Theoretical and Experimental Comparison of Two Interoperable Dynamic Wireless Power Transfer System for Electric Vehicles

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Outline

• Introduction
• SS-Topology theoretical analysis (System A)
• TSS-Topology theoretical analysis (System B)
• Experimental Setup
• Experimental Results
• Conclusions
Introduction
Introduction

• Series-series compensation have been chosen for two compared systems.
• A transformer have been added at the primary side in order to add a degree of freedom in the design.
• The comparison between the two systems have been done considering the same receiver structure.

• SS-topology (System A)

• TSS-topology (System B)
SS-Topology (System A)

- High voltage (Voltage Rating), high current (Nominal Current) and high frequency (low ESR) capacitor is needed at the primary side.
- Find a capacitor that could satisfy all these requirements is an hard task!

\[ \Delta V_{C1} = \frac{I_1}{\omega_0 C_{1_{sysA}}} \]

\[ M = \frac{8 V_{in} V_{bat}}{\pi^2 \omega_0 P_2} \]

- No losses
- Rectifier at the secondary side
- Maximum battery voltage
- Maximum angle fire at the primary side
TSS-Topology (System B)

\[ I_1 = I_1' N, V_1 = \frac{V_1}{N} \]

\[ M = \frac{8 V_{in} V_{bat}}{\pi^2 \omega_0 P_2} \frac{1}{N} \]

Same Power

\[ \alpha \frac{1}{N} \]

Same receiver => only the transmitter number of turn could be changed

\[ \frac{1}{N^2} \]

Same resonance frequency

\[ \alpha N^2 \]
TSS-Topology (System B)

\[ M = \frac{8}{\pi^2} \frac{V_{in} V_{bat}}{\omega_0 P_2} \frac{1}{N} \]

- \( M \): Power
- \( L_1 \): Trasmitter
- \( C_1 \): Resonance frequency

\[ \Delta V_{C1} = \frac{I_1}{\omega_0 C_{1_{sysB}}} = \frac{NI_1'}{\omega_0 C_{1_{sysA}} N^2} \]

\[ \omega_0 = \frac{1}{\sqrt{(L_{lk} + L_1)C_1}} \]

Short-circuit inductance seen at the secondary side
# Experimental Setup

## Transmitter (System A)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmitter resistance, $R_1$</td>
<td>0.5</td>
<td>Ω</td>
</tr>
<tr>
<td>Transmitter inductance, $L_1$</td>
<td>280</td>
<td>µH</td>
</tr>
<tr>
<td>Transmitter capacitor, $C_1$</td>
<td>12.5</td>
<td>nF</td>
</tr>
<tr>
<td>Mutual inductance, $M$</td>
<td>14.3</td>
<td>µH</td>
</tr>
<tr>
<td>Transmitter coil length</td>
<td>150</td>
<td>cm</td>
</tr>
<tr>
<td>Transmitter coil width</td>
<td>50</td>
<td>cm</td>
</tr>
<tr>
<td>Transmitter coil number of turns</td>
<td>10</td>
<td>-</td>
</tr>
<tr>
<td>Wire diameter</td>
<td>5</td>
<td>mm</td>
</tr>
</tbody>
</table>
## Experimental Setup

Transmitter (System B)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmitter resistance, $R_1$</td>
<td>8.6</td>
<td>mΩ</td>
</tr>
<tr>
<td>Transmitter inductance, $L_1$</td>
<td>5.2</td>
<td>µH</td>
</tr>
<tr>
<td>Transmitter capacitor, $C_1$</td>
<td>600</td>
<td>nF</td>
</tr>
<tr>
<td>Transmitter coil length</td>
<td>200</td>
<td>cm</td>
</tr>
<tr>
<td>Transmitter coil width</td>
<td>58</td>
<td>cm</td>
</tr>
<tr>
<td>Mutual inductance, $M$</td>
<td>1.7</td>
<td>µH</td>
</tr>
<tr>
<td>Transmitter coil number of turns</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Wire diameter</td>
<td>10</td>
<td>mm</td>
</tr>
<tr>
<td>Transformer turn ratio, $N$</td>
<td>10</td>
<td>-</td>
</tr>
<tr>
<td>Transformer leakage inductance referred to low voltage side, $L_{lk}$</td>
<td>0.55</td>
<td>µH</td>
</tr>
<tr>
<td>Transformer magnetizing inductance</td>
<td>2.85</td>
<td>mH</td>
</tr>
</tbody>
</table>
Experimental Setup

Receiver

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Receiver resistance, $R_2$</td>
<td>0.3</td>
<td>Ω</td>
</tr>
<tr>
<td>Receiver inductance, $L_2$</td>
<td>120</td>
<td>µH</td>
</tr>
<tr>
<td>Receiver capacitor, $C_2$</td>
<td>29.2</td>
<td>nF</td>
</tr>
<tr>
<td>Receiver coil external length</td>
<td>60</td>
<td>cm</td>
</tr>
<tr>
<td>Receiver coil external width</td>
<td>40</td>
<td>cm</td>
</tr>
<tr>
<td>Receiver coil number of turns</td>
<td>10</td>
<td>-</td>
</tr>
</tbody>
</table>
Experimental Result

- **SS-topology (System A)**
  - 10 kW
  - Voltage at the H-Bridge converter (Magenta)
  - Primary current (Yellow)
  - Rectify current at the secondary side (Cyan)

- **TSS-topology (System B)**
Experimental Result

- Efficiency between the output and input DC power.
- The efficiency of the system B is lower respect the system A. This is due to the transformer introduction.

- Thanks to the introduction of the transformer the voltage at the capacitor side is lower for the system B.
Experimental Result

Ground current due to parasitics capacitance

- Insulation transformer
- AC/DC converter
- DC distribution line
- H-bridge converter
- Comp. cap.
- Transmitter coil
- Rectifier
- Battery converter
- Receiver coil
- Vehicle

SiC !!

H-bridge converter

SiC !!

DC distribution line

Vdc = 600 V

Omopolar Current

10m

Ground

Parasitics capacitance

10m
Experimental Result

System A

- Voltage at the H-Bridge converter (Green)
- Primary current (Yellow)
- Omopolar current (Cyan)

System B

- 18 $A_{peak}$
- 0, 46 $A_{peak}$
- 0, 065 $A_{rms}$
- 1 $A_{peak}$
- 0, 12 $A_{rms}$
Conclusion

• A transformer in the SS system have introduced in order to add a degree of freedom.
• Different benefits (Capacitor research simplyfied, EMC and EMI Reduction)
• Different drawbacks (Cost, Efficiency reduction)
Thank you for your attention

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