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Bidirectional Charge- and Traction-System

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Summary

The field of fast charging is diverse. Many solutions use dedicated additional costly components for each charging type. To push the E-Mobility market, a new system for charging is proposed comprising of E-Machine, Inverter and Boost DC/DC converter with a minimum of additional components. The new Bidirectional Charge- and Traction-System (BCTS) is capable for traction and all kinds of conductive charging with reduced system costs.

Keywords: inverter, charging, fast charge, AC motor, V2G (vehicle to grid)

1 Introduction

The electric vehicle (EV) market growth is below the expectations from beginning of this decade [1] [2]. Besides pricing per EV, the main technical reason is the limited range. To increase the range in principal two options are possible: Increase battery capacity or increase availability of (ultra) fast charging. An economic charging solution, making as little as possible changes in car and utility necessary is a key enabler for E-Mobility. Several high power charging solutions are available on the market: On the one hand 3-phase AC charging of about 20 kW and up to 43 kW. State-of-the-art chargers comprise always a dedicated rectifier only used in charging mode [3] [4]. The infrastructure usually supports about up to 20 kW only, mainly due to investment costs [3] [5]. Rare 1-phase solutions for medium power are available as well, like a 10 kW one-phase charger for the US market [6]. On the other hand DC charging for 40 kW and above is available as simple solution in the car for some car manufacturers, such as [7] [8] [9]. Vehicle costs are low, but infrastructure investments are high. Based on this situation the distribution of DC-fast charging stations is not sufficient and growing slowly [5] [10], except for single-company solutions like Tesla [9]. Latest publications ask for even higher charging power than available today [11]. Higher charging power is a must for long range vehicles due to both, growing battery capacities and the driver's request for short charging times.

The current situation of the fast-charging infrastructure is a classical chicken-and-egg problem. On the one hand the business case for fast-charging stations is difficult, since no EVs are charging. On the other hand there are no EVs, since their travelling without a charging station is not possible. With the Bidirectional Charge- and Traction System we present an attractive solution for E-Mobility to overcome this problem.

We introduce here an architecture with high power components covering both, the traction and the charging function. It reuses existing components in the car enabling AC fast charging. This enables reduction of investment costs for charging stations, since no expensive DC charging electronics are necessary. Furthermore, the system is compatible with existing DC charging infrastructure.

2 Bidirectional Charge- and Traction System

2.1 System Architecture

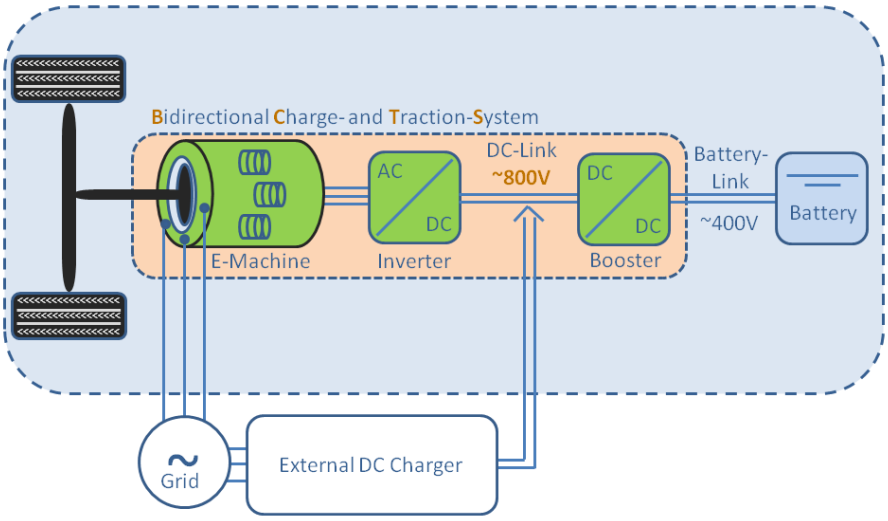

Figure 1: Bidirectional Charge- and Traction System (BCTS)

The Bidirectional Charge- and Traction-System (BCTS), as shown in Fig. 1, comprises mainly out of a serial connection of the following key components: The E-Machine, the Inverter and a Boost DC/DC Converter (DC Booster). There is no separate unit on board for the charging mode.

In ***traction mode***, when no plug is connected to the car, it is an energy-optimized architecture. The battery is connected via the Battery-Link to a DC Booster, which is used to stabilize the DC-Link voltage on an optimized maximal level. In partial load the control strategy reduces the DC-Link voltage to optimize the energy consumption and semiconductor lifetime. Furthermore the inverter costs are reduced significantly, since the system design can be optimized for a lower E-Machine/Inverter current. This also contains a lot of implicit benefits, like lower current, enabling lighter cables and connectors, lower switching transients, reduced electromagnetic interference (EMI) and higher efficiency.

To enable High-Power EV applications there is a trend for higher DC-Link voltage levels such as ~800 V [12]. The BCTS supports this trend.

In ***charging mode*** the main task is the transformation from the 1- or 3-phase AC mains power to DC power as input for the battery. To fulfil the grid requirements, a mains filter and an active rectifier is necessary. Further a DC/DC converter to adapt the rectifier output to the battery's needs. In case of an AC charging system, the charger is on board of the vehicle. In case of a DC charging system, it is inside the charging station. Both competing systems are available today, but either the car manufacturer or the public utility wants to avoid its additional cost. Reusing the inverter for this function is proposed in [13].

In the presented BCTS all three functions are included in components, which are already on board of the vehicle: The E-Machine stator is used as the AC mains filter, the inverter as the 1- or 3-phase rectifier and the DC Booster adapts the DC-Link voltage to the Battery-Link voltage for battery management. In principle, this solution could support AC charging with power as high as the installed continuous traction power depending on additional filter efforts. Counting both, vehicle and charging station, the system cost is optimized.

BCTS is also capable for (ultra) fast DC charging (charging above 100 kW). We propose the connection to the DC-Link (see Fig. 1). This reduces DC charging station costs, since it can operate on a stable voltage and an additional DC/DC converter in the charging station is not necessary[1]. Furthermore the charger is compatible to state-of-the-art systems at ~400 V that connect directly to the Battery-Link. So, this architecture is prepared for both, ~400 V and ~800 V DC charging stations.

[1] Such a charging station is not compatible to batter-link charging

For (ultra) fast charging, the charging cable becomes a major issue due to its weight and stiffness for the user. A transition to higher voltages offers lighter cables[2]. The BCTS offers a cost efficient high voltage (~800 V) solution.

Since all components are designed for bi-directional usage, an integration of the BCTS into Vehicle-to-Grid (V2G) applications is simply possible from power electronics point of view.

The BCTS can be beneficially used in all kinds of battery electric vehicles. In case of hybrid energy sources, a DC-Link management is needed anyway and a DC/DC Converter would be beneficial for the system efficiency. So it is prepared for the integration of a Fuel-Cell Range Extender, different independent battery packages and an ICE-based serial hybrid; a parallel hybrid is already an EV and thus prepared for the BCTS.

2.2 Use Cases

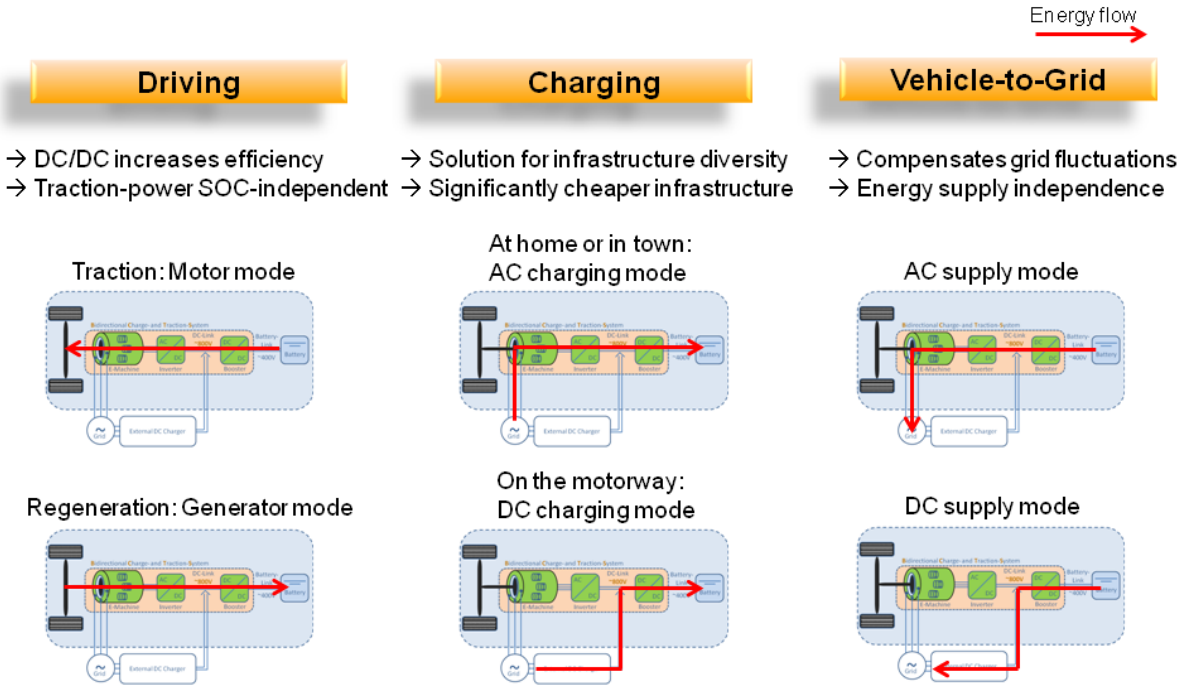

Figure 2: BCTS Use Cases

The BCTS is designed for three use case areas with six main use cases. Fig. 2 shows the energy flow paths for the different use cases.

The first area is **Driving** with the use cases traction and regeneration. In ***traction mode*** the battery is discharged via the Battery-Link, the DC Booster converts the voltage to the DC-Link in the range of battery voltage and 800 V output. The DC-Link supplies the energy flow to the inverter which converts the DC to AC for the E-machine. In ***regeneration mode*** the direction of the energy flow and the energy conversion in the BCTS components is reverse. Between high SOC and regeneration mode[3] to low SOC and full acceleration[4] the battery voltage has roughly a ratio of 2 (typically 450 V to 270 V). This wide range is covered by the DC Booster and no margin in the Inverter is necessary.

The second area is **Charging** with the use cases AC charging and DC charging.

The ***AC charging mode*** is split into the sub modes 1-phase charging and 3-phase charging. 1-phase charging uses the standard interfaces at every home. It is possible at both, 230 V and 110 V. The charging power hereby is limited to some kW only, depending on local regulations. 3-phase charging enables higher power with low investment costs in charging stations. All kinds of AC charging modes require a mains

[2] Competing concepts are charging robots or water-cooled cables.
[3] Battery voltage increases due to internal resistance
[4] Battery voltage decreases due to internal resistance

filter, a rectifier and a DC voltage adaptation on board. The maximal power is mainly limited by the on-board charger. The energy flow in the BCTS is as following: From the charger plug socket the 1- or 3-phase AC current is fed through the E-Machine via the opened star point. The inductance of the E-Machine is used as filter. Via the DC-Link the AC current reaches the inverter, which rectifies the current. The DC Booster sets the voltage down to the battery needs on the Battery-Link.

For the ***DC charging mode*** we propose the connection of the DC socket to the DC-Link so that the energy flow is going through the DC Booster towards the battery. This is beneficial since on the one hand the BCTS gives flexibility for different DC voltages in charging stations. Especially both, 400 V and 800 V charging stations can be supported without any modification on charging station side. On the other hand, the charging time is decreased by using a DC Booster on board. For this use case the charging power is not limited at low battery voltage ($P_{charge} = I_{cable} \cdot V_{bat}$), since a high voltage is always used between car and station ($I_{cable} < I_{bat}$) [12].

The third area is **Vehicle-to-Grid** with the use cases of ***AC supply mode*** and ***DC supply mode***. In both modes the direction of the energy flow and the energy conversion in the BCTS components is reverse to the *AC charging mode* and *DC charging mode*, respectively. These modes are possible, since no component on board is unidirectional (see Fig.1), since the *regeneration mode* already requires bidirectional components.[5]

2.3 Comparison with state of the art systems

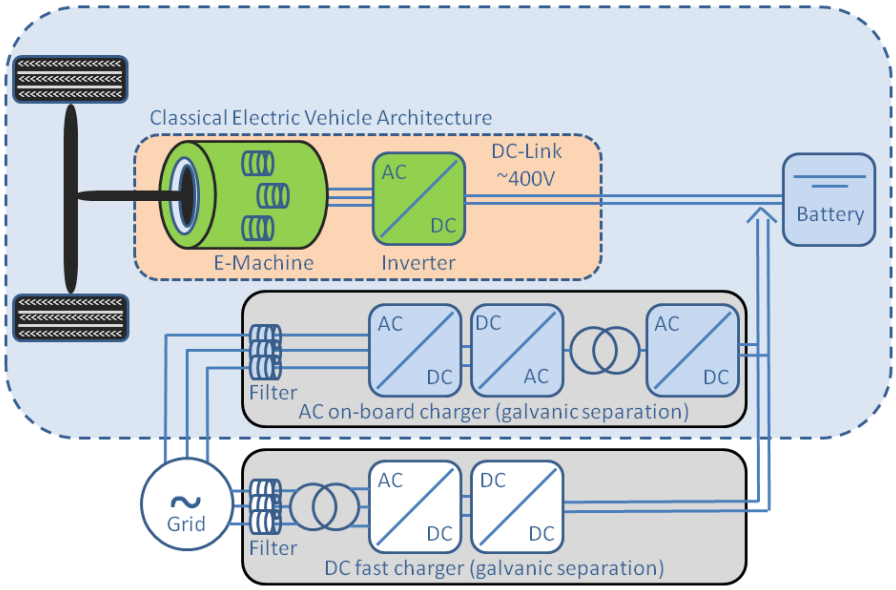

Figure 3: State of the art EV architecture for traction and charging

Today every EV on the market has a 1-phase AC charger on board. This comprises a mains filter, a rectifier (AC/DC) and a DC voltage adaptation (DC/DC). The DC/DC converter in this charger is unidirectional and has usually a galvanic separation [14]. It comprises a DC/AC inverter, a transformer and a AC/DC rectifier [15] (see Fig. 3). The 1-phase charging power is limited in some regions, like central Europe, to e.g. 3.7 kW due to grid regulations, which should avoid strong deviations on the mains [16]. Furthermore, increasing the 1-phase charging power leads to high current ripples on the DC-Link.

Several of the first EVs from 2010-2012, the ***Slow-Chargers***, were equipped with the 1-phase AC charging function only. With the introduction of 3-phase AC on-board charger from 2013 on, the charging power for the ***AC-Chargers*** increased to 22 kW. Although even 43 kW have been installed [3], the public charging stations often do not supply more than 22 kW, which is sufficient for a full charge of typical today's battery capacities in about one hour.

As an alternative for fast charging, the ***DC-Chargers*** have a direct connection for DC power supply to the Battery-Link. This keeps the power electronics for the conversion out of the car, but requires the same

[5] Bidirectional functionality of charging station required

functionality in the charging station (see Fig. 3).[6] Beside today's Battery-Link charging stations, in near future some 800 V DC charging stations could show up [12][17]. This requires either a dual voltage interface for the charging station or leads into an incompatibility for some cars. Technically, the *DC-Chargers* shall be prepared for DC power supply, depending on the features of the charging station and the implemented protocol.

DC charging stations are costly [3] and need more space. Today in urban areas, AC charging stations are more often present than DC charging stations. Both, the *Slow-Chargers* and the *DC-Chargers* can use the AC charging stations, but with the limited power of the 1-phase on-board charger. Therefore urban public charging often is more efficient for the *AC-Chargers*.

Fig. 3 depicts the state-of-the-art architecture for an EV with an AC on-board charger and the commonly used state-of-the-art DC-charging architecture [18][19]. *DC-Chargers* have already been used for V2G applications without extra hardware on vehicle side. Since V2G requires AC power supply, the DC/AC conversion is done with an extra unit off-board [20].

To overcome this diverse charging landscape it is a clever idea to equip the EV with all these charging interfaces. Today such ***All-Chargers*** have all the chargers as dedicated boxes for charging-only on board. This brings with it additional costs and requires additional installation space and thus is not yet seen for the mass market. With the **BCTS** we propose an advanced concept for the *All-Chargers* with reduced costs and installation space. Furthermore both, DC- and AC power supply, is possible. To be able to use the traction components as AC-Charger additional components are necessary. This is mainly affecting the motor configuration. Two switches are introduced to open the star point of the motor. To connect the system to the grid additional three phase switches are necessary like in any other existing charger. For the DC charging we propose the connection of the DC Socket to the DC-Link so that the energy flow is going through the DC Booster towards the battery. Since the DC-Link is designed for voltages between battery voltage and ~800 V, DC charging at all those voltages is supported. Thus the BCTS is compatible to any existing or planned charging system worldwide. Fig. 4 summarizes the comparison of the BCTS functions with state-of-the-art solutions.

Use cases / Vehicle types	AC Charging		DC Charging		Vehicle-to-Grid	
	1-phase (must have)	3-phase	@200-450V	@"800V"	AC	DC
Slow-Chargers	✓	✗	✗	✗	✗	✗
AC-Chargers	✓	✓	✗	✗	✗	✗
DC-Chargers @200-450V	✓	✗	✓	✗	✗	✓
DC-Chargers @"800V"	✓	✗	✗	✓	✗	✓
All-Chargers	✓	✓	✓	✗	✗	✓
BCTS	✓	✓	✓	✓	✓	✓

✓ Vehicle hardware sufficient (charging station potentially to be adapted) ✗ Vehicle hardware not sufficient

Figure 4: Functional benchmark summary of BCTS and state-of-the-art solutions. Vehicle types defined in text. DC-Chargers @ "800 V" and "800 V" charging stations not yet available in the market

3 Component development

3.1 Inverter

In principle, the Inverter used in the BCTS does not differ in hardware to a standard Inverter. The power stack is carried out in a B6C circuit for 3-phase operation. The used semiconductors are Si-IGBTs and Si-diodes.[7] In addition to the DC-Link voltage the power semiconductors are loaded by switching voltages generated by the unavoidable parasitic inductance of the internal interconnections. Therefore 1200 V IGBTs and diodes are used. The existing power module components have a power rating of approximately 200 kVA at 800 V DC-Link voltage. This corresponds to an E-Machine current of 225 A_{rms}.

[6] On top, a complex communication is needed for the battery monitoring system.

[7] Today, the usage of SiC-semiconductors wouldn't be economic, because the additional costs are out of proportion to the achievable inductor reduction.

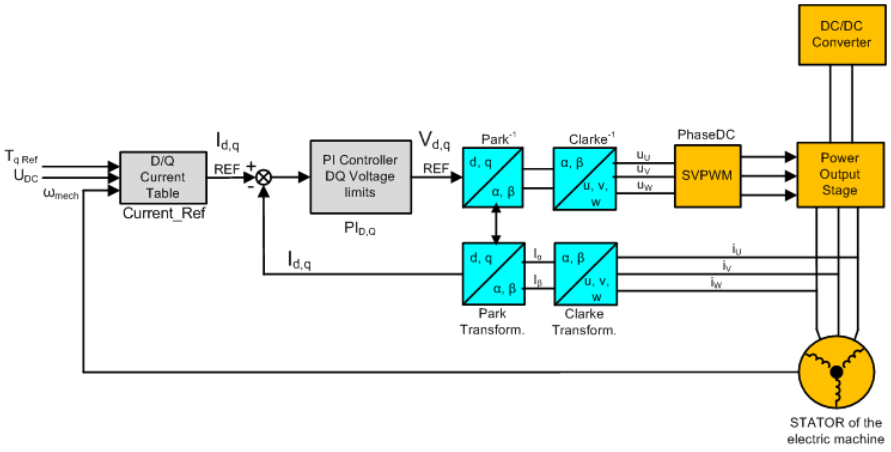

Figure 5: Inverter control architecture based on the field-oriented principle

The control software uses the field-oriented control principle (see Fig. 5). In addition to the standard *traction operating mode*, an additional *charging operating mode* is implemented.

In ***traction*** and ***regeneration mode***, while driving, the electric motor position encoder provides the mechanical position of the rotor which is used for the determination of the rotor field orientation. The switching frequency of the power stack is 10 kHz.

In ***AC charging mode***, the same field-oriented control is used in principle, but with an adapted parameter set. Additionally the phase voltages angle of mains supply instead of the position encoder angle is adapted (see Fig. 6). Similar to the *traction mode*, the power stack is switches at 10 kHz initially. It is also planned to investigate the increase of the inverter's switching frequency above 10 kHz to create positive effects regarding grid harmonics and performance. This is possible, since the traction power is greater than even the highest available 3-phase AC charging power, which is limited by grid installation (typically 43 kW corresponding to 64A in Europe) [16].

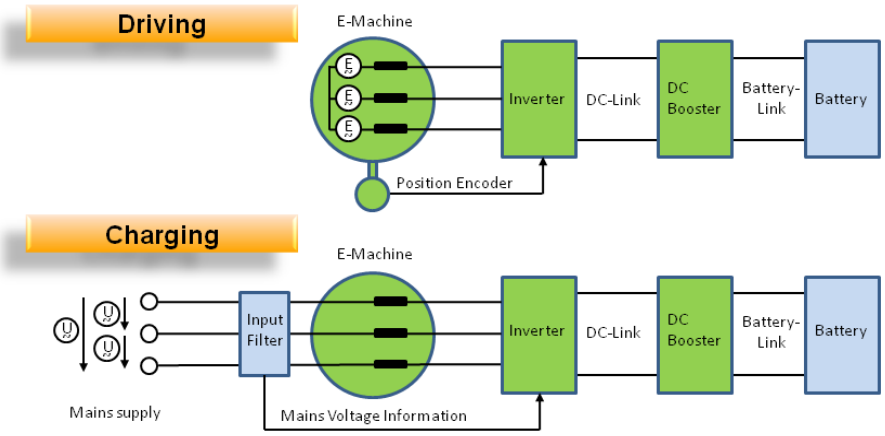

Figure 6: Schematical view of traction mode and charging mode in the Inverter software

With the field-oriented control, the Inverter adapts the different, speed dependent machine voltages to the DC-Link in both, *traction* and *regeneration mode*. Reusing this principle also for charging brings a simple adaption to the mains voltage and frequency. On top the power factor $\cos\varphi$ can be set and controlled even to values of 1 (see Fig. 7) or capacitive values.

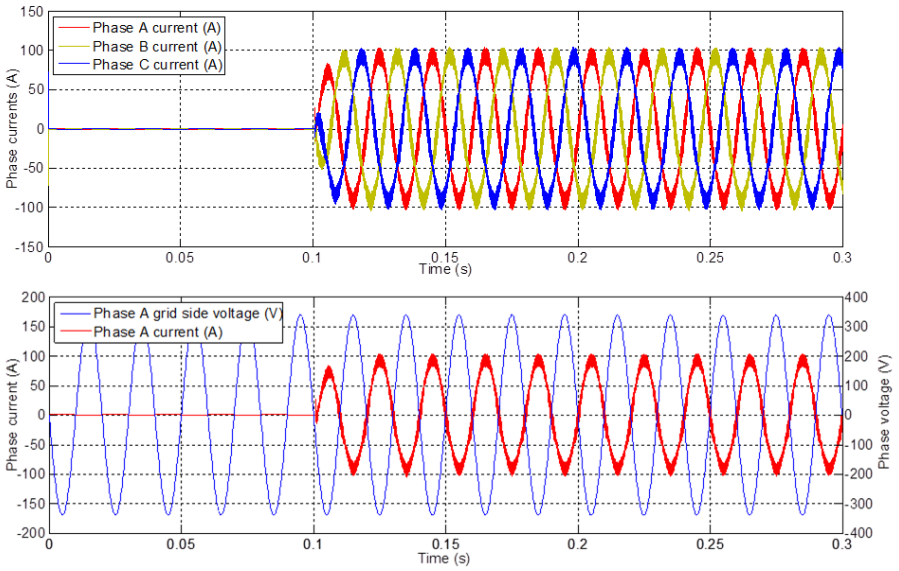

Figure 7: Simulation of 3-phase charging, starting after 100 ms. Top: Current of the 3 phases on Inverter input, Bottom: Current and voltage of phase A.

As unified solution [13], the 1-phase charging operation can be realized with the same principle, which was demonstrated by simulation (see Fig. 8).

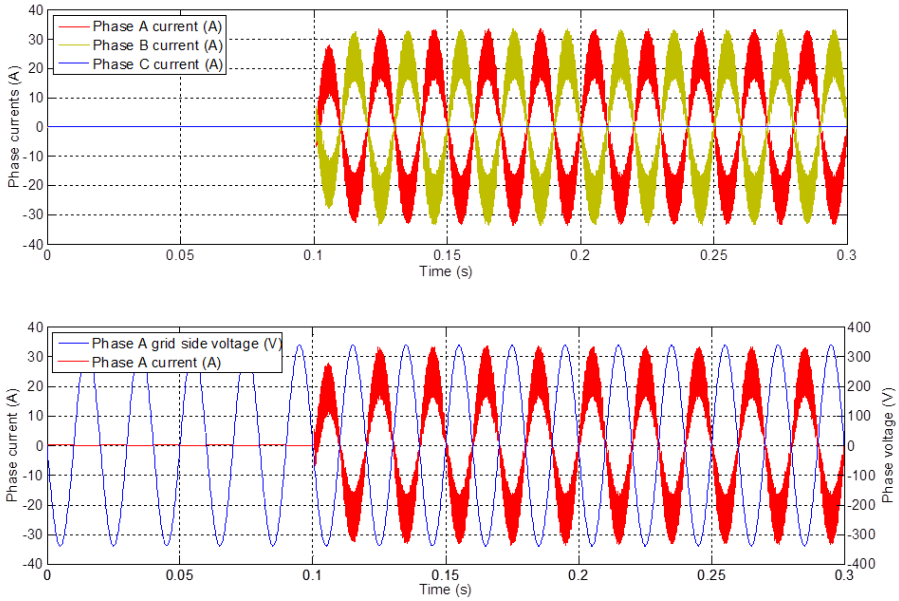

Figure 8: Simulation of 1-phase charging, starting after 100 ms. Top: Current of the phase A on Inverter input, whereas N is connected to phase B. Bottom: Current and voltage of phase A

3.2 Boost DC/DC Converter

The DC Booster for the BCTS shall step up the voltage from the Battery-Link to a controlled DC-Link voltage of up to ~800 V. Therefore an inductor as temporary energy storage is needed. To achieve a low overall size of this component, SiC MOSFETs are used as power semiconductor devices in this DC/DC Converter, enabling a high switching frequency of 80 kHz.

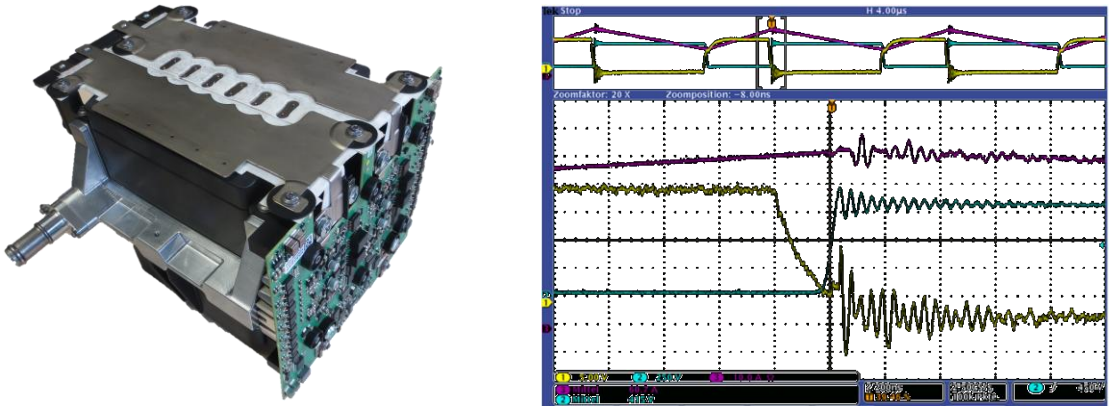

Figure 9: Integrated DC/DC prototype with SiC power module, capacitor, inductor and cooler (left), switch off transition at 25 kW one phase operation

A low inductive assembly concept is essential for power electronics with SiC fast switching semiconductors, i.e. this means among others a compact assembly. Therefore we had to limit the power of one converter module to 30 kW, since commercially available power modules have been used.

The first prototype (see Fig. 9) was realized as a step-up/step-down converter in H-bridge configuration. This is reasonable for overlapping input and output voltage ranges. For applications expecting the DC charging voltage to be always higher than the battery voltage, a single half bridge design is sufficient.

Higher power is generated by paralleling of such modules. The semiconductor switching timing is shifted according the number of modules. The DC-Link capacitors can then be downsized [21].

3.3 E-Machine

Figure 10: E-Machine Stator with hair pin winding technology and access to the three phases and the star-point.

For e-traction drives three-phase rotating field machines are beneficially applied, as externally excited synchronous machines, permanent magnet synchronous machines and induction machines. For these E-machine types different stator winding types can be realized. Distributed windings can be carried out as e.g. a round wire pull-in winding or a hair pin winding, concentrated windings – which are not feasible for induction machines – as a single tooth winding. Main design criteria are high copper filling factors, low stator heights (resulting in maximum rotor diameters within a given outer contour), short winding heads and a satisfying heat transfer from the stator copper into the stator stack, in addition to the further criteria of an automotive series production as easy scalability (here in stack length) [22].

Besides well known manufacturing applications for round wire pull-in winding, robust winding bodies gain more and more interest in automotive sector. So hair pin winding, a technology that hasn't been used in recent applications, is catching up due to best fit for the extreme size requirements of automotive branches.

Hair pin windings mostly consist of bended rectangular solid wires, inserted in the slots of the lamination stack. In fact producing this kind of stator is very time-consuming. Besides three dimensional bending of isolated wires and insertion into with isolation paper filled slots, every single pair of pins had to be interconnected by the use of specialized (laser) welding processes. Furthermore the winding heads had to be flattened using a twist treatment. Uprising aspects of this buildup is, that highest filling factors are reached (here in the range of 60 to 70% in a series mass production), the process itself is clearly definable and can be stabilized as well as hugely easy to handle. Systematic and casual errors – such as damaged wires due to layup on sharp edges – are nearly or completely visualized and can be solved in common [22].

The E-machine design for the described BCTS applications can be beneficially realized with the hair pin technology, as different circuit configurations (star or delta connection of the stator phases, series or parallel connections of the stator coils and also the separation of the star point connection) and the necessary design of the stator connecting points can be easily done with different modifications of simple bus bar connections (see Fig. 10). The E-machine cooling is carried out as a water jacket cooling, which is combined with the power electronic water cooling in one cooling circuit.

Based on a reference design for classical DC-Link voltages up to 450 V a derived modified E-machine design for DC-Link voltages up to 800 V for the BCTS will be created by an adaptation of the effective number of stator turns, while using the same lamination shapes and dimensions, beside the necessary enforcement of the insulation system and redesign of the air and creepage paths.

3.4 Switch

For the preparation of the *charging mode*, the BCTS requires the opening of the E-Machine's star point to connect the 3 inner machine phases to the mains phases independently. And for the preparation of the *traction mode* the star point shall be reestablished. This must be done with switches, which turn out to be a key component for the BCTS. A comparison of different switch technologies is shown in Tab. 1.

Since energy consumption is crucial in EVs, on-state losses is the most important selection criterion. Switching transitions in terms of dV/dt and current switch off capability are not important, since the switch is not active under load conditions and does not have to guarantee for safety disconnect. Based on this, we decided to choose contactors in the BCTS prototype system.

Table 1: Comparison of switch technologies

Element	On state losses per switch (@250 A)	Reverse state	Pro	Con
Contactor	R_{dson} ~ 1mOhm (begin of life) ⇨ P = 62,5 W	conducting	low on state losses	reliability, availability, noise
Thyristor	V_{on} ~ 1,4V ⇨ P = ~350 W	blocking		on state losses, availability
IGBT	V_{on} ~ 1,3V – 1,9V ⇨ P = ~350 W	diode conducting	component availability	on state losses
MOSFET	R_{dson} dependend ⇨ P = 100 W - 600 W	conducting	on state losses	

4 Summary

We have developed a cost efficient solution for E-Mobility targeting all kinds of conductive charging. It solves the chicken-and-egg problem of investment for fast charging electronics by reusing existing electronics in the car. It makes the charging station as simple as possible, which is AC charging. Furthermore all conductive charging interfaces can be used when the BCTS is installed. In this paper we have discussed the system architecture, the use cases and the needs and the current development status of the involved components.

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References

[1] "Global EV Outlook 2013," International Energy Agency, Apr. 2013.

[2] "Global EV Outlook 2015 Update," International Energy Agency, 2015.

[3] J. S. Johansen, *Fast-Charging Electric Vehicles using AC,* Technical University of Denmark, 2013.

[4] S. Loudot, B. Briane, O. Ploix and A. Villeneuve, "Fast charging device for an electric vehicle". EU Patent EP2406098 B1, 11 03 2010.

[5] C. Schwarzer, "Heise online," Heise Medien GmbH & Co. KG, 5 10 2015. [Online]. Available: http://www.heise.de/autos/artikel/DC-Ladeinfrastruktur-im-Alltagstest-2839530.html. [Accessed 30 10 2015].

[6] "Leistungssteuerung," Tesla Motors, [Online]. Available: my.teslamotors.com/de_DE/roadster/technology/power-electronics-module. [Accessed 30 10 2015].

[7] "BMW i3 aufladen," BMW, [Online]. Available: www.bmw.com/com/de/newvehicles/i/i3/2013/showroom/charging.html. [Accessed 30 10 2015].

[8] "Charging electric vehicles," Volkswagen, [Online]. Available: www.volkswagen.co.uk/technology/electric-technology/charging-electric-vehicles. [Accessed 30 10 2015].

[9] "Supercharger," Tesla Motors, [Online]. Available: www.teslamotors.com/supercharger. [Accessed 30 10 2015].

[10] *Position Ladeinfrastruktur-Ausbau in Deutschland,* Verband der Automobilindustrie e.V., 1.Juli 2015.

[11] "Schnellladenetz für Achsen und Metropolen," 2014-2017. [Online]. Available: www.slam-projekt.de. [Accessed 30 10 2015].

[12] C. Jung, O. Bitsche, N. Lobenstein, F. Grill and M. Falk, "The Future of Fast Charging: 800V," in *Advanced Automotive & Industrial Battery Conference (AABC) Europe*, Mainz, 2016.

[13] A. Arancibia, K. Strunz and F. Mancilla-David, "A Unified Single- and Three-Phase Control for Grid Connected Electric Vehicles," *IEEE transactions on smart grid*, vol. 4, no. 4, pp. 1780-1789, Dec. 2013.

[14] Mercedes-Benz company standard, *Electrical Characteristics and Electrical Safety of High-Voltage Components in Road Vehicles – Requirements and Tests*, Mercedes-Benz, 2014.

[15] O. Kilgenstein, Schaltnetzteile in der Praxis. Arten der Schaltregler, ihre Eigenschaften und Bauelemente, ausgeführte und durchgemessene Beispiele, Würzburg: Vogel, 1992.

[16] "E-Mobility: Ladekonzepte," VDE Verband der Elektrotechnik Elektronik Informationstechnik e.V., [Online]. Available: https://www.vde.com/de/e-

mobility/ladeinfrastruktur/ladekonzepte/seiten/default.aspx. [Accessed 10 03 2016].

[17] Efacec Electric Mobility, S.A., "efacec," [Online]. Available: http://electricmobility.efacec.com/ev-qcbus/. [Accessed 06 03 2016].

[18] VDE, *Standard Electric vehicle conductive charging system - Part 23: DC electric vehicle charging station*, Germany: VDE, 2014.

[19] Schneider Electric GmbH, "Schnell-Ladestation - Infrastruktur zum Wiederaufladen von Elektrofahrzeugen," [Online]. Available: http://www.schneider-electric.com/products/de/de/1800-evlink-losungen-zur-wiederaufladung-von-elektrofahrzeugen/1830-evlink-fur-schnellladung/60852-schnell-ladestation/?CATEGORY=1830. [Accessed 07 03 2016].

[20] K. Ogawa, "Vehicle-to-Home technology boosting the value of automobiles," Nikkei BP Japan Technology Report / A1407-060-011, 2014.

[21] D. Christen, S. Tschannen and J. Biela, "Highly Efficient and Compact DC-DC Converter for Ultra-Fast Charging of Electric Vehicles," in *15th International Power Electronics and Motion Control Conference*, Novi Sad, Serbia, 2012.

[22] W. Hackmann, M. Weseler, N. Pitarevic and R. Schmid, "Comparison of the Performance Capabilities and Impacts on Production of different E-traction Motors: Synchronous Machine, PM Machine, Induction Machine and Reluctance Machine," in *HdT-Tagung 'Elektrische Antriebstechnologie für Hybrid- und Elektrofahrzeuge'*, Munich, 2013.

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