

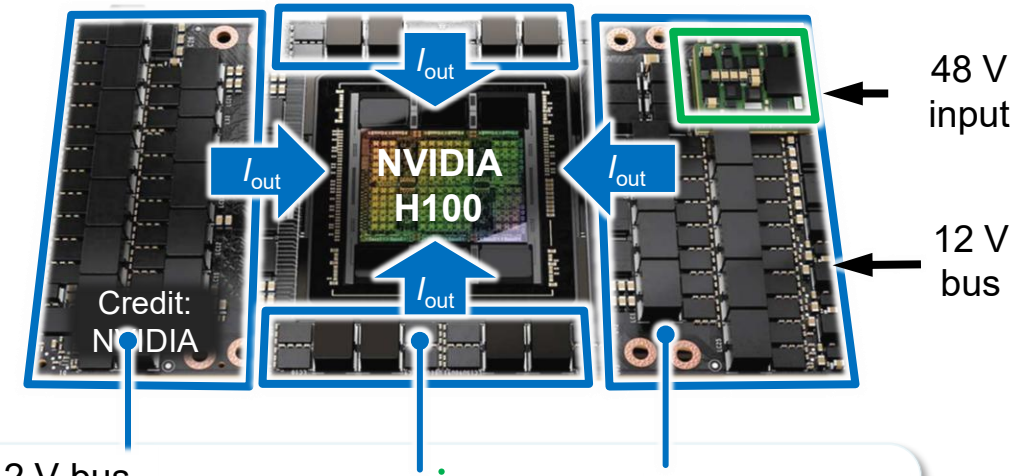
Compensation-Winding-Current-Based Constant On-Time Control of Trans-Inductor Voltage Regulators (TLVRs)

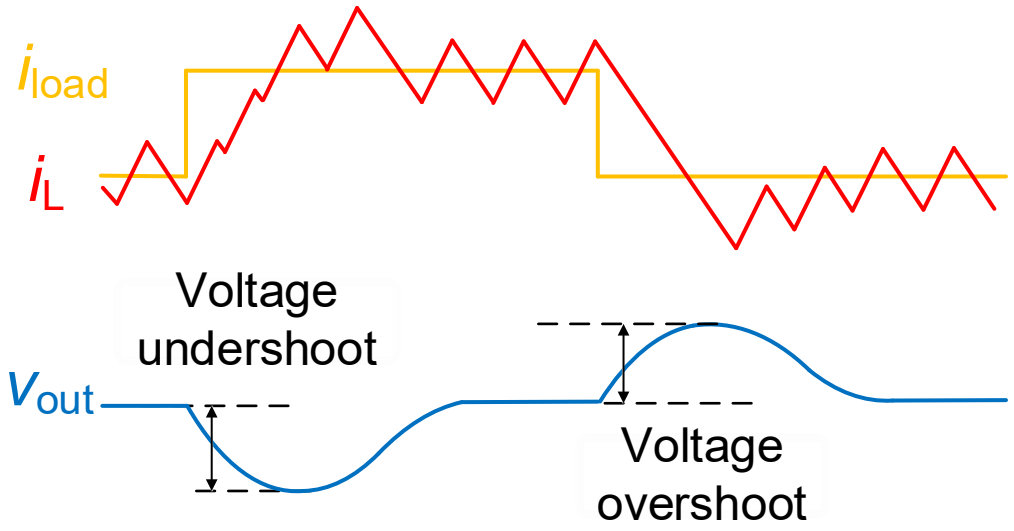
Shuyu Zhang, Yicheng Zhu, Nathan Biesterfeld, and Robert C. N. Pilawa-Podgurski
University of California, Berkeley
Email: shuyu-zhang@berkeley.edu

BPEC
Berkeley Power & Energy Center

Fast-transient converter is a must in datacenters

- Two-stage power delivery architecture





To limit the output voltage deviation (ΔV) :

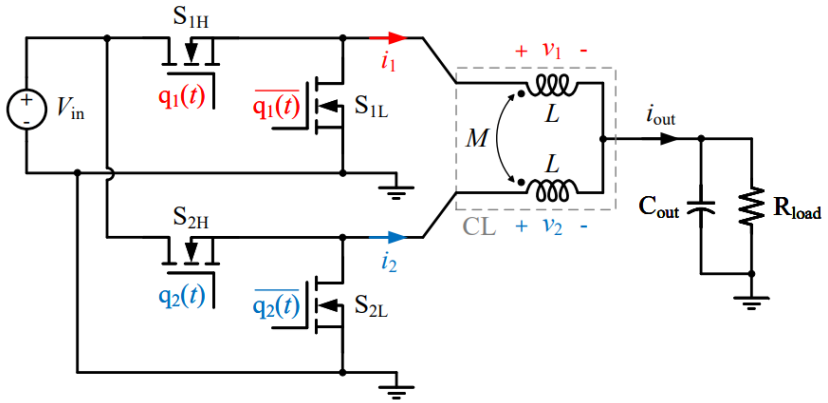
→ **increase slew rate of $i_{L,sum}$**
(e.g. by reducing the inductance)

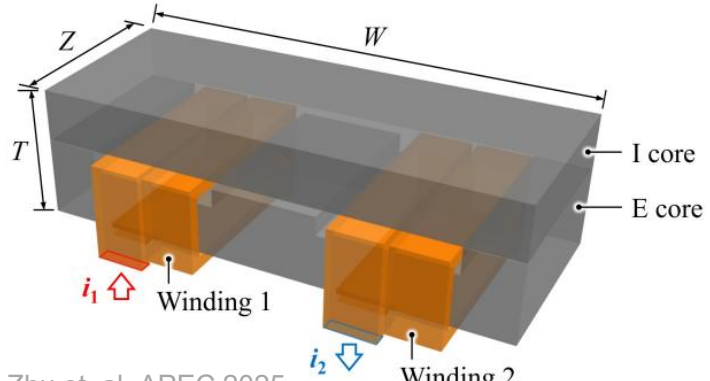
Coupled inductor and TLVR

Coupled inductor: Pros and cons

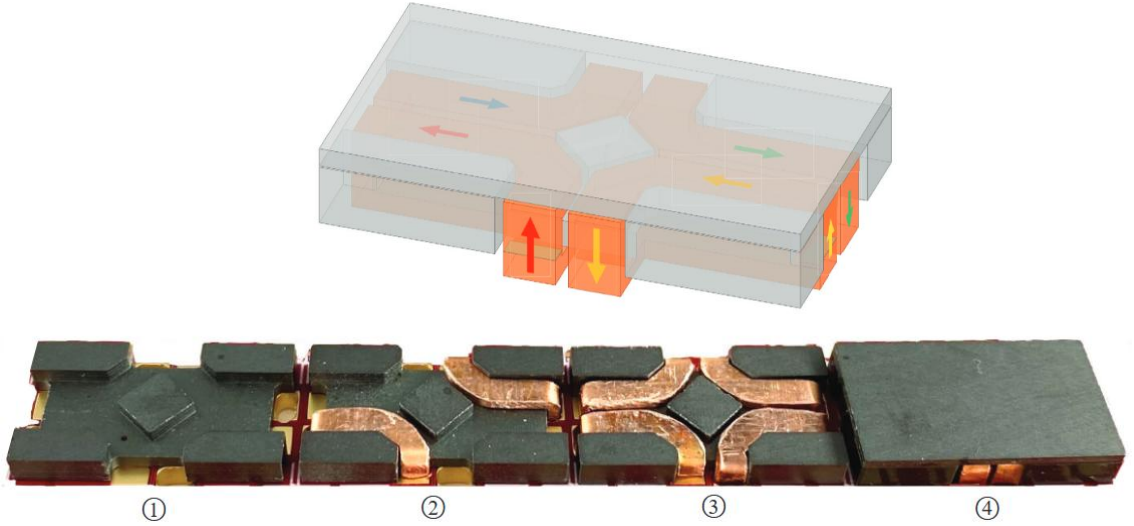
- Faster transient response
- High power density

- Proprietary
- Limited PCB layout flexibility
- Difficult coupling control





Y. Zhu et. al. APEC 2025

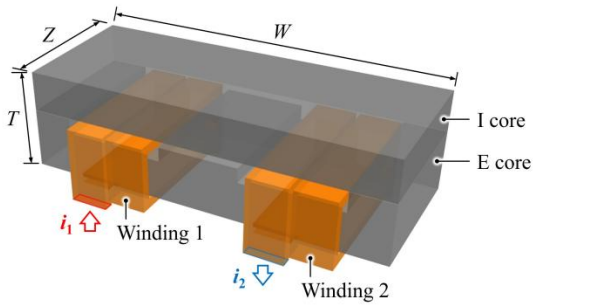


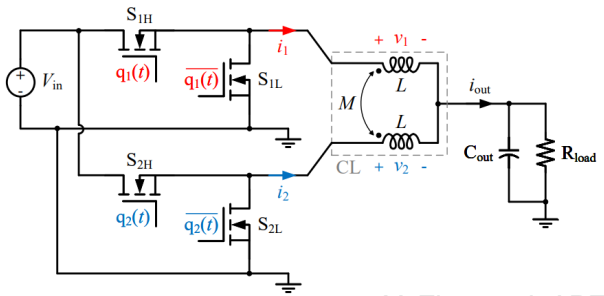
Y. Zhu et. Al TPEL 2024

Coupled inductor and TLVR

Coupled inductor

- Proprietary
- Limited PCB layout flexibility
- Difficult coupling control

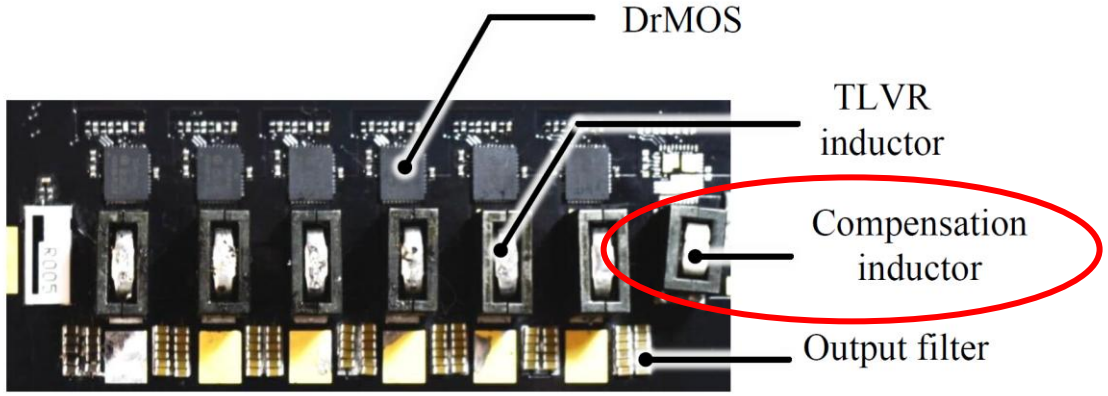




Y. Zhu et. al. APEC 2025

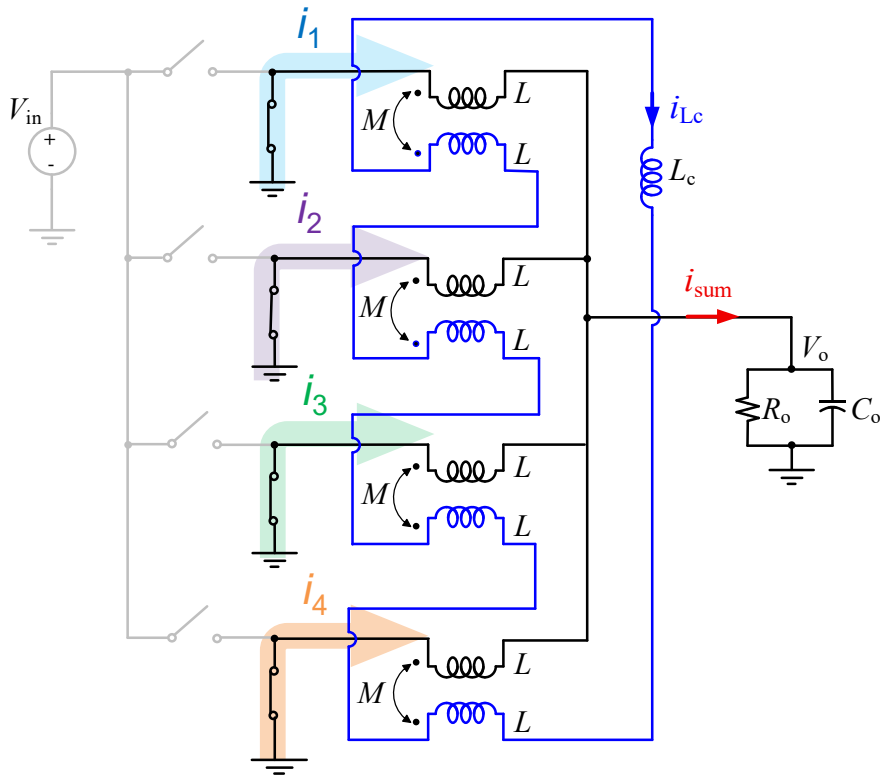
TLVR

- Non-exclusive
- Simpler magnetic design
- Good scalability to high-phase-count
- Adjustable coupling

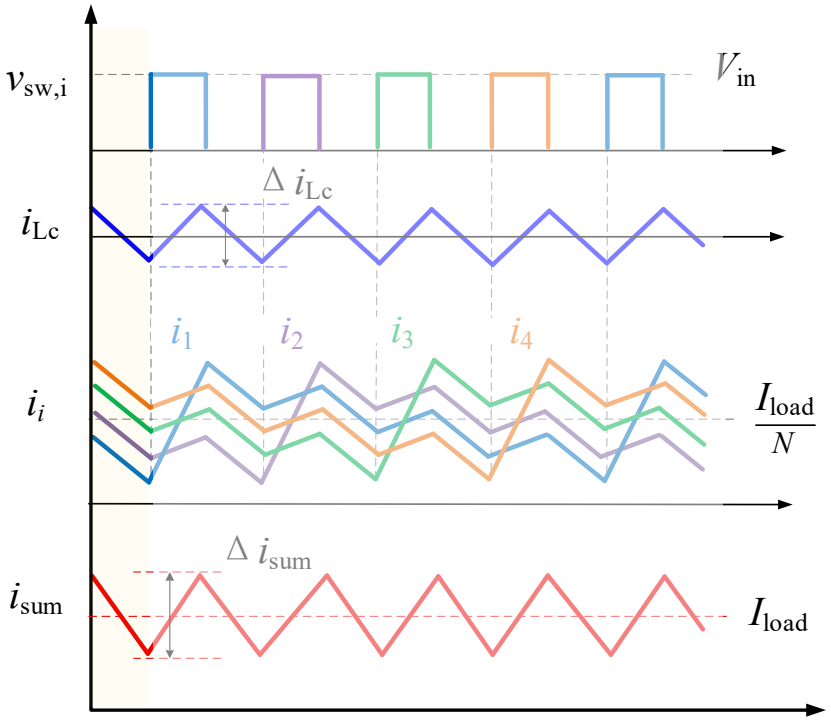


TLVR operation

- All phases off

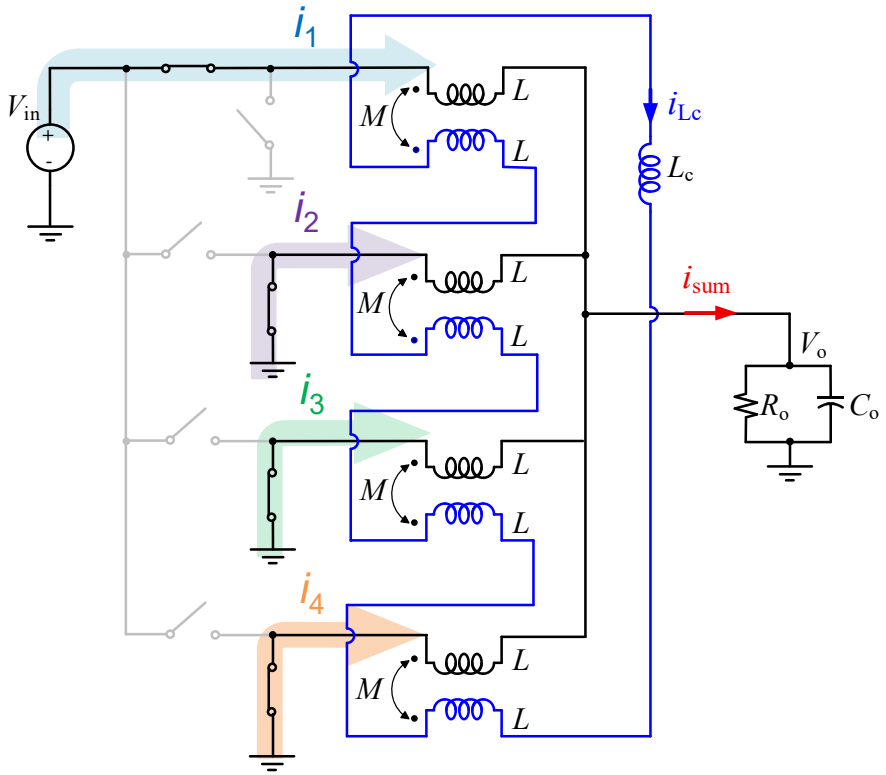


Every phase discharges

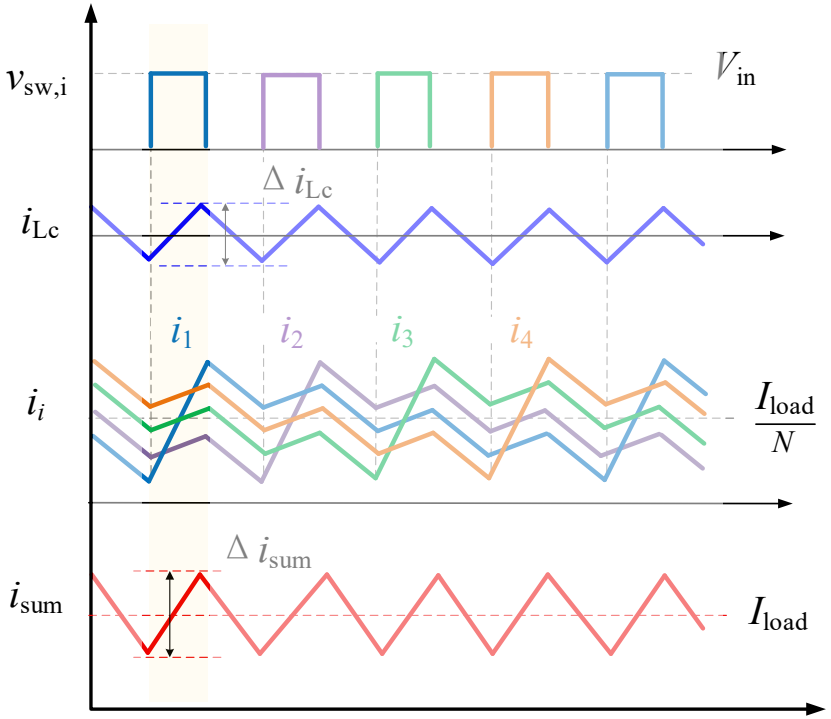


TLVR operation

- Phase 1 ON
- Apply voltage to L_c winding!

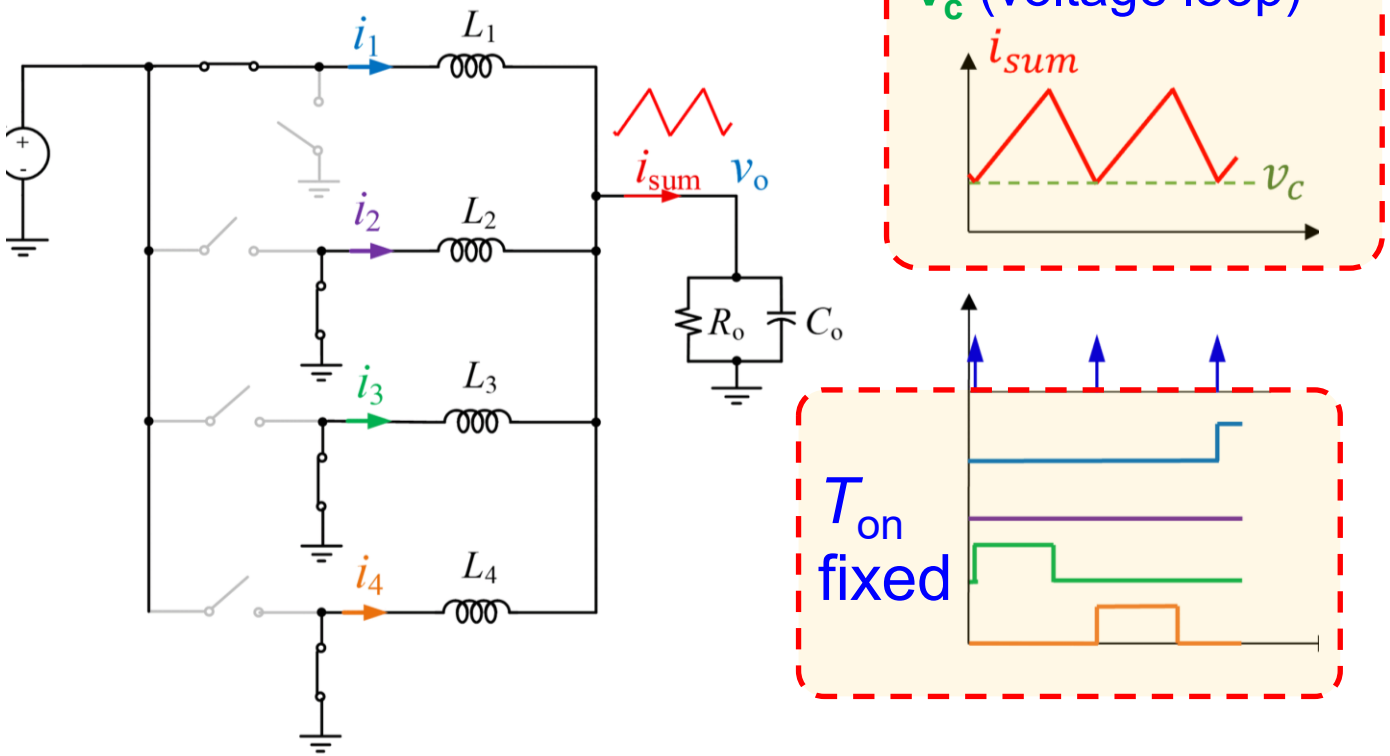


L_1, L_c charged
→ Every phase current rises!

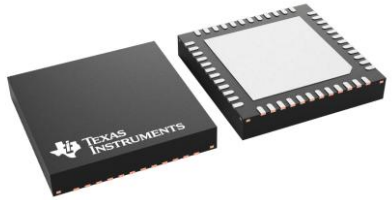


Multiphase COT control

- Multiphase interleaved buck:
- Constant on-time (COT) current mode control

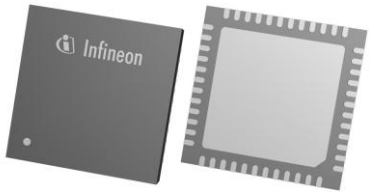


- Commercial multiphase buck **COT controllers**



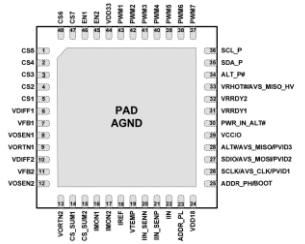
TPS536C7

Credit: TI



XDPE152C4D

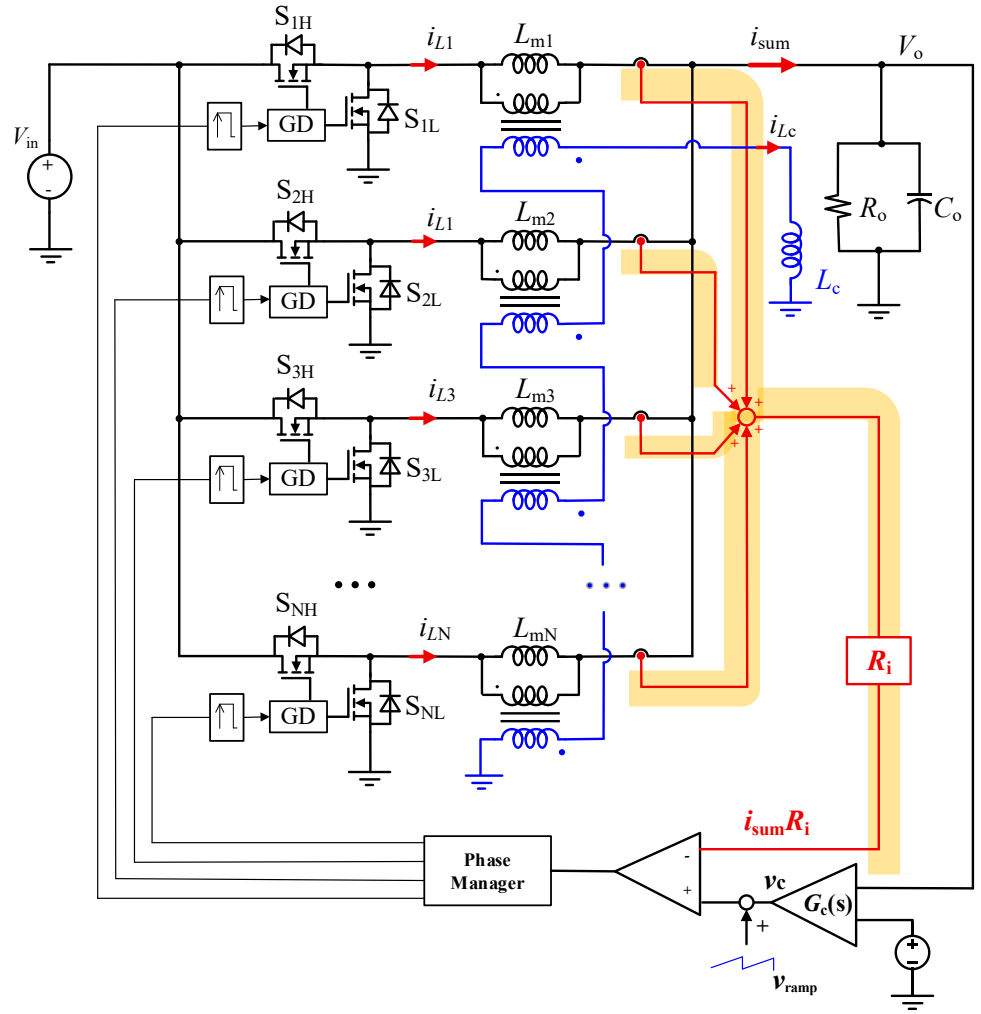
Credit: Infineon



MP2965

Credit: MPS

Conventional multiphase COT controllers



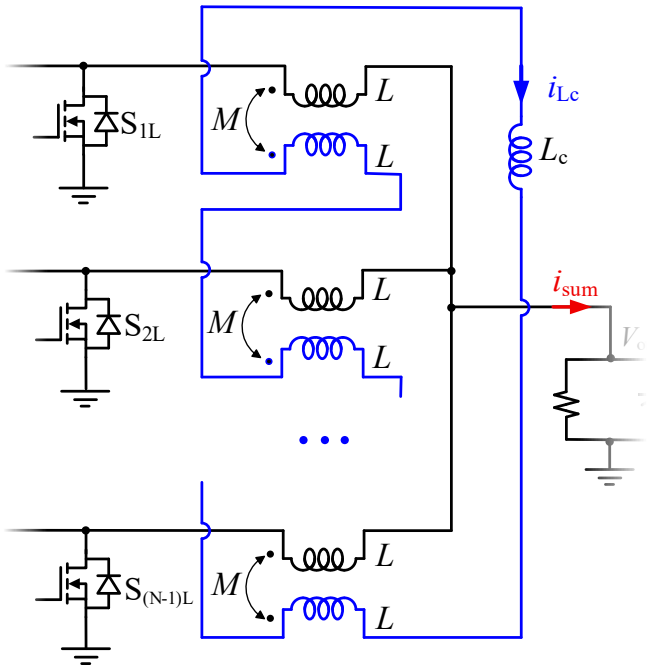
- **Sense** the per phase currents
- **Add up** to get i_{sum}
- **Compare** with the valley reference
- **Generate** interleaved PWM

N of differential high bandwidth current sensors
+ Summing circuit required

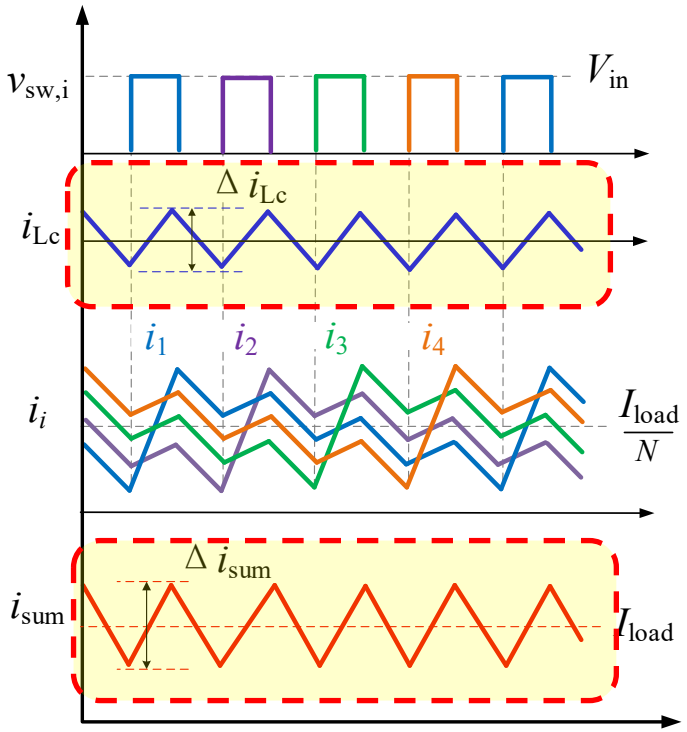
Can we do something better?

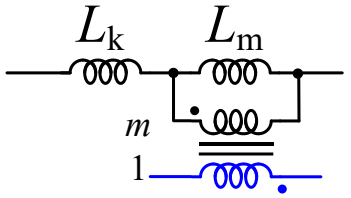
Let us look into i_{Lc}: ripple v.s. i_{sum}

- TLVR topology



- i_{Lc} and i_{sum}





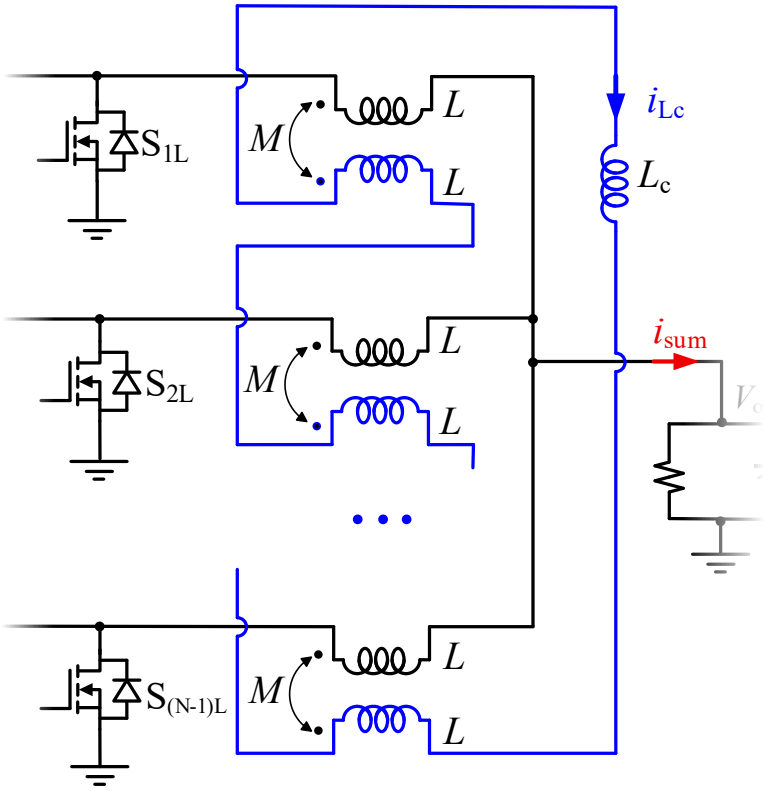
- i_{sum} and i_{Lc} dynamics

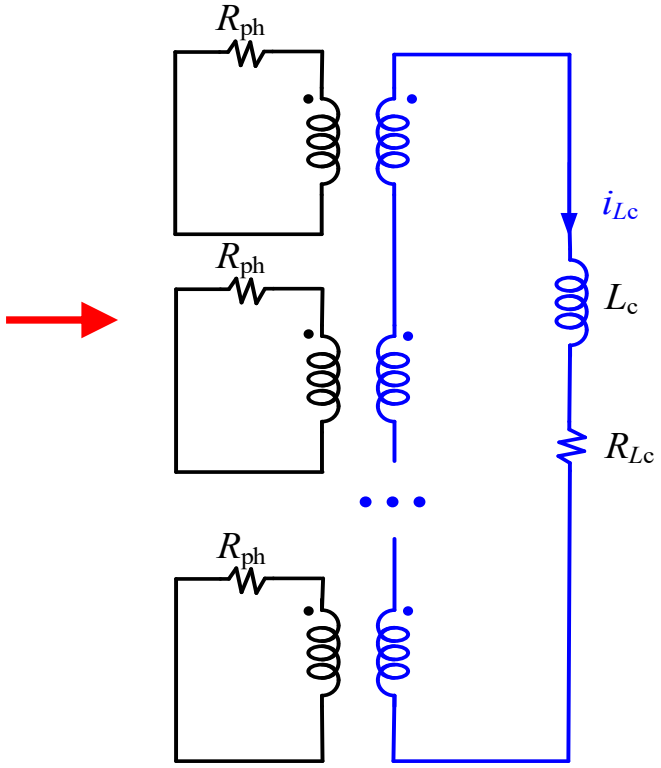
$$\frac{di_{\text{sum}}}{dt} = \left[\frac{L_c + N(L_k + L_m)}{mL_m}\right]\frac{di_{L_c}}{dt}$$

i_{Lc} contains the ripples of i_{sum}!

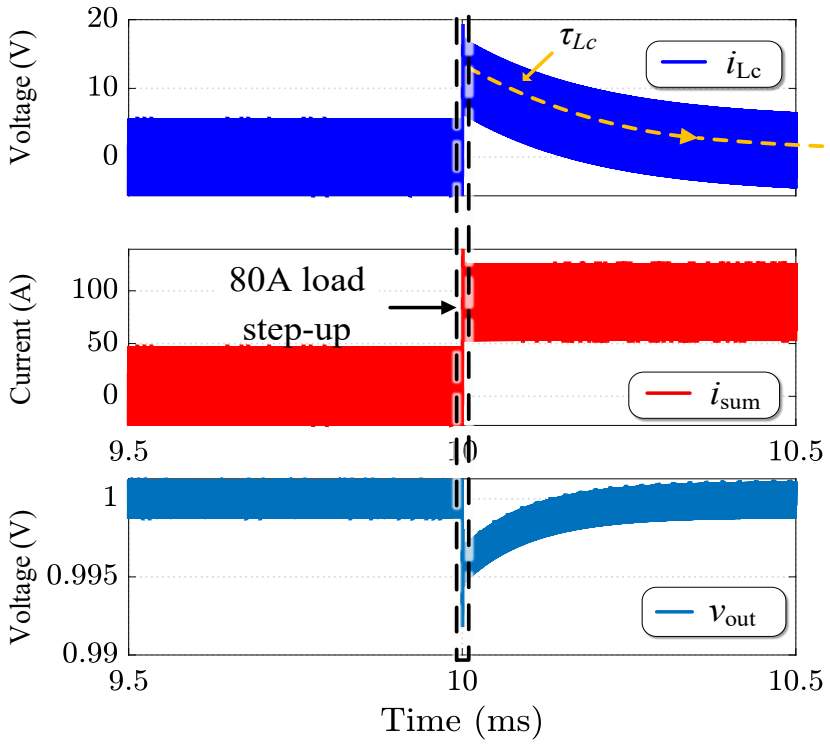
iLc: an AC current at the steady state

- **Lc & secondary resistance** decide the RL damping time constant





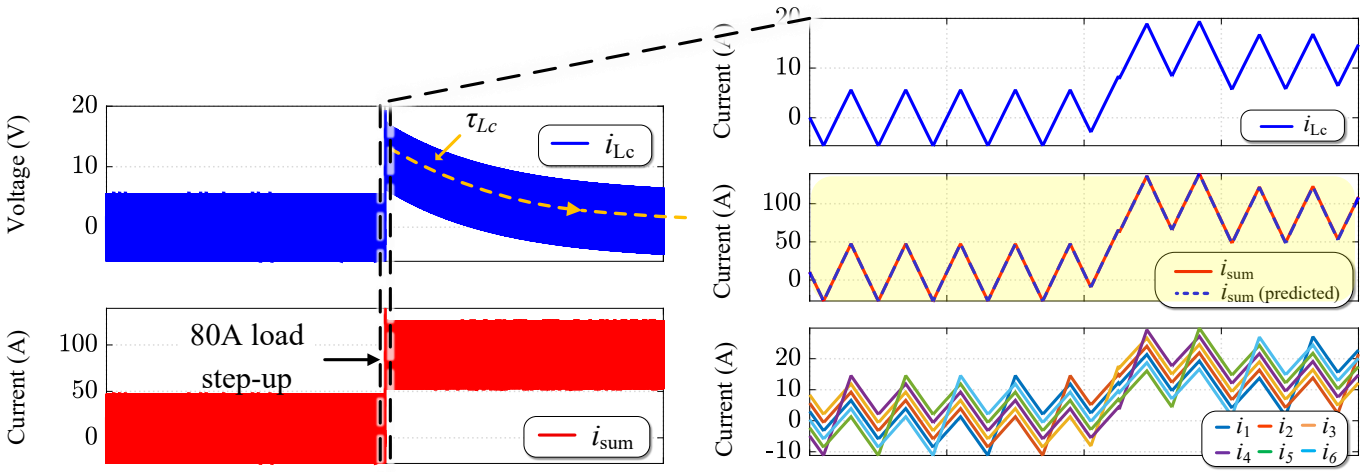
RL damping equivalent circuit

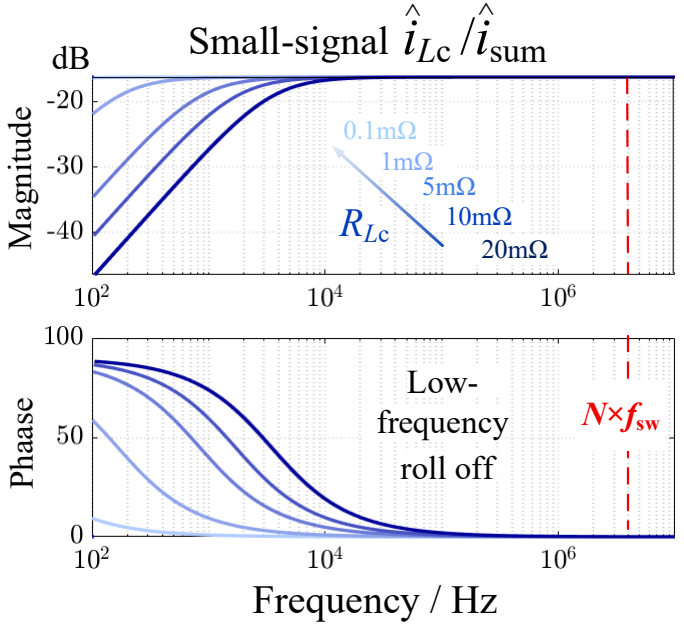


Response after a transient event

With voltage loop, we only need i_{sum} ripples

- i_{Lc} contains high-frequency ripples of i_{sum}. Therefore, it can be used to replace isum in current-mode control.

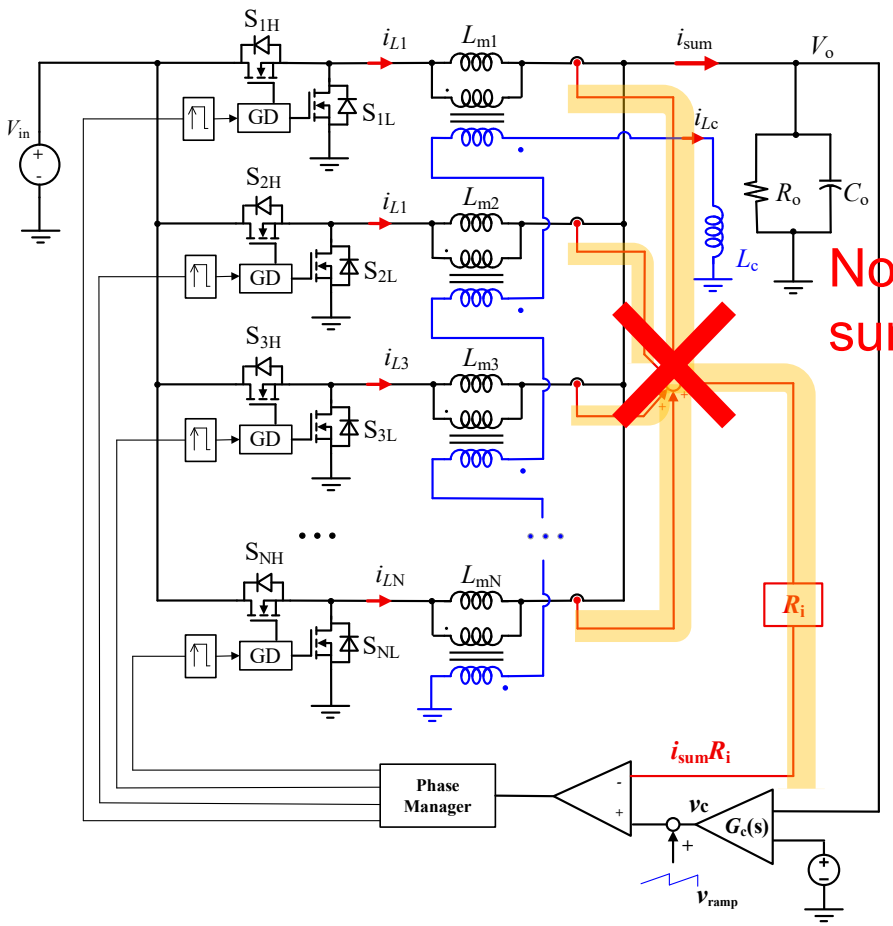




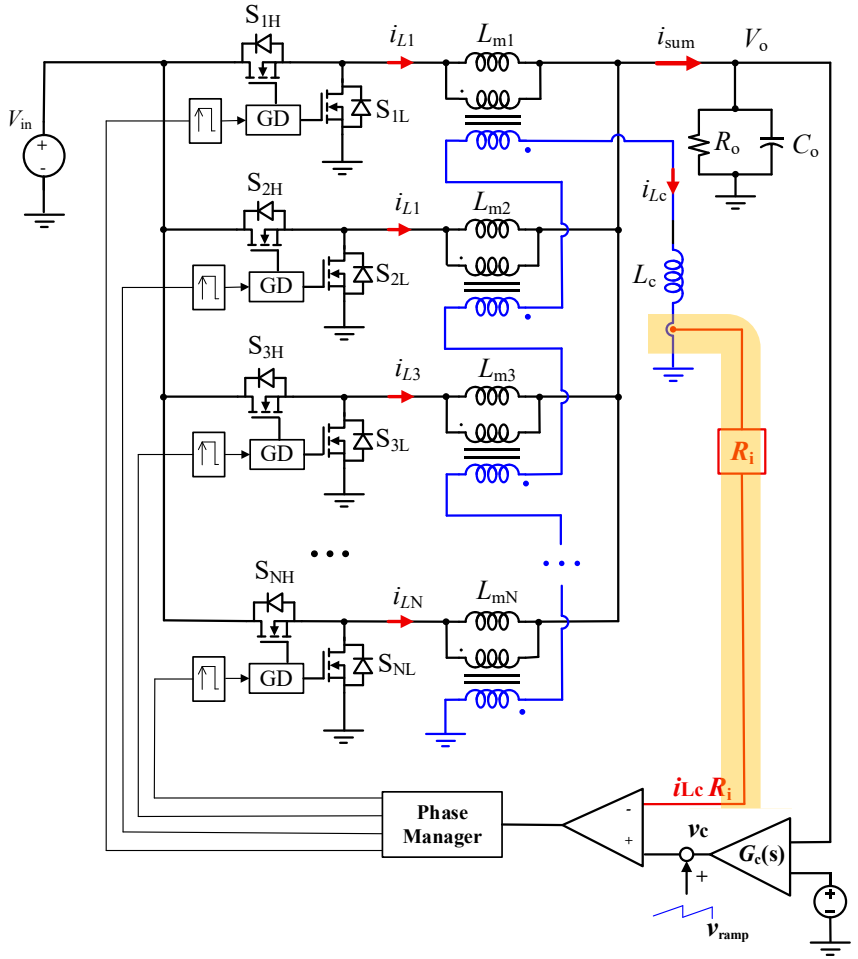
We are able to implement the COT control by ONLY i_{Lc}

(With a voltage loop to regulate)

i_{Lc}-based COT control

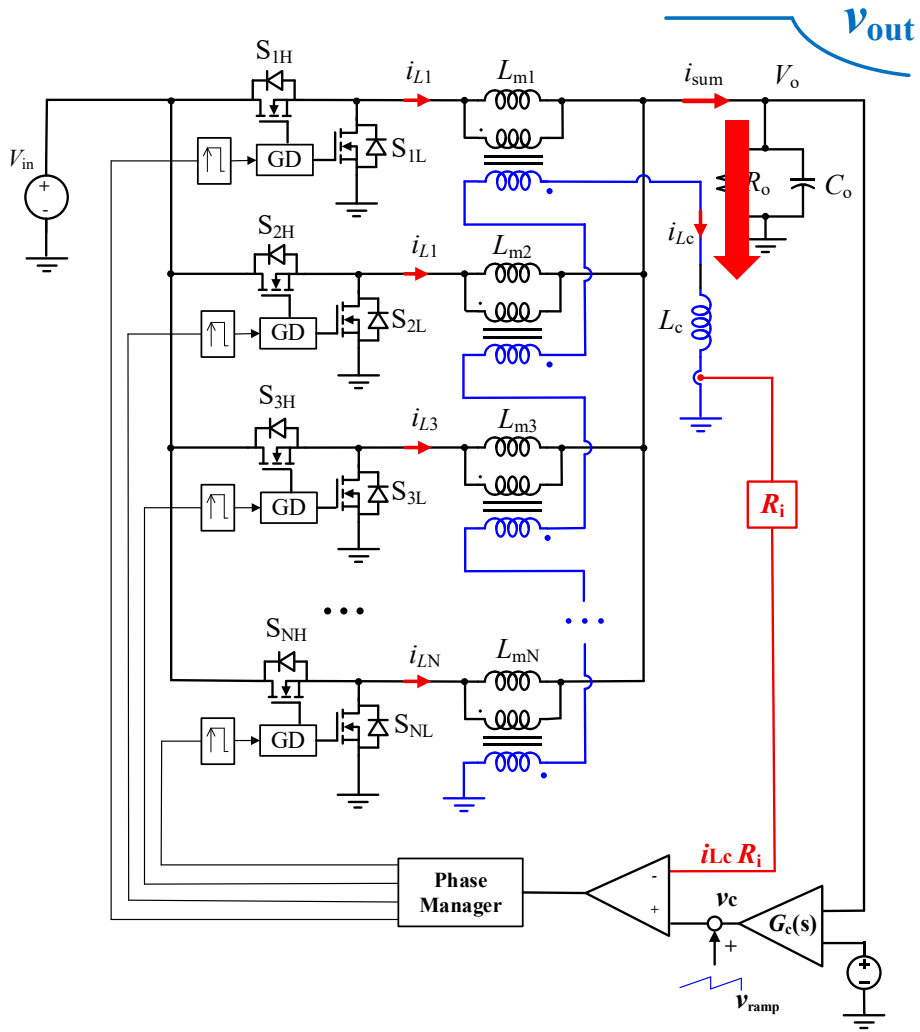


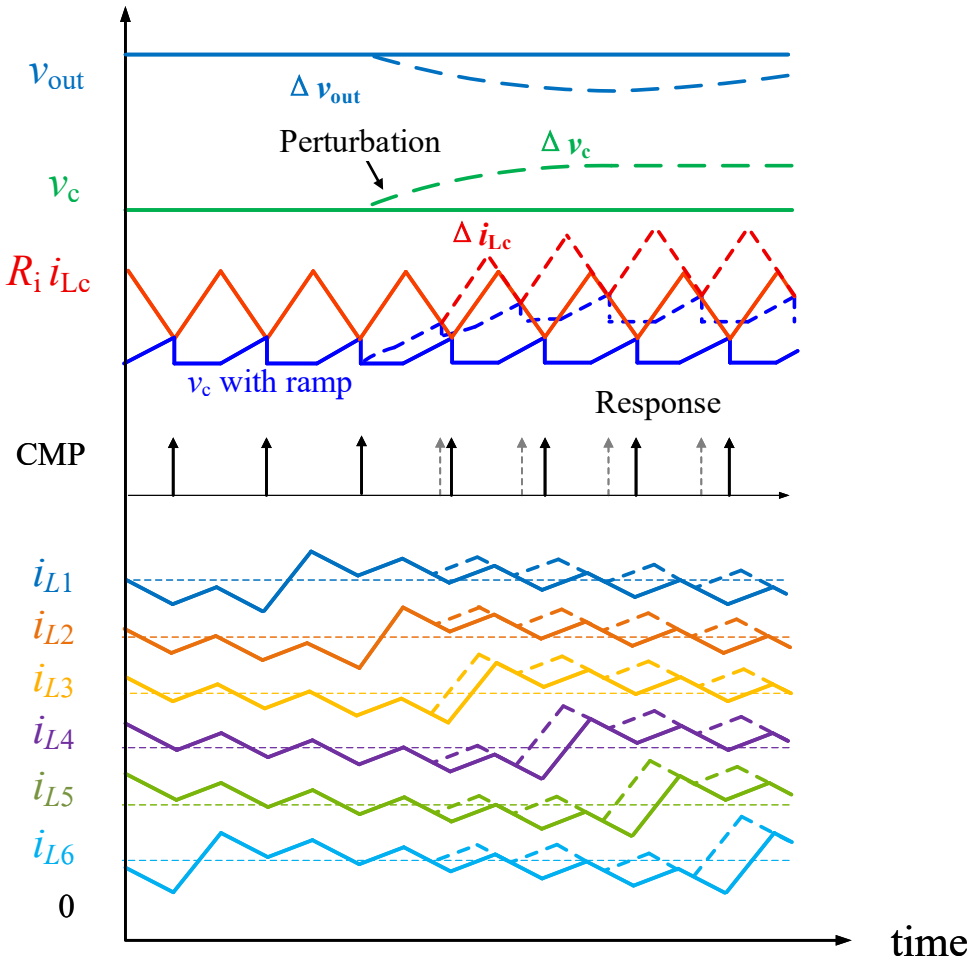
No need for summer



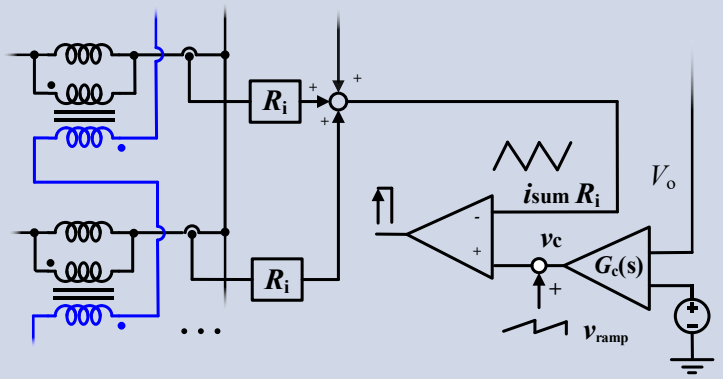
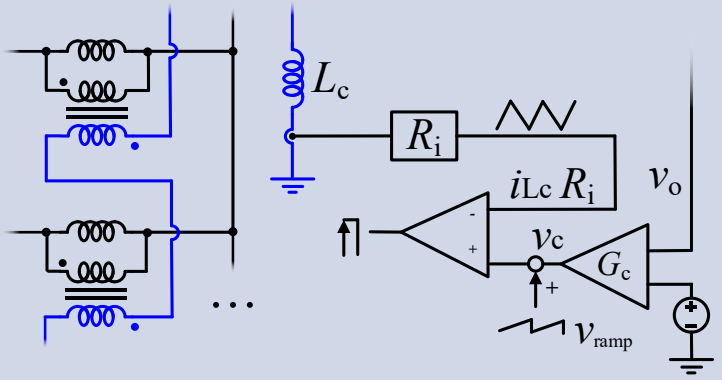
N high-side sensors → **1 low-side sensor**

Operation principle



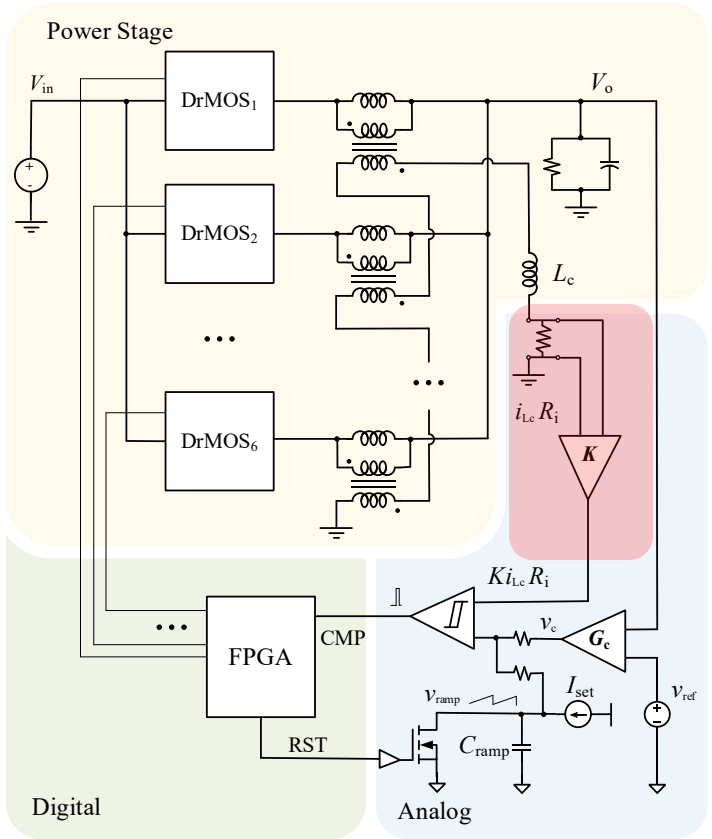


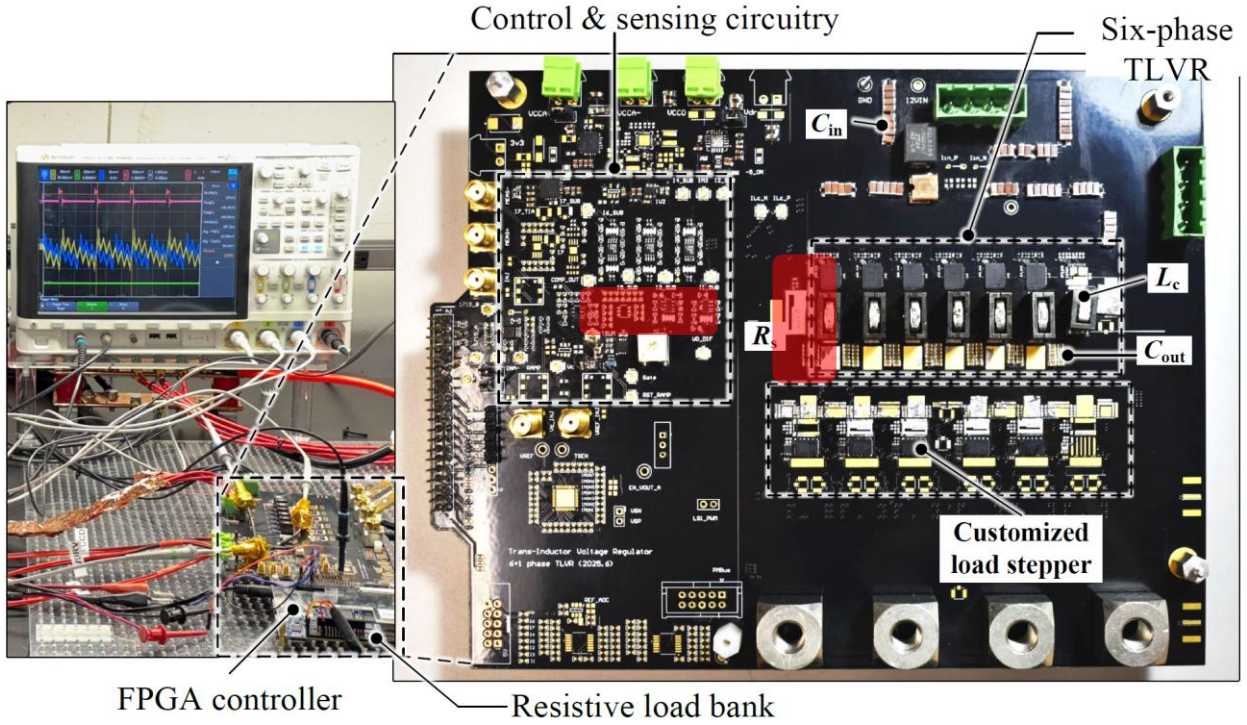
Performance comparison

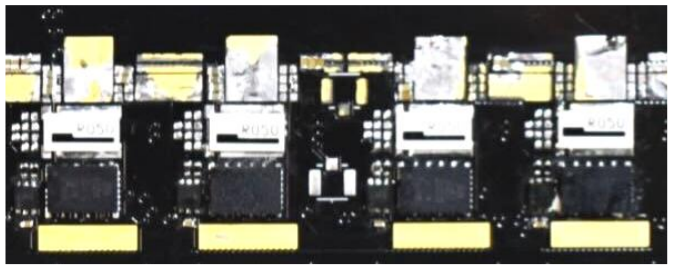
Comparison	Conventional COT	i_{Lc}-based COT
Implementation Example		
High bandwidth sensors	Need N	**Need 1**
Sensor type	Differential	**Ground referenced**
RMS of sensed current	High	**Low**
Cost	Medium	**Low**
Need of summing circuit	Yes	**No**
Complexity	High	**Low**
System reliability	Medium	**Good**

Experimental setup

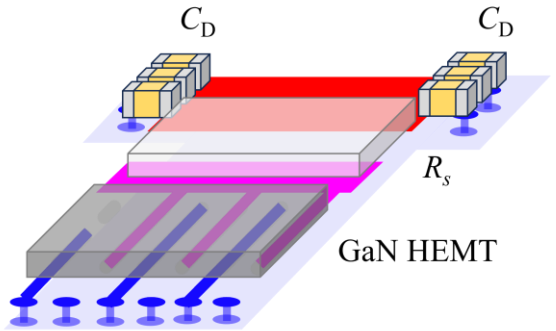
- Hardware block diagram of a six-phase TLVR







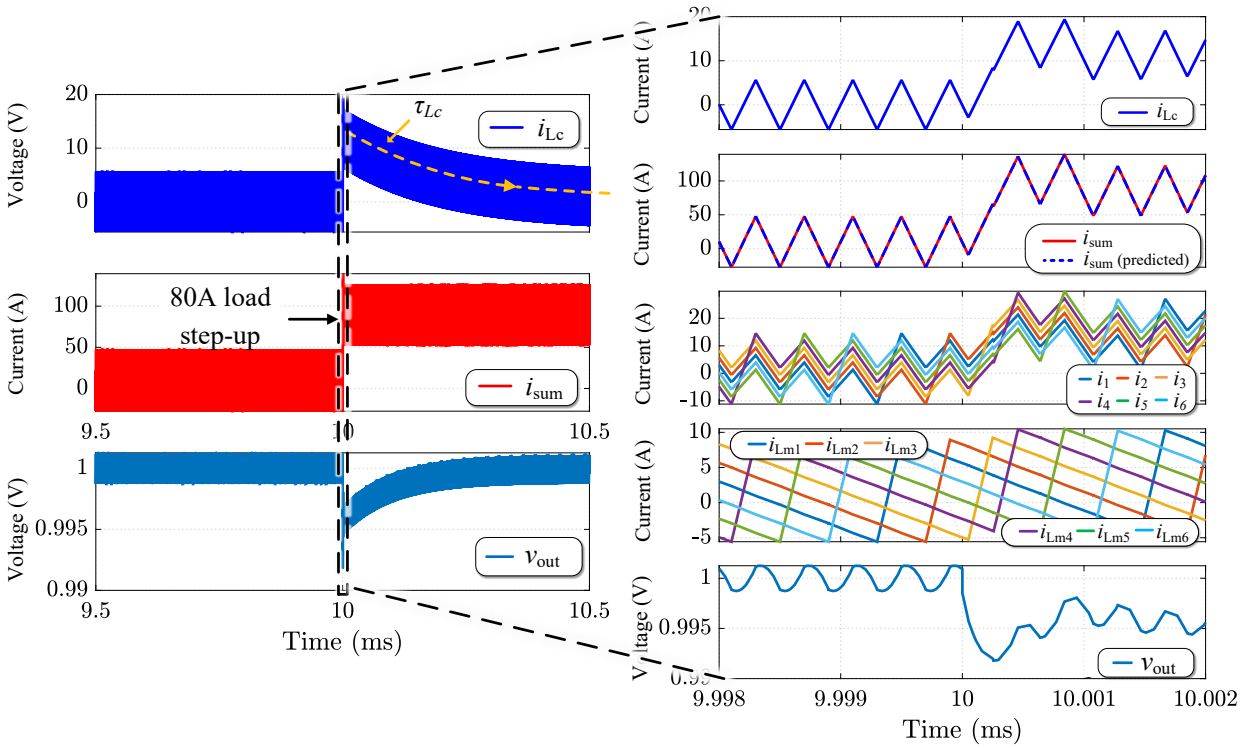
Dynamic load stepper

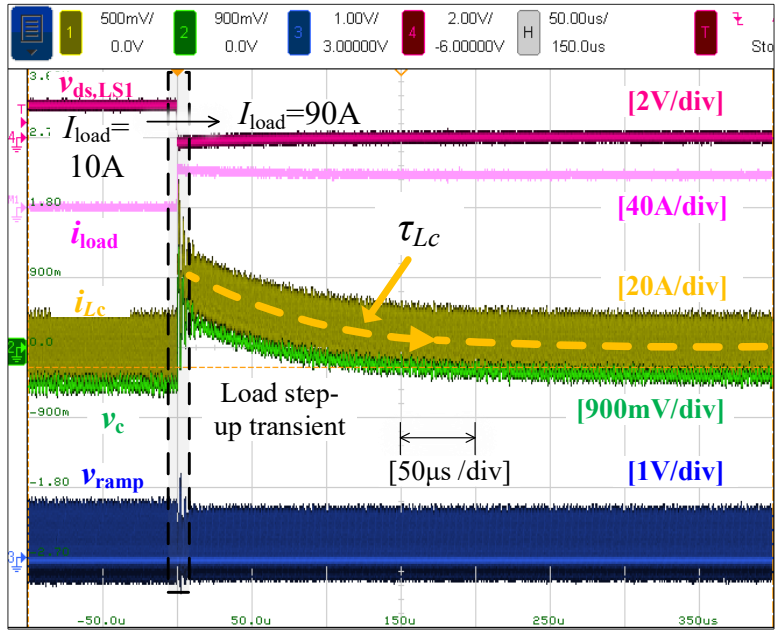


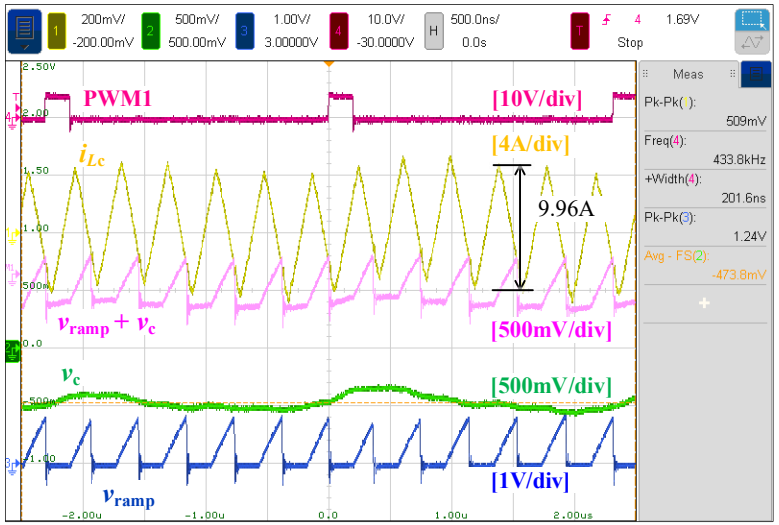
6A/ns capability

Compare with simulation

- Same RL damping characteristics



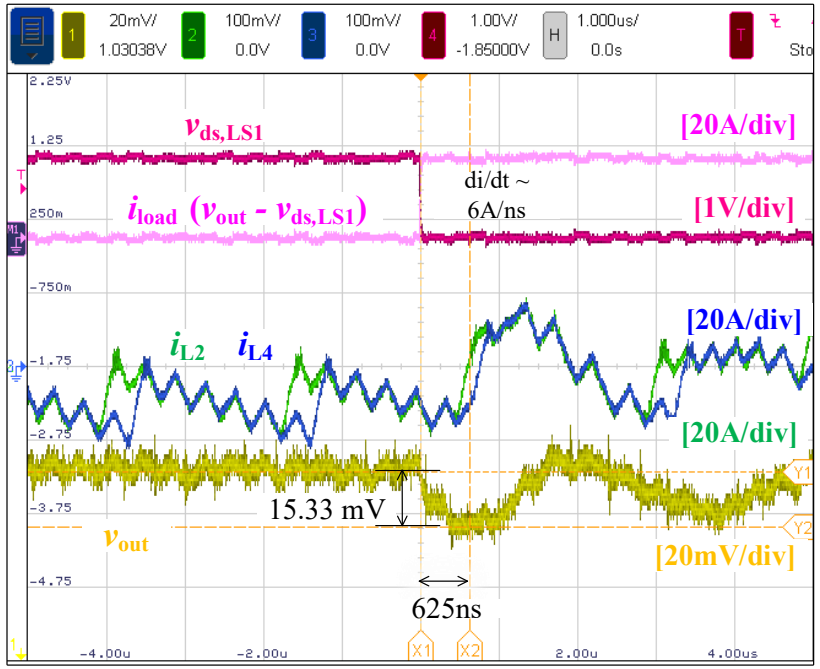




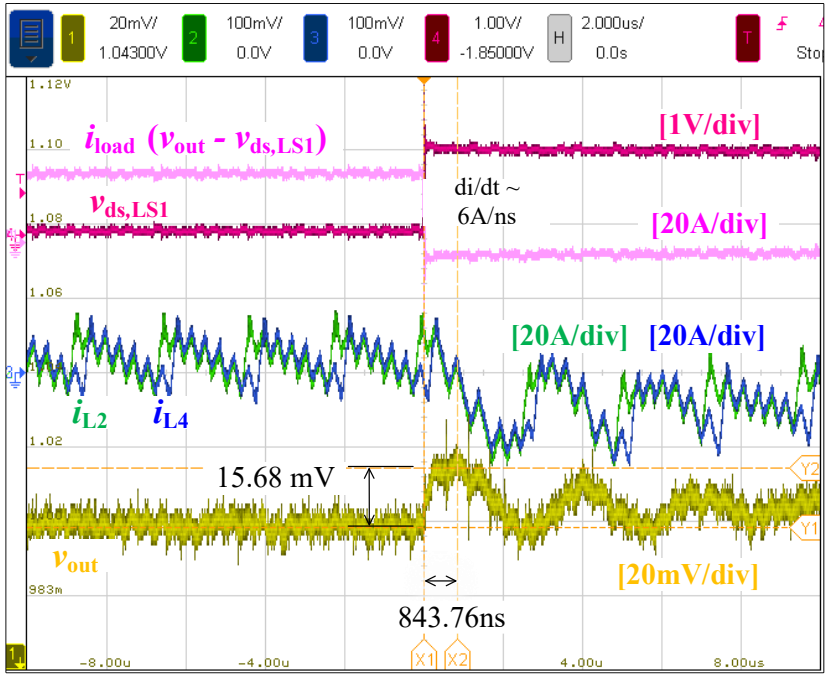
Load transient response

- The proposed controller demonstrates tight regulation under load-step transients

80A load step up



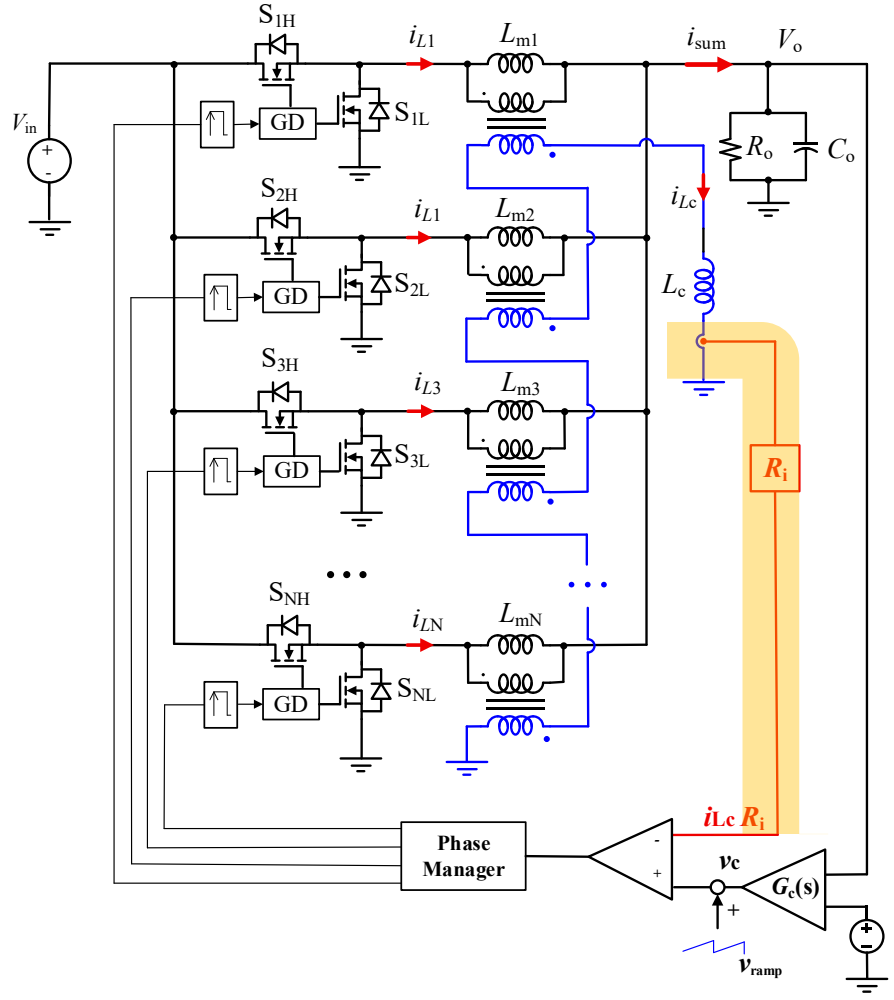
80A load step down



Summary: advantages of this control scheme

- **Reduced Complexity & Cost reduction**
- No need for *high-bandwidth differential per-phase sensing*.
- No need for *summing circuit*. → greatly reducing system complexity & controller die size

- **Flexibility**
- Adapt to *all current-mode control schemes*
- Flexible to *all TLVR-derived topologies* compared to DrMOS with IMON. e.g.: series-capacitor buck converters
- Easier *layout for sensing circuits*





Thank you!

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