Demonstrator 3: Integrated on-board battery charging using multiphase machines and power electronics

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Introduction

Charging possibilities for EVs: ✓ Wireless battery charging ('on the move' and stationary) ✓ Wired (plug-in) battery charging using ✓ Single-phase or three-phase mains supply ✓ Dc charging stations Supply options: ✓ Two-level inverters/rectifiers

Multilevel multiphase inverters/rectifiers



Charger types: On-board charger (recommended) BUT: Takes space, adds weight, adds cost – when designed as a separate unit.





Concept of integrated on-board charger

- Re-use of the propulsion components in the charging process
- No additional space required, no weight added, no cost added.



Using a three-phase machine

- Three-phase machine: three-phase (fast) charging with zero torque not possible without additional components; singlephase (slow) charging with zero torque is possible.
- Passing three-phase currents through a three-phase motor during charging will not cause rotation since the voltage across the stator is small, but will nevertheless create rotating field and mechanical braking will have to be used.







Current semi-integrated solution (3-phase motor): Renault ZOE

43 kW "Chameleon charger"

- Inverter and motor (synchronous, with field winding) are integrated into the charging process. Dc from junction box charges battery through the neutral point of the 3-phase winding and the negative rail of the dc-link. No reconfiguration required.
- The junction box: 1) manages the charging process; 2) changes the alternating current to direct current; 3) communicates with the charging station.
- The system does require additional power electronic components.







Using a multiphase system instead of a 3-phase one

Advantages of multiphase machines include:
✓ Reduced current/power rating per-phase – this is relevant for EVs since, although the power may not be too high, voltage level may be low requiring high current.

✓ Additional degrees of freedom, which enable:

✓ Improved fault tolerance (relevant for propulsion operation – 'limp-home mode').

✓ Integrated on-board battery charging for EVs – as discussed further on, fully integrated on-board battery chargers can be realised, using both three-phase and single-phase supply, with zero torque generation during charging/V2G mode.



A current solution based on multiphase system concept: Valeo

The machine operates as a three-phase one in propulsion mode, but is in essence a symmetrical six-phase machine in charging and V2G modes; in propulsion mode each phase is supplied from an H-bridge inverter.

- Grid terminals are connected to machine windings' mid-points.
- Field is canceled within each winding no torque.
- No reconfiguration necessary.
- Machine has to be custom made (in essence symmetrical six-phase machine).







Five-phase topology

- Requires hardware reconfiguration, which however consists of only two switches as additional components.
- Phase impedances seen by different grid phases are not all equal (impacts on control).
- Space vectors of currents during charging are in the two planes governed with (pulsating excitation in both planes):

$$i_{\alpha\beta} = I \cdot \sqrt{2} \cos(\omega t - 0.659)$$

$$\underline{i}_{xy} = I \cdot \sqrt{2} \cos(\omega t + 0.659)$$



Asymmetrical six-phase topology

- Propulsion: dual three-phase winding with two isolated neutral points, vector control with two pairs of current controllers.
- Charging/V2G: hardware reconfiguration for fast charging; six-phase system of grid voltages obtainable from three-winding transformer with star/delta connected secondaries; single-phase charging by connecting two neutral points to the grid.
- No excitation in the first plane; only the second plane is excited.





Symmetrical six-phase topology

- Propulsion: dual three-phase winding with two isolated neutral points, vector control with two pairs of current controllers.
- Charging/V2G: hardware reconfiguration for fast charging; six-phase system of grid voltages obtainable from a transformer with open-end winding secondary; single-phase charging by connecting two neutral points directly to the grid.
- Both planes excited, but only by pulsating current:

$$\underline{i}_{\alpha\beta} = \sqrt{6}I\cos(\omega t) \qquad \qquad \underline{i}_{xy} = j\sqrt{6}I\sin(\omega t)$$











VEHICLE ELECTRICAL SYSTEMS INTEGRATION (VESI)

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A Video Presenting the Operation of the Demonstrator:

"An Integrated On-board Battery Charger Using a Highly Integrated Drive and a Ninephase Machine, with V2G Capability"





Single-phase charging: five-phase and six-phase systems

- In all systems with at least two neutral points single-phase supply can be connected between (any) two neutral points; no hardware reconfiguration is required.
- If phase number is an odd number, a suitable hardware reconfiguration has to be used a single switch suffices for any odd phase number. However, different number of phases is paralleled at two sides of the single-phase supply (this impacts on the control).



Efficiency testing results: singlephase grid

Efficiency results obtained with and without interleaving for charging/V2G, and with and without the dc-dc converter: Induction machine Permanent magnet machine



vesl

Efficiency testing results: three-phase grid

Efficiency results obtained with and without interleaving for charging/V2G, and with and without the dc-dc converter: Induction machine



Permanent magnet machine





<u>What's next</u>: We are keen and are looking for partners to take the solution(s) to TR5-TRL6 level through APC or Innovate UK or H2020 calls: if interested, please contact us!

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Thank you for your advice during project running!

