Swiss Competence Center for Energy Research
Efficient Technologies and Systems for Mobility

Supported by:
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Innosuisse – Swiss Innovation Agency

Bidirectional Wireless Power Transfer System with Optimized Coil Geometry and New Control Method

Electric vehicles (EVs) offer the opportunity to use vehicle-to-grid technology to utilize the vehicle battery as a grid connected energy storage device and deliver power to the grid and local loads. Recently, wireless power transfer (WPT) in EVs has been studied by numerous researchers due to advantages such as convenience of wireless operation and safety in inductive power transfer. Design challenges for WPT systems in EVs include high efficiency, a large air gap, and good tolerance for misalignment. By optimizing the coupler coil geometry, the efficiency can be increased at different parking positions and ground clearances while limiting the electrical component stress. With a new control method, the semiconductor stress is minimized and the losses are reduced compared to conventional control. A fully functional prototype was built to test the V2G capabilities.

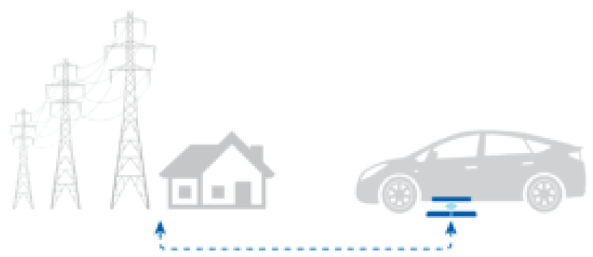
Simon Nigsch
University of Applied Sciences NTB
Institute for Energy Systems, Buchs SG, Switzerland
http://www.ntb.ch/ies/ / simon.nigsch@ntb.ch

Falk Kyburz
University of Applied Sciences NTB
Institute for Energy Systems, Buchs SG, Switzerland
falk.kyburz@ntb.ch

Kurt Schenk
University of Applied Sciences NTB
Institute for Energy Systems, Buchs SG, Switzerland
kurt.schenk.@ntb.ch

Motivation

Renewable sources of energy like wind and solar power have been playing an increasingly important role on the electric grid. However, it is challenging to maintain a balance between renewable energy availability and the peak energy demand placed on the grid. Distributed energy storage in the form of parked electric vehicles, which are connected to the grid and capable of bi-directional energy flow, is seen to have excellent potential for stabilizing the balance between supply and demand on the power grid.



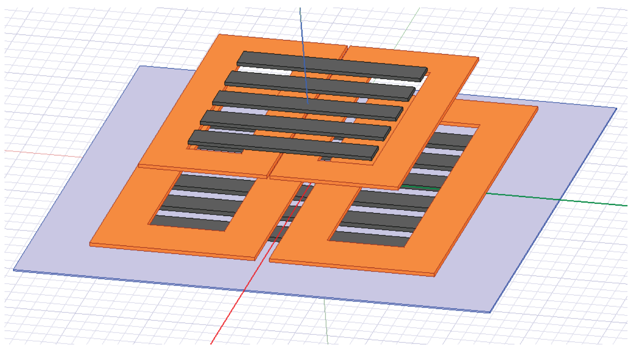
Specifications

The system is based on the key specifications shown in the table below. The bidirectional charging system can be connected to a standard single phase 16 A outlet and allows dis-/charging an EV within a few hours. The values for the ground clearance and the frequency range meet the standards IEC 61980 and SAE J2954.

Nominal power	3600 W
Input voltage	400 V
Battery voltage	330 – 440 V
Switching frequency range	81.3 – 90.0 kHz
Transmitter dimensions	360 mm x 450 mm
Receiver dimensions	500 mm x 500 mm
Ground clearance	100 – 200 mm
Misalignment	±75 mm / ±100 mm

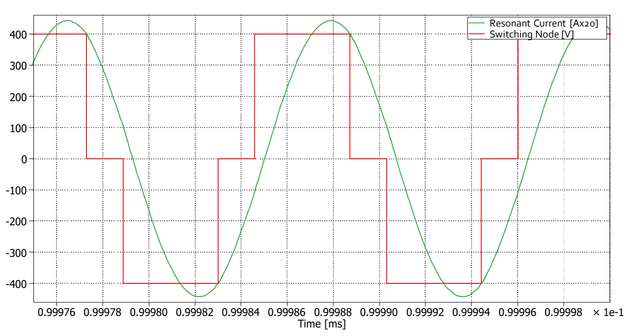
Optimized Coupler Design

The central element of an WPT system is the magnetic coupler. The geometric parameters of the coupler have a strong impact on the behavior of the system. With a new optimized double-D coupler design, the magnetic coupling variation is minimized for all parking positions. Moreover, the magnetic stray field for this winding design is much lower than other geometries, i.e., rectangular winding geometries.



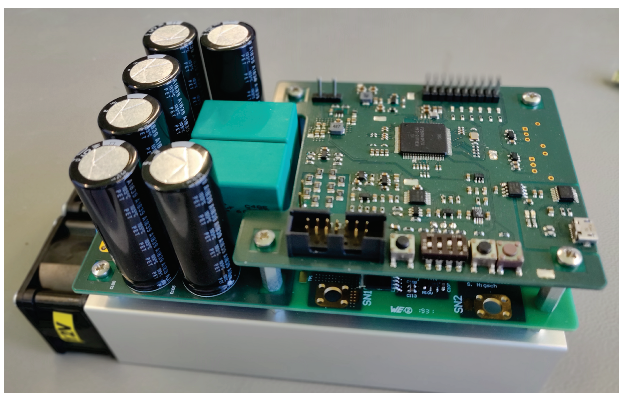
Control Method

For this design a series-series compensation method is used. This ensures zero voltage switching (ZVS) of the semiconductors. By using an additional phase shift control method, besides controlling the switching frequency, the switch turn-on current can be set to a minimum for reaching ZVS. This method reduces the losses and limits the dv/dt on the switch node which is beneficial for EMI reasons.



Mechanical Prototype

To verify the behavior of the bidirectional WPT, a fully functional prototype was built. A 3.6 kW wall box and receiver module was designed. The phase detection of the resonant current and controlling the dis-/charge current including communication between ground and car pad is implemented by means of a microcontroller.



Conclusion

In this work, a 3.6 kW bidirectional inductive charging system has been designed, optimized an built. A double-D magnetic coupler is the pivotal link that connects the EV to the grid and enables a bidirectional power flow. The new optimized coupler design enables a minimized coupling variation for all parking positions. Additionally, the magnetic stray field is smaller for this design compared to other coupler shapes.

To further optimize the transfer efficiency, a new control method is presented. Not only the switching frequency will be controlled to dis-/charge the battery, also the phase shift of the full bridge to maintain ZVS and keeping the turn-on current at a minimum. This further reduces the semiconductor losses and improves the EMI behavior. With this design, efficiencies similar to a conductive charging system are achieved with the additional benefit of improved safety and convenience.

References

[1] J. Marquart, F. Kyburz, C. Mathis and K. Schenk, "FEA assisted design and optimization for a highly efficient 22 kW inductive charging system for electric vehicles with large air gap and output voltage variation," *2017 IEEE Applied Power Electronics Conference and Exposition (APEC)*, Tampa, FL, 2017, pp. 3640-3647.

[2] R. Haldi and K. Schenk, "A 3.5 kW wireless charger for electric vehicles with ultra high efficiency," *2014 IEEE Energy Conversion Congress and Exposition (ECCE)*, Pittsburgh, PA, 2014.

[3] S. Li and C. C. Mi, "Wireless power transfer for electric vehicle applications," IEEE Journal of Emerging and Selected Topics in Power Electronics, March 2015

[4] G. A. Covic and J. T. Boys, "Modern trends in inductive power transfer for transportation applications," IEEE Journal of Emerging and Selected Topics in Power Electronics, March 2013.

Partners

NTB Interstaatliche Hochschule für Technik Buchs
FHO Fachhochschule Ostschweiz
thyssenkrupp
BATTERY CONSULT
energy depot
BRUSA