Boost Composite Converter Design
Based on Drive Cycle Weighted Losses in Electric Vehicle Powertrain Applications
Hyeokjin Kim, Hua Chen, Dragan Maksimovic, and Robert Erickson

Department of Electrical, Computer, and Energy Engineering, University of Colorado, Boulder, Colorado, 80309

Abstract
A weighted design optimization is introduced to minimize total loss of electric vehicle drivetrain power electronics over EPA standard drive cycles. It is shown that the net loss of the conventional boost converter can be reduced by a factor of 1.5 with this approach, while computational effort is reduced by three orders of magnitude. Even larger efficiency improvements are achieved by optimized boost composite converters: losses are reduced by factors of 4.5, 2.9, and 4.3 for US06, UDDS, and HWFET driving cycles, respectively. These design optimization results are experimentally verified with a 30 kW laboratory prototype boost composite converter, which demonstrates 98.4% average efficiency over the US06 driving cycle.

EV power conversion unit
- Decouples battery and machine optimization
- Inverter, motor, and system efficiencies can be higher, compared to the battery-inverter architecture.
- Boost converter design significantly contributes to the system efficiency.

EV powertrain simulation model
- Vehicle parameters are imported from Nissan LEAF vehicle.
- Motor parameters are estimated based on Parker PMAC motor.
- Variable DC bus voltage control scheme is employed for inverter DC bus voltage control.

US06 driving cycle simulation
- Required bus voltage and power are distributed over a wide operating range which necessitates boost converter optimization.

Weighted loss method for converter optimization
- Brute-force, point-by-point loss evaluation over a drive cycle requires a prohibitively large computational effort.
- Weighted loss method is proposed to reduce computational effort without loss of accuracy.

30 kW composite converter prototype experimental results
- Based on the weighted loss, composite boost converter is optimized and designed.

Design summary
- Buck / Boost
- MOSFET IPW65R041CFD
- Switching frequency 20 kHz
- Inductance 60 µH / 48 µH
- Transformer core METGLAS
- DCX
- MOSFET IPW65R041CFD
- Switching frequency 33 kHz
- Tank inductance 4.5 µH
- Transformer ratio 8 : 12
- Transformer core Ferrite

Vehicle simulation parameter
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle weight (Curb + occupants)</td>
<td>1493 + 250 Kg</td>
</tr>
<tr>
<td>Maximum speed</td>
<td>95 mph</td>
</tr>
<tr>
<td>Motor ratio</td>
<td>7.15</td>
</tr>
<tr>
<td>Motor poles</td>
<td>6</td>
</tr>
<tr>
<td>Nominal battery voltage</td>
<td>250 V</td>
</tr>
<tr>
<td>Maximum inverter DC voltage</td>
<td>800 V</td>
</tr>
</tbody>
</table>

30 kW composite converter prototype

Comparison of measured efficiency, loss model efficiency, and conventional DC-DC converter efficiency at 250 V, 650V bus, 15 kW and maintains high efficiency over a remarkably wide operating range.

Conclusions
- Required operating points over EPA standard driving cycles are distributed over a wide operating range which necessitates boost converter optimization.
- Weighted loss method is introduced to reduce the number of operating points to be considered, resulting in substantially reduced computing effort without loss of accuracy.
- 30kW laboratory composite boost converter projects 98.6% CAFE efficiency and 70.4 of converter quality factor.

References

Efficiency contour plot at 250 V in the bus voltage vs. power plane, and operating points over US06.