LEGO-PoL: A 93.1% 54V-1.5V 300A Merged-Two-Stage Hybrid Converter with a Linear Extendable Group Operated Point-of-Load (LEGO-PoL) Architecture

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Background & Motivation

Future data center needs 48V architecture & extreme high current computing system (CPUs, GPUs, and TPUs)

Challenge of PoL Converter
- High conversion ratio
- High output current
- High bandwidth
- High efficiency
- High power density

Fig. 1. Requirements of Point-of-Load (PoL) converter for future data center.

Traditional Approaches

Single-stage transformer based design (Fig. 2)
- High voltage conversion ratio
- Low efficiency
- Low power density
- Low bandwidth

Two-stage hybrid-switched-capacitor based design (Fig. 3)
- High efficiency with soft charging & soft switching operations
- High control bandwidth

- Resonant inductors (LPS, LPS, LPS) ➔ Additional loss & Low power density
- Decoupling capacitor (CPS) ➔ Low power density
- Series/Parallel connection ➔ Unbalanced voltage and current distribution

Merged-Two-Stage LEGO-PoL Architecture

Linear Extendable Group Operated (LEGO) Architecture (Fig. 5)
- One module (two units) ➔ Linearly extendable
- Group operated
- N series SC units ➔ N low voltage domains
- N parallel buck units ➔ N low current paths
- Output current sharing
- Input voltage balancing

Fig. 6. 54V-1.5V/300A LEGO-PoL Design.

Table I: Key parameters of a 54V-1.5V/300A PoL prototype

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Traditional two-stage PoL</th>
<th>LEGO-PoL</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1 &amp; G2</td>
<td>BS2013N05LS (25V, 1.3mΩ)</td>
<td>BS2013N05LS (25V, 1.3mΩ)</td>
</tr>
<tr>
<td>G3 &amp; G4</td>
<td>BS2025N04LS (40V, 2.5mΩ)</td>
<td>BS2025N04LS (40V, 2.5mΩ)</td>
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<tr>
<td>C1 &amp; C2</td>
<td>6µF, 63V, X7R, 3EA</td>
<td>6µF, 63V, X7R, 3EA</td>
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<tr>
<td>L1 &amp; L2</td>
<td>22µF, 18V, X7R, 45EA</td>
<td>22µF, 18V, X7R, 45EA</td>
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<tr>
<td>C5</td>
<td>BSZ013N2LS (25V, 1.3mΩ)</td>
<td>BSZ013N2LS (25V, 1.3mΩ)</td>
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<td>CDC</td>
<td>45µF, 63V, X7R, 45EA</td>
<td>45µF, 63V, X7R, 45EA</td>
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<tr>
<td>G1 &amp; G2</td>
<td>SiC632 (DrMOS, 24V, 50A)</td>
<td>SiC632 (DrMOS, 24V, 50A)</td>
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<tr>
<td>L1 to L12</td>
<td>1.0µH (XAL 1030-102)</td>
<td>1.0µH (XAL 1030-102)</td>
</tr>
</tbody>
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Switching frequency
- SC units: 125kHz, Buck units: 500kHz

Experimental Results

One Merged-Two-Stage Module

Fig. 4. Schematic of one submodule of Merged-Two-Stage LEGO PoL
- Merged operation ➔ No resonant inductor & No decoupling capacitor
- Inductors in buck unit ➔ Soft charging and soft switching operations
- SC unit ➔ Reduced switching loss & Reduced capacitor size

Design Example of LEGO-PoL Architecture

Three stacked submodules for 54V-1.5V/300A application

- Simplified bottom submodule
- Decoupled voltage and current stress
- Each module ➔ Low voltage & current stress
- Zero current switching in SC units
- Pulsed square wave current in all units
- Soft charging operation
- Reduced capacitor size
- Automatic current sharing operation

Fig. 7. Operational waveforms.

Fig. 8. Soft charging mechanism.

Fig. 9. Pictures of 54V-1.5V/300A LEGO-PoL prototype and experimental platform.

Fig. 10. Simulation results.

Fig. 11. Measured waveforms at 54V-1.5V/300A condition.

Fig. 12. Measured efficiency and loss analysis of 54V-1.5V/300A LEGO-PoL converter.