J/cm^3)
b) 600 V, 100 kHz, 25 µF, 1/2 soda cans (polyester type, 0.03 J/cm^3)
c) Modular: 600 V, 100 kHz, 5 µF, 0.1 soda cans (polyester type, 0.03 J/cm^3)
d) Modular: 150 V, 100 kHz, 20 µF, 0.1 soda cans (polyester type, 0.03 J/cm^3)

Integrated modular electric drives

- Advantages:
  - Small capacitance requirements due to high switching frequency and carrier interleaving
  - Potential fault tolerance in-built
- Challenges:
  - Modular converter and machine designs
  - Fault handling
  - Modular control and communication

Modular automotive converters at KTH

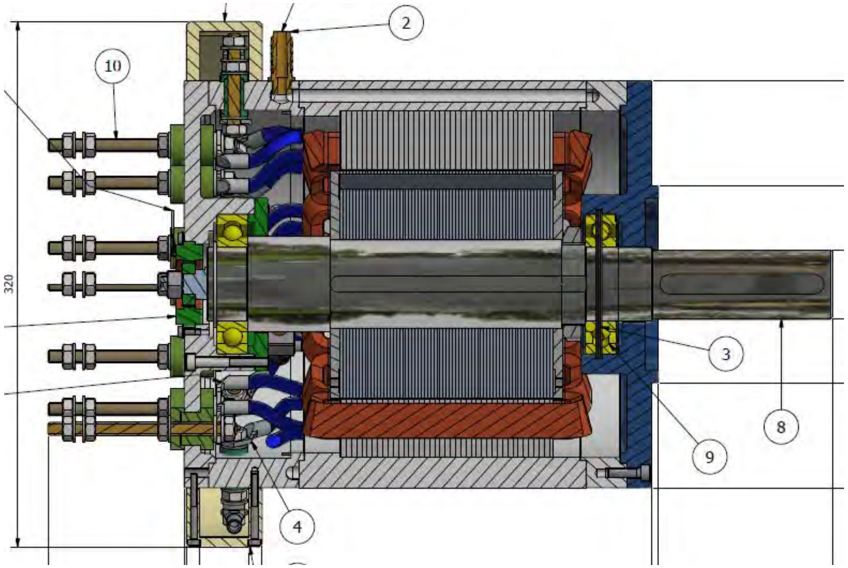


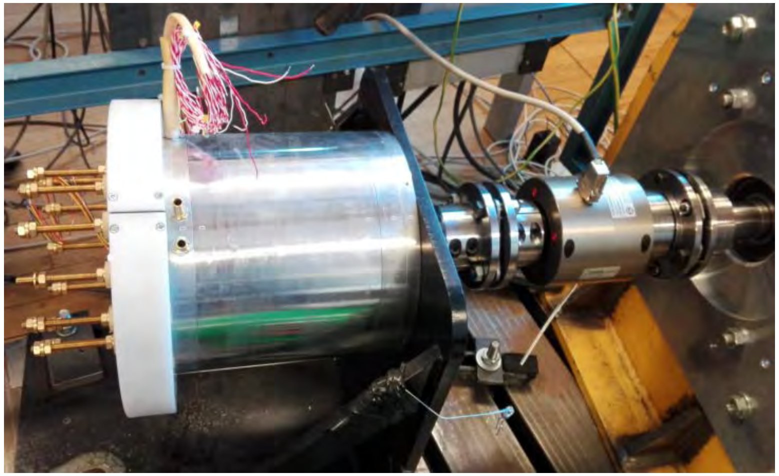


ESKILSTUNA Elektronik Partner

- Two modular converters built for concept evaluation (2 and 4 submodules, PhD students Mojgan Nikouei Harnefors and Lebing Jin)
- High-current (100 Arms) design to be completed in January 2017 (PhD student M. Nikouei Harnefors in collaboration with Eskilstuna Elektronikpartner AB)

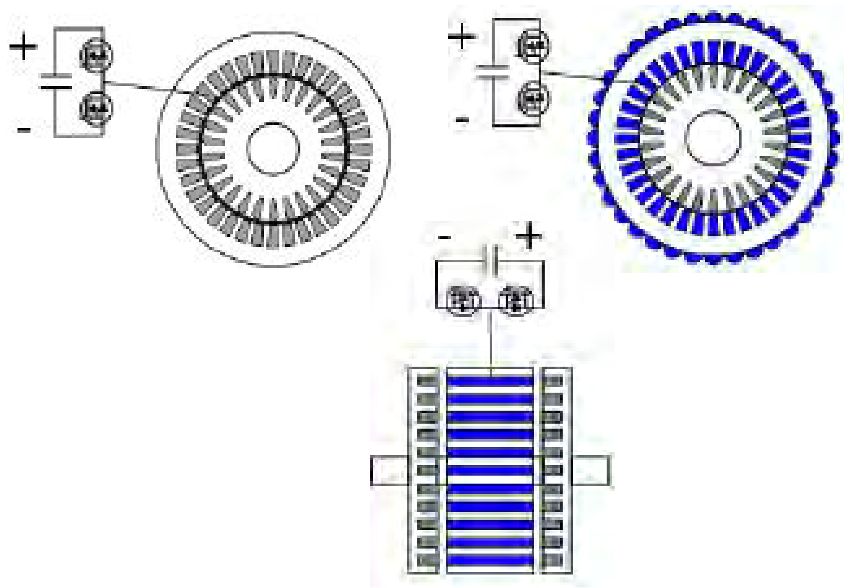
Modular automotive converters at KTH

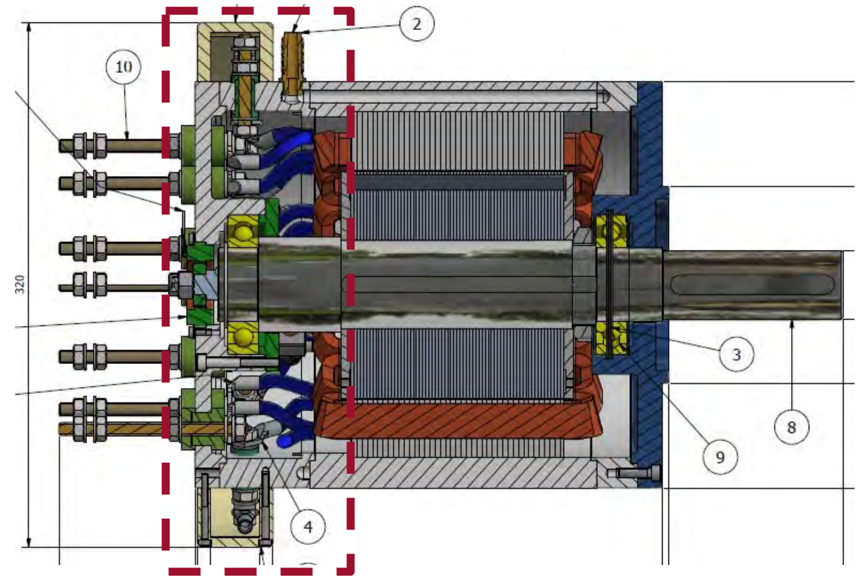




- Prototype designed at KTH with specifications from Volvo Cars Corporation (PhD student Hui Zhang)

New activities during 2017





- New PhD student on novel modular drive concepts and their integration
- New postdoctoral researcher on design of stator designs for mass production (American Axle, China Europe Vehicle Technology AB, Swerea/IVF)

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  - Swedish Energy Agency
  - Scania AB
  - Vinnova