Functionally Integratef E-axle Ready for Mass Market Third GENeration Electric Veichles

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Coiltech

Outline

- Introduction
- E-axle architecture
- Definition of E-axle requirements
- Components design
- Conclusions

Introduction to FITGEN EU project

In the last decade, **research interest in the field of road transport** moved from combustion engines to hybrid and electric vehicles

- Reducing emissions in urban areas
- Reducing environmental and acoustic impact
- Improving the life quality of the citizens

This trend was strongly supported by **private and public investments**

- New generation batteries
- Advanced e-motors and PE converters

FITGEN European project (H2020 LC-GV-01-2018 call) aims to **develop a brand-independent fully electric vehicle architecture**

Target

The FITGEN e-axle targets significant advances over the 2018 State of the Art:

1) 40% increase of **motor power density**
- 6-phase PM e-machine operating above 18.000 rpm

2) 50% increase of **inverter power density**
- SiC power switches

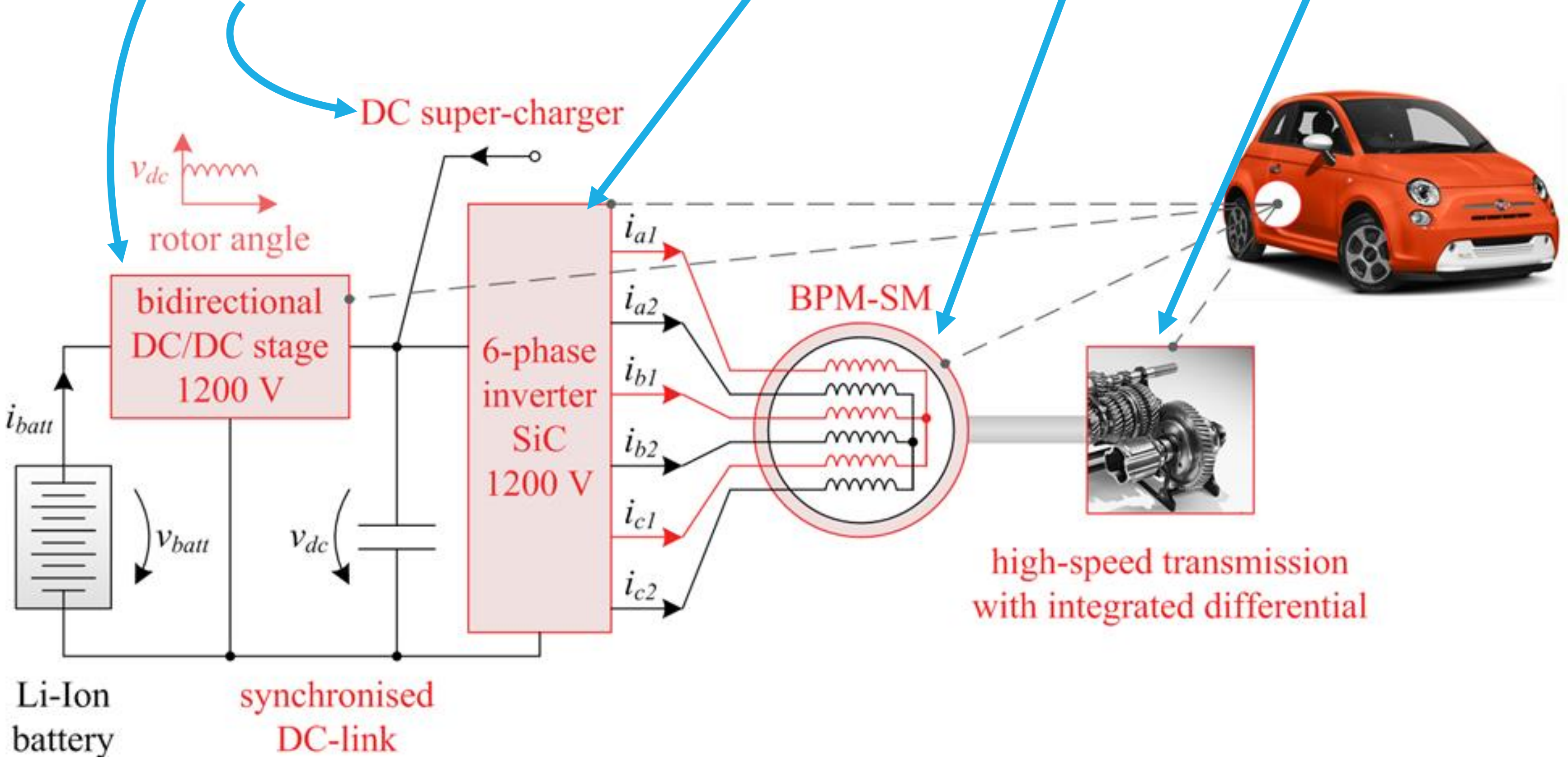
3) Affordable and integrated in-built **fast charge capability**
- 80 kW average, up to 120 kW peak power

4) Increase of **electric driving range** to 700-1000 km/day
- including 1h30’ of charging time

5) High level of industrialization (**TRL 7**)

E-axle architecture

Integration of **DC/DC converter**, **6-phase inverter**, **PMSM** and **transmission**, including **fast charging capability** and **OBC**



Partners

Austrian Institute of Technology (coordinator)

Centro Ricerche Fiat

Tecnalia

BRUSA

Politecnico di Torino

ST-I microelectronics

GKN

Vrije Universiteit Brussel

Definition of the e-axle

Reference platform

The FITGEN e-axle is designed to be **brand independent**

Reference vehicle platforms:

- A-segment 2 wheel driving BEV
- Small SUV 4 wheel driving PHEV
  (combustion engine in the front, e-axle in the rear)
- Large SUV 4 wheel driving BEV

Main contributor:

FIAT CHRYSLER AUTOMOBILES

CRF

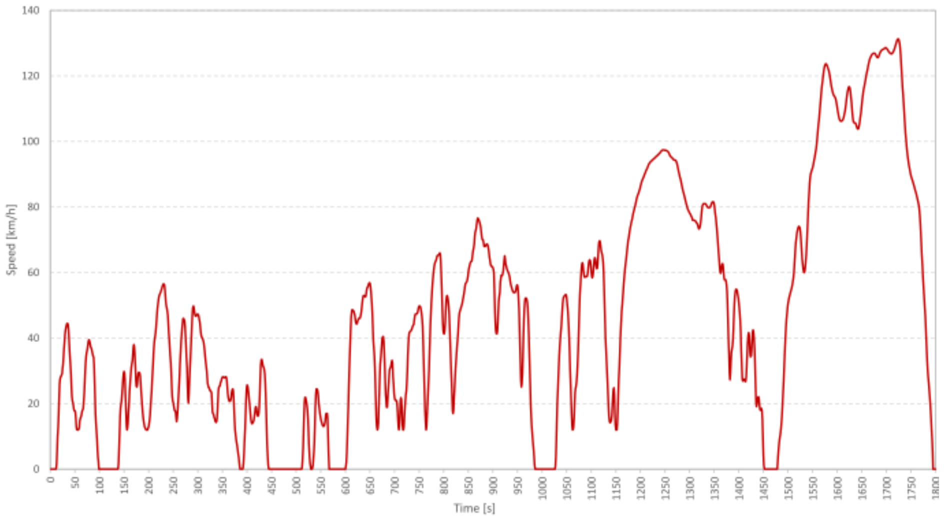
A full scale prototype e-axle will be integrated and tested on an A-segment pure EV mule in rear axle configuration

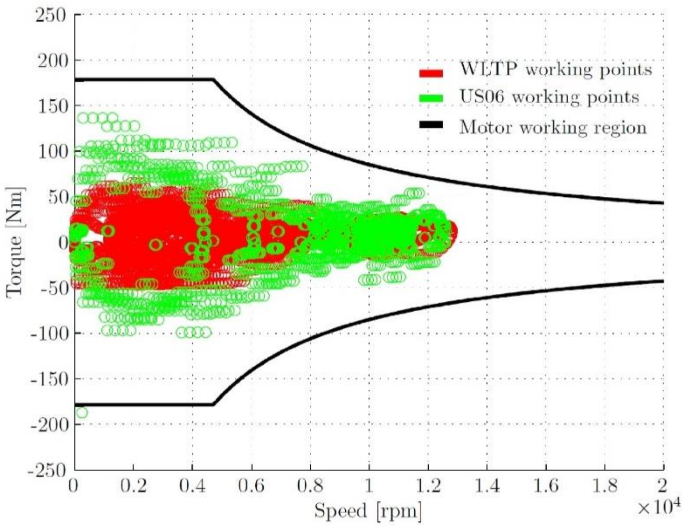
End-user requirements: speed profiles

The end user requirements were defined based on a **set of speed profiles**

- Homologation procedures (WLTP and US06)
- Driving cycles (experimental)
- Constant speed highway driving (target range: 700 km with three fast charges)

WLTP (large SUV)





WLTP: Worldwide harmonized Light vehicles Test Procedure

End-user requirements: reduction ratio

Two reduction ratios for the single speed transmission unit were considered (1:9.6 and 1:12.5)

The most demanding condition for the Large SUV platform, at a maximum torque and corner speed

- 240 Nm @ 3800 rpm for the 1:9.6 ratio
- 180 Nm @ 4800 rpm for the 1:12.5 ratio

The FITGEN preliminary design favors the **1:12.5 solution**, to allow the electric motor operation above 18 krpm

Components design

Hybrid synchronous motor

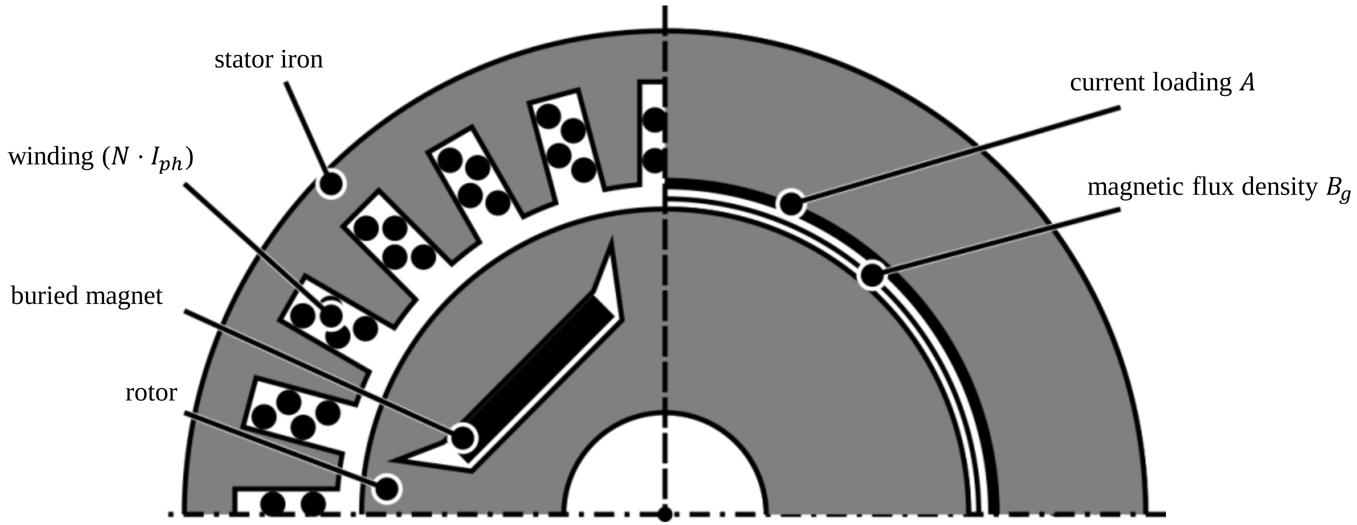
Buried Permanent Magnet Synchronous Machine (**BPM-SM**)

Optimal design criteria:

- Target rotational speed
- Losses evaluation
- Cooling system (overload)
- Winding technology

Main contributor:

BRUSA



Winding technology

Considering the **frequency dependency of the copper losses**:

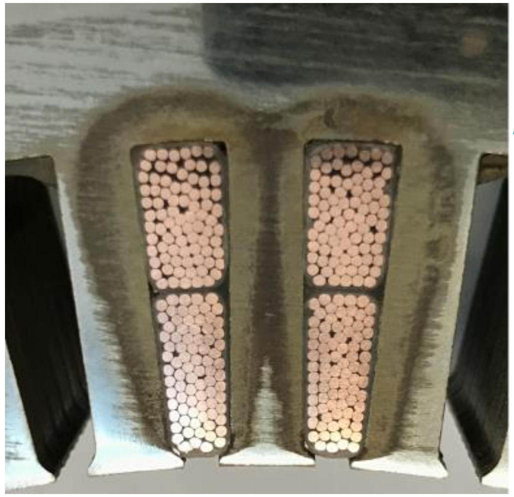
$$P_{cu} \propto I_{ph}^2 R_{ph,AC}(f_e)$$

where $R_{ph,AC}$ is the frequency dependent AC-phase resistance

Two types of winding technology are analyzed:

- Hair Pin Windings (HPW)
- Form Litz Wire (FLW)

Winding technology



HPW is formed by rectangular solid copper conductors

- Good slot fill factor
- Significant AC losses due to skin and proximity effects

FLW consists of stranded conductors that are inserted into the stator slots

- Slot fill factor is worse than HPW
- Greatly reduced skin and proximity effects

The FITGEN rotational speed (18 krpm) leads to very high electrical frequency (900 Hz)

Therefore, **FLW was chosen**

Single speed transmission

Mechanical transmission designed by GKN

Integration of high efficiency **reduction unit,** the **differential** and the **e-motor**

Electrically driven disconnect clutch (for hybrid vehicles)

Oil cooling , investigating the possibility of employing transmission cooling lubricating oil also to cool the e-drive

Main contributor:

GKN

SiC inverter

Main contributors:

life.augmented BRUSA

Functionally integrated with BPM-SM, DC/DC converter the on-board charger

Three-phase and six-phase scenarios are considered

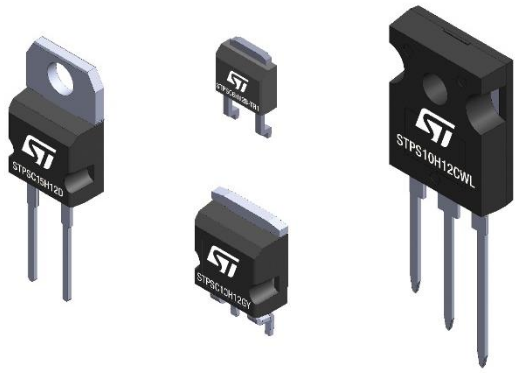
Inverter voltage and current size related to the size of the e-motor:

$$VA_{SOA} = \left(k_{v,SOA} k_{A,SOA} k_{motor,SOA}\right) P_{max}$$

Where

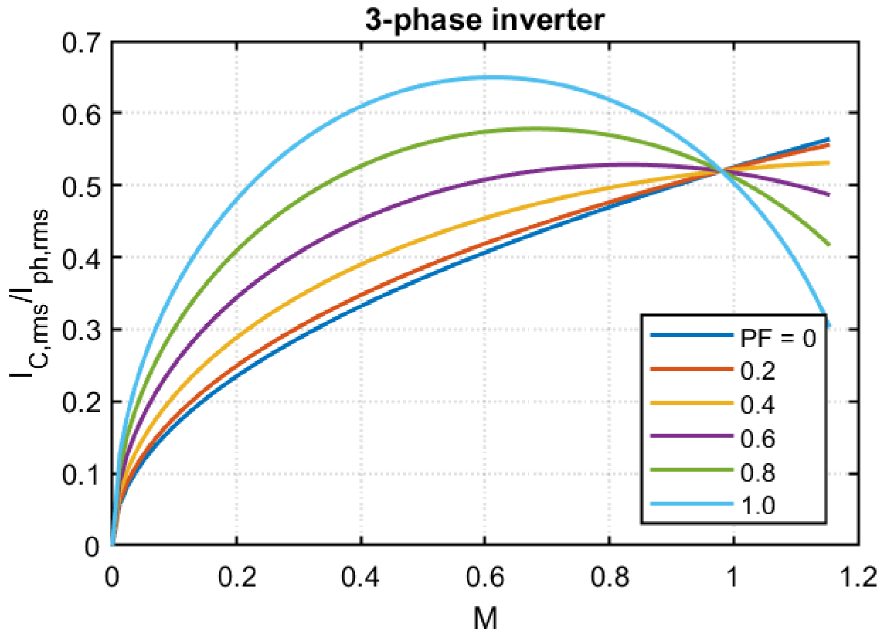
$$k_{V,SOA} = \frac{V_{SOA}}{\sqrt{3}\hat{V}_{ph,max}} \quad ; \quad k_{A,SOA} = \frac{I_{SOA}}{\hat{I}_{ph,max}} \quad ; \quad k_{motor,SOA} = \frac{1}{\eta \cos\varphi}$$

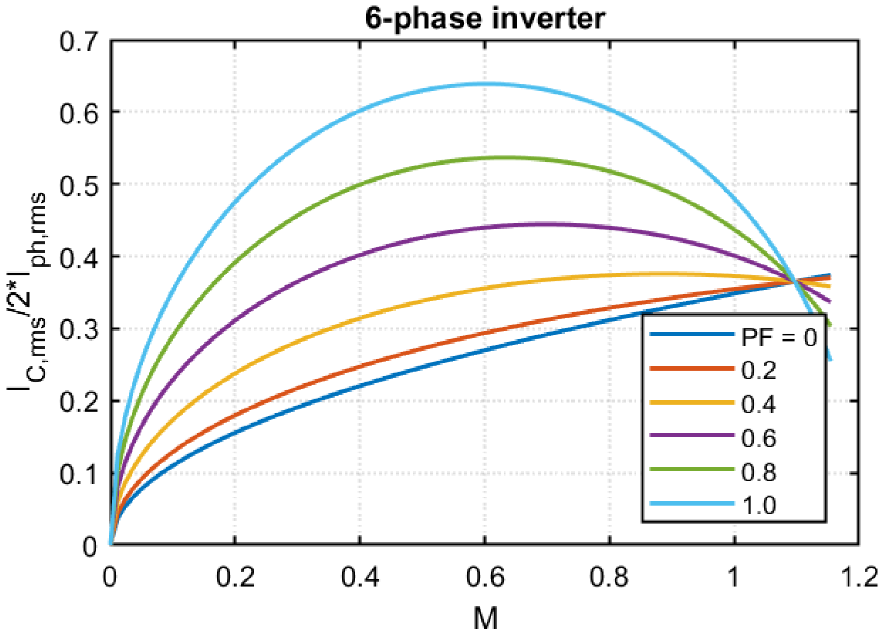
- The adoption of the DC/DC converter reduces the voltage factor $k_{V,SOA}$
- The adoption of the 6-phase configuration can (slightly) increase the e-motor efficiency and so the motor factor $k_{motor,SOA}$



SiC inverter: DC-link

6-phase configuration helps reducing the size of the DC-link capacitor especially in case of low power factor





$$I_{c,RMS} = I_{ph,RMS}\sqrt{2M\left[\frac{\sqrt{3}}{4\pi} + \cos^2\varphi\left(\frac{\sqrt{3}}{\pi} - \frac{9}{16}M\right)\right]}$$

$$I_{c,RMS} = I_{ph,RMS}\sqrt{2M[0.243 + \cos^2\varphi\,(2.468 - 2.25M)]}$$

SiC inverter: control strategy

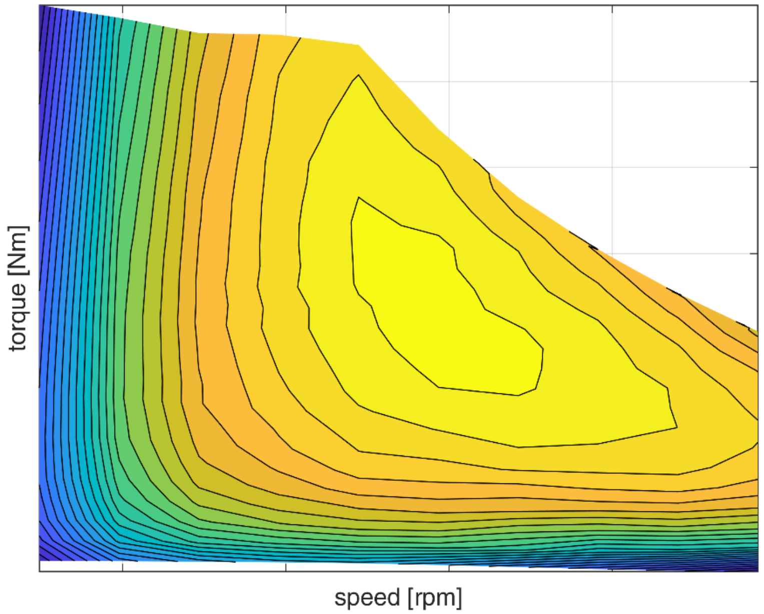
High **non-linearities** caused by the magnetic saturation effect

Electrical **parameters variation** due to machine ageing, manufacture tolerances and temperature dependency

Most common solution: **dq current control**

Sliding Mode Control will be also considered

Optimal current set-point generation algorithm, including Field Weakening



Main contributor:

tecnalia

Battery charging: DC/DC

The high voltage **DC/DC-converter** steps-up the battery voltage from a nominal 320-420 V, creating a controlled DC-link with a maximum rating up to 750 V

- **Motor and inverter current rating reduction** (450 to 200 A rms if 3-phase, 225 to 100 A rms if 6-phase)
- Compatibility with **high voltage DC-chargers** up to 750 V (with flexibility to lower rated values)
- **Smart-use of the DC-link voltage**

The Smart DC-link control enables instantaneous DC **voltage optimisation** in traction, minimizing the **switching losses** and possibly reducing the **number of commutations** by synchronizing the DC-link with the motor phase angle

Battery charging: OBC

A low-to-mid power **AC/DC on-board charger** is also foreseen, integrated into the powertrain

Three options under investigation:

- Single-phase charging with EMI filter (no PFC)
- Single-phase charging with EMI filter and PFC
- 3-phase charging with EMI filter

The first option uses the **inverter switches and the e-machine stator phases as coupled inductances** to realize an interleaved PFC rectifier

Main contributor:

POLITECNICO DI TORINO

Conclusions

- **FITGEN** H2020 project aims at developing a **functionally integrated e-axle**, demonstrated on an A-segment BEV platform
- BPM-SM: **maximum speed of 20 – 22 krpm** is targeted (increased power density), favouring a transmission reduction ratio of 1:12.5 and leading to T_{max}=180 Nm and n_b=4.8 krpm
- **FLW** against **HPW** are preferred for the stator design
- A **6-phase configuration of the SiC-inverter** is selected, improving efficiency, combined with a **DC/DC and smart DC-link** to enable fast charge and optimise voltage level in traction
- The system is complemented with an **on-board charger**

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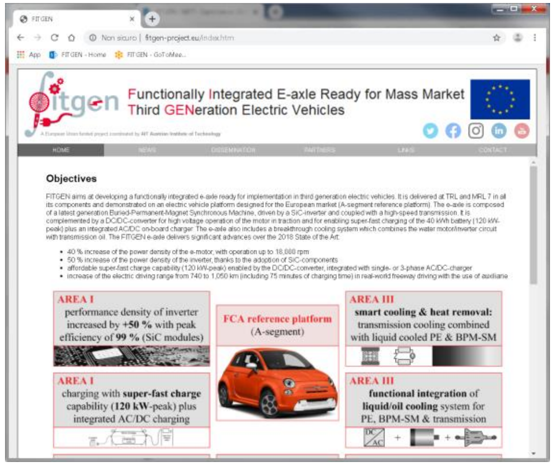

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Thanks for your attention

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