Design and implementation of an 85-kHz Bidirectional Wireless Charger

Wireless charging and V2G market and grid integration

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Scenario & Goal:

First WPT prototype (2013-2014)

- Litz Wire
- IGBTs
  - Unidirectional
  - 20 kHz
  - 3.7 kW
- Semikron drivers


- Bidirectional
- 85 kHz
- 7 kW
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- System implementation
- Experimental results
- Control algorithm
- Conclusions
- Power Electronics for power transfer at 85 kHz (Recommendations SAE J2954)
- Bidirectional systems.
- Control system
  - Symmetric compensation topology (Series-Series)
Coil construction

Design based on an iterative algorithm with the main goals:

- Maximize the efficiency of the system
- Reduce the costs of the Litz wire
- Avoid bifurcation

![Graphs showing performance metrics](a), (b), (c), (d)]

Our design: to avoid bifurcation of the number of turns in the primary and secondary coils.
Coil construction

Secondary coil
(0.5x0.5 m$^2$,
14 turns,
20 mm$^2$)

Primary coil
(0.75x0.75 m$^2$,
11 turns,
20 mm$^2$)
Power electronics

SiC MOSFET

(switching frequency and power)

CREE KIT8020CRD8FF1217P-1 with C2M0080120D

Controller

Intel Edison + PIC16F18344 (Phyton)
Communication system

The controller has a Low Energy Bluetooth module

Maximum distance: 30 m
Communication rate: 24 Mbps
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❖ System implementation
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❖ Conclusions
## Experimental Results

### Electrical features of the WPT system

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>85 kHz</td>
</tr>
<tr>
<td>Primary coil dimensions</td>
<td>0.75 m × 0.75 m</td>
</tr>
<tr>
<td>Cross-sectional area of the primary coil wire</td>
<td>20 mm²</td>
</tr>
<tr>
<td>Resistance of the primary coil (R₁)</td>
<td>195.6 mΩ</td>
</tr>
<tr>
<td>Self-inductance of the primary coil (L₁)</td>
<td>240.5 μH</td>
</tr>
<tr>
<td>Secondary coil dimensions</td>
<td>0.5 m × 0.5 m</td>
</tr>
<tr>
<td>Cross-sectional area of the secondary coil wire</td>
<td>20 mm²</td>
</tr>
<tr>
<td>Resistance of the secondary coil (R₂)</td>
<td>143.1 mΩ</td>
</tr>
<tr>
<td>Self-inductance of the secondary coil (L₂)</td>
<td>230.6 μH</td>
</tr>
<tr>
<td>Distance between coils assumed in the design (gd)</td>
<td>0.2 m</td>
</tr>
<tr>
<td>Compensation topology</td>
<td>Series-Series</td>
</tr>
<tr>
<td>Capacitance of the primary side (C₁)</td>
<td>17.05 nF</td>
</tr>
<tr>
<td>Capacitance of the secondary side (C₂)</td>
<td>15.88 nF</td>
</tr>
<tr>
<td>Load resistance</td>
<td>24 Ω</td>
</tr>
</tbody>
</table>
Experimental results: charging the EV

<table>
<thead>
<tr>
<th>PRIMARY SIDE (GRID)</th>
<th>SECONDARY SIDE (EV)</th>
</tr>
</thead>
</table>

**Inverter input**

- Voltage
- Current

**Inverter output**

- Voltage
- Current

**Rectifier input**

- Voltage
- Current

**Battery**

- Voltage
- Current

<table>
<thead>
<tr>
<th><strong>Power</strong></th>
<th><strong>Voltage</strong></th>
<th><strong>Current</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>3.6 kW</td>
<td>288V</td>
<td>6.28A</td>
</tr>
<tr>
<td></td>
<td>287V</td>
<td></td>
</tr>
<tr>
<td></td>
<td>208mA</td>
<td></td>
</tr>
<tr>
<td>3.5 kW</td>
<td>288V</td>
<td>6.086A</td>
</tr>
<tr>
<td></td>
<td>6.38A</td>
<td></td>
</tr>
</tbody>
</table>
Experimental results: discharging the EV – injecting to the grid

<table>
<thead>
<tr>
<th>PRIMARY SIDE (EV)</th>
<th>SECONDARY SIDE (GRID)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Voltage</strong></td>
<td><strong>Voltage</strong></td>
</tr>
<tr>
<td><strong>Current</strong></td>
<td><strong>Current</strong></td>
</tr>
<tr>
<td><strong>Power</strong>: 2.72 kW</td>
<td><strong>Power</strong>: 2.65 kW</td>
</tr>
</tbody>
</table>

![Graphs showing experimental results](image-url)
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Control algorithm

Goals:

- To control the **power delivered** to the load while **restricting** some other electrical magnitudes.
- To work under **misalignments** conditions.

Primary current is clearly affected by misalignment
A phase-shift technique is implemented:
Implementation of the control algorithm
Control algorithm: results

(a) NO MALIGNMENT, (b) CONTROL

(a) NO CONTROL

(b) CONTROL

MISALIGNMENT

NO MISALIGNMENT

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Conclusions & Future work

- We have built a bidirectional 3.7-kW WPT system operating at 85 kHz (difficulty of the power electronics).

- Future work:
  - Control algorithms (misalignments, V2G services)
  - Communication systems
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