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)

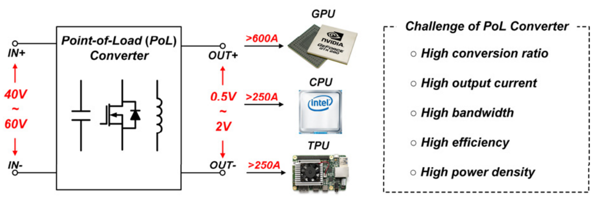
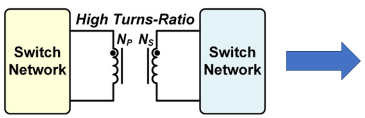


Fig. 1. Requirements of Point-of-Load (PoL) converter for future data center.

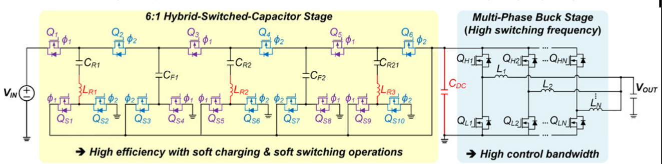
Traditional Approaches

➢ 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)



- **Resonant inductors (L_{R1}, L_{R2}, L_{R3}) → Additional loss & Low power density**
- **Decoupling capacitor (C_{DC}) → Low power density**
- **Series/Parallel connection → Unbalanced voltage and current distribution**

One Merged-Two-Stage Module

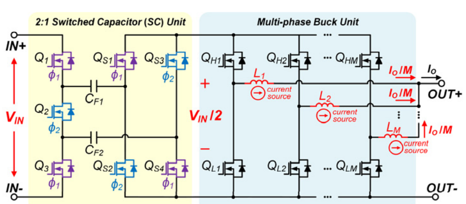
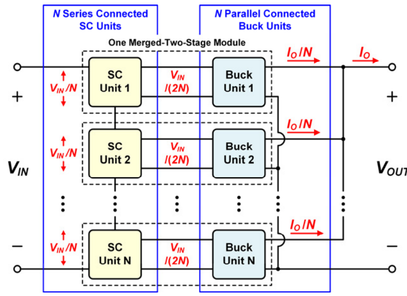


Fig. 4. Schematic of one submodule of Merged-Two-Stage LEGO PoL

- **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**

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**
  - **→ Output current sharing**
- ***N* parallel buck units**
  - **→ *N* low current paths**
  - **→ Input voltage balancing**

Design Example of LEGO-PoL Architecture

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

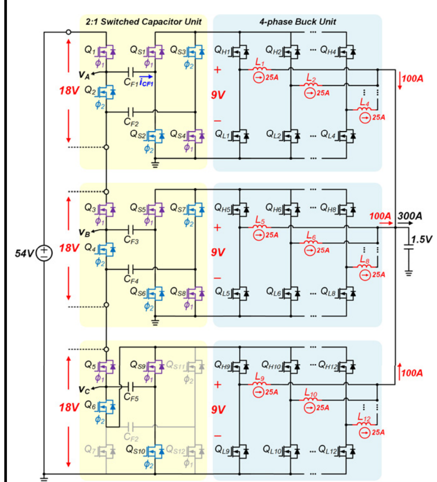


Fig. 6. 54V-1.5V/300A LEGO-PoL Design.

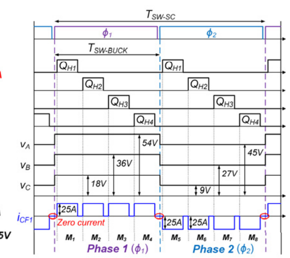


Fig. 7. Operational waveforms. (SC units achieve ZCS operation)

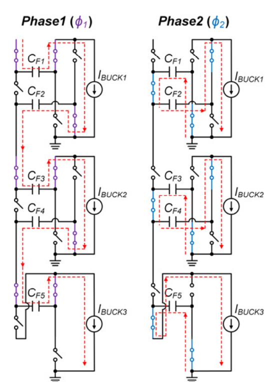


Fig. 8. Soft charging mechanism. (Charge balancing requirement)

- **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**

Experimental Results

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

	Traditional two-stage PoL	*LEGO-PoL*
Q_1 & Q_6	BSZ013N2LS (25V, 1.3mΩ)	
Q_2 - Q_5	BSZ025N04LS (40V, 2.5mΩ)	
Q_{S1} - Q_{S10}	BSZ013N2LS (25V, 1.3mΩ)	
C_{F1}-C_{F4}	10μF, 63V, X7R, 45EA	10μF, 63V, X7R, 13EA
C_{F5}	10μF, 25V, X7S, 45EA	10μF, 25V, X7S, 13EA
C_{DC}	22μF, 16V, X7R, 45EA	-
Q_H & Q_L	SiC632 (DrMOS, 24V, 50A)	
L_1-L_{12}	1.0μH (XAL 1030-102ME)	
Switching frequency	SC units : 125kHz, Buck units : 500kHz	

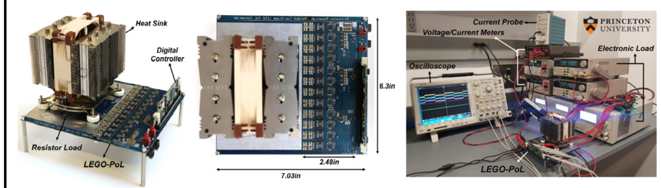


Fig. 9. Pictures of 54V-1.5V/300A LEGO-PoL prototype and experimental platform.

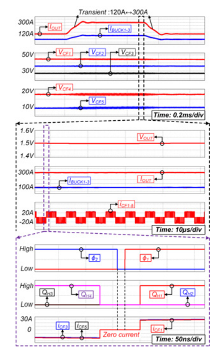
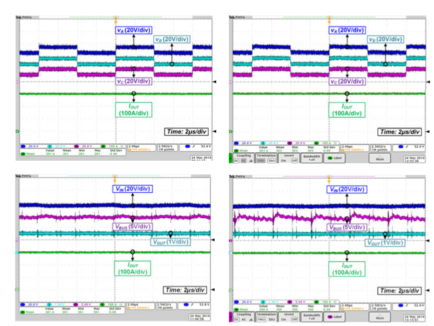
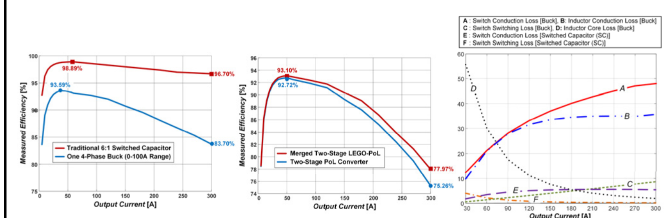


Fig. 10. Simulation results.



(a) Traditional PoL. (b)Proposed LEGO-PoL.

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



(a) Traditional PoL. (b) LEGO-PoL. (c) Loss analysis of LEGO-PoL.

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