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.

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 bidirectional energy flow, is seen to have excellent potential for stabilizing the balance between supply and demand on the power grid.

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 and 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


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.

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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.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal power</td>
<td>3600 W</td>
</tr>
<tr>
<td>Input voltage</td>
<td>400 V</td>
</tr>
<tr>
<td>Battery voltage</td>
<td>330 – 440 V</td>
</tr>
<tr>
<td>Switching frequency</td>
<td>81.3 – 90.0 kHz</td>
</tr>
<tr>
<td>Transmitter dimensions</td>
<td>360 mm x 450 mm</td>
</tr>
<tr>
<td>Receiver dimensions</td>
<td>500 mm x 500 mm</td>
</tr>
<tr>
<td>Ground clearance</td>
<td>100 – 200 mm</td>
</tr>
<tr>
<td>Misalignment</td>
<td>±75 mm / ±100 mm</td>
</tr>
</tbody>
</table>

Table 1: Key system specifications

Partners

- NTB Interstadinche Hochschule für Technik Buchs
- thyssenkrupp
- BATTERY CONSULT
- energy depot
- BRUSA