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Three-level interleaved non-isolated DC/DC converter for battery energy storage systems

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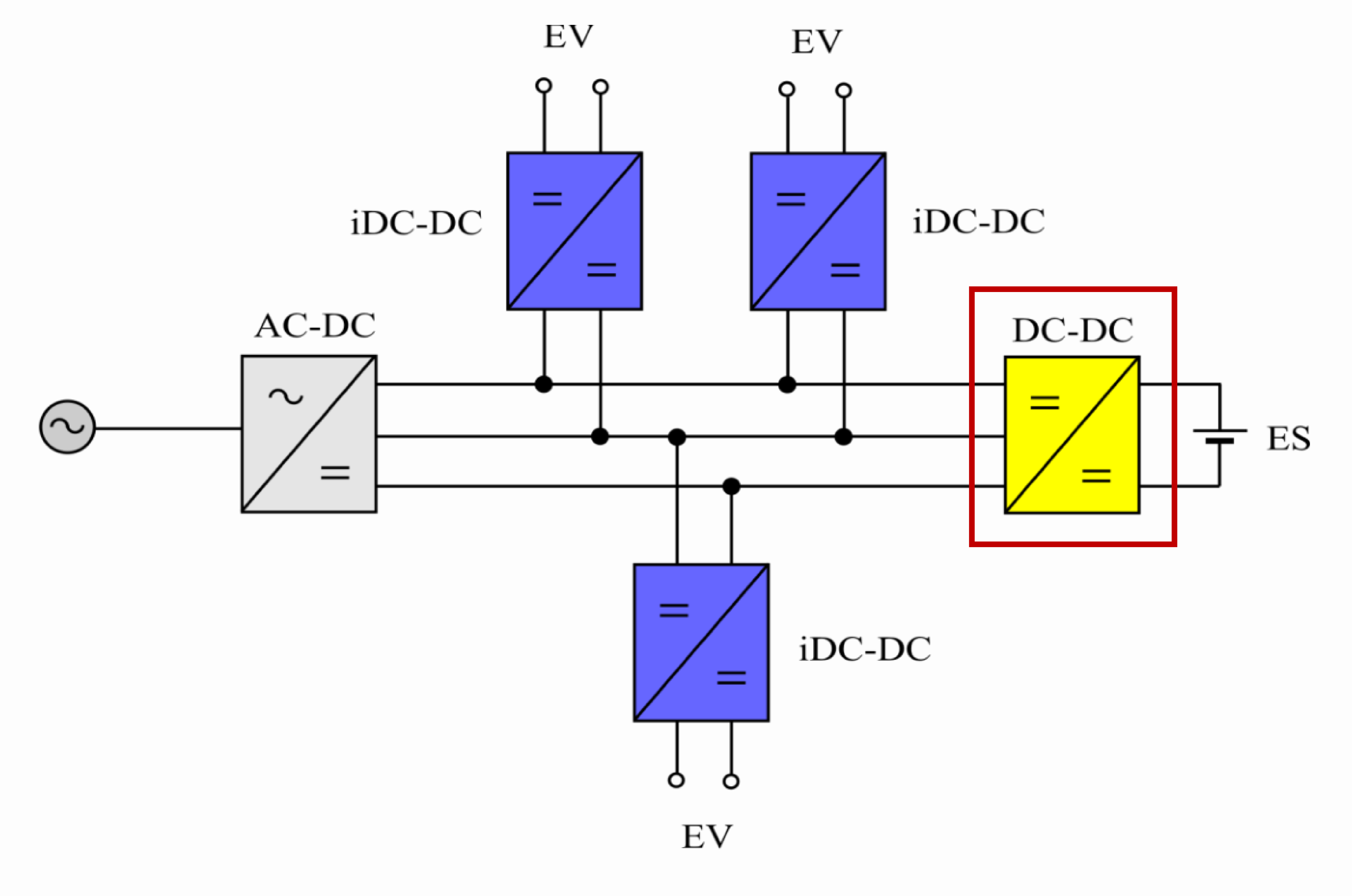
DC/DC bidirectional converter as a battery interface in scope of full EV bipolar fast-charging station

Requirements:

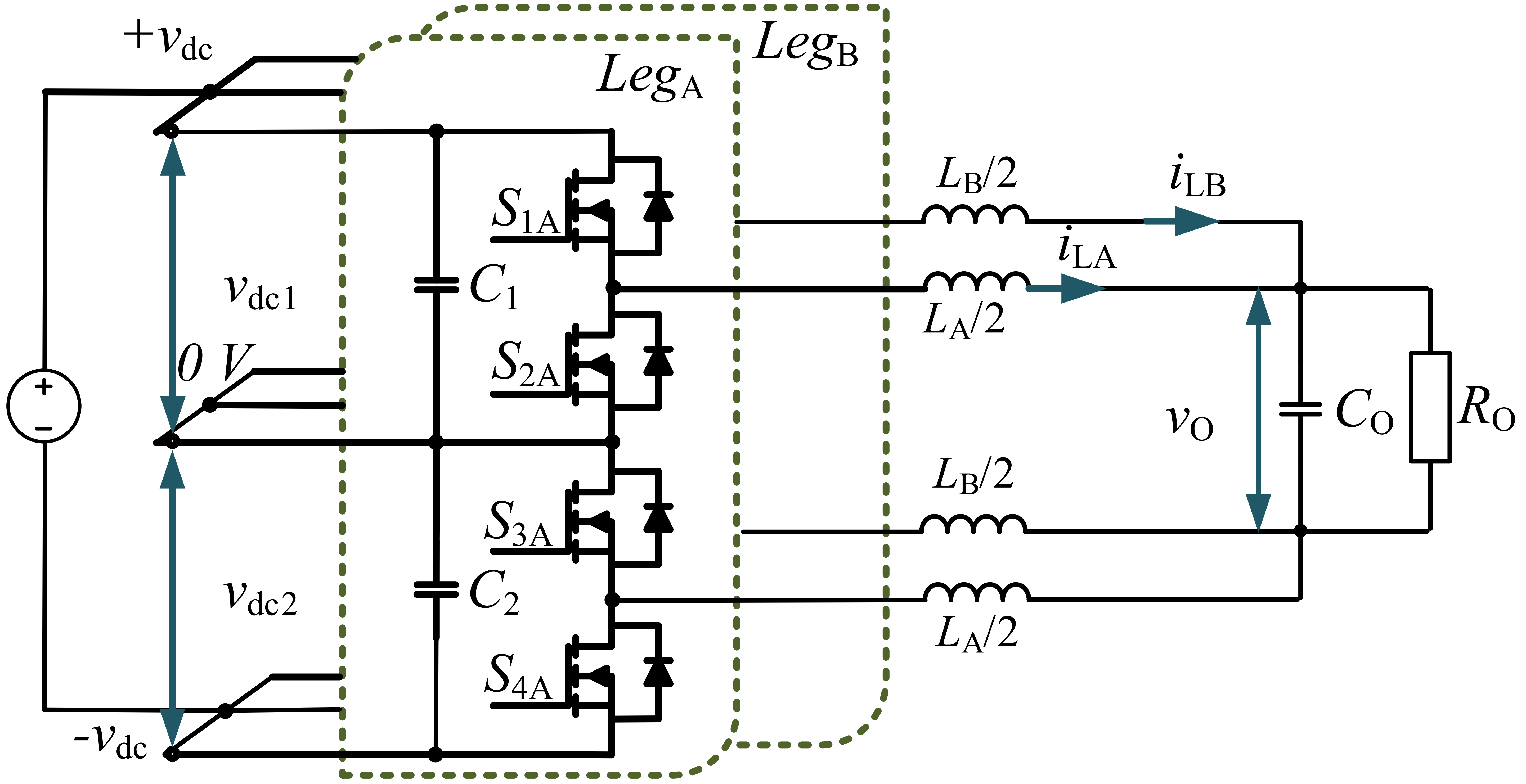
- **Non-isolated structure**
- **Bidirectional operation**
- **3-pole connection feasibility**
- **Low output ripples**
- **Structure compatibility with the rest of the system**



Three-level (3L) DC/DC bidirectional converter

Characteristics:

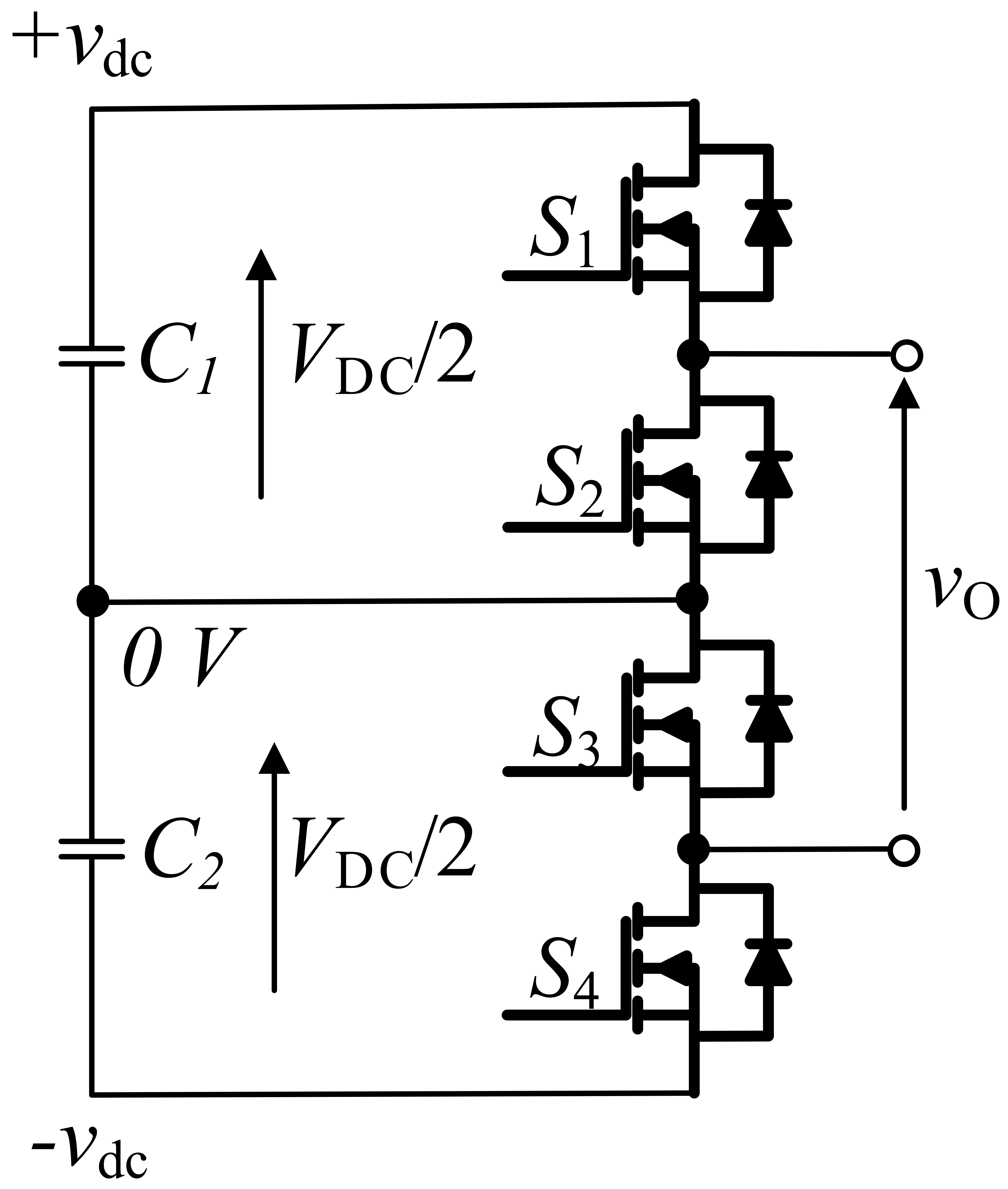
- Simple structure
- High possible efficiency
- Bipolar DC grid balancing capability
- Low ripples due to interleaved operation
- Suitable for the universal power submodule



3L DC/DC converter – basic operation principles for one leg

Converter switching states

State	S_1	S_2	S_3	S_4	Output voltage
High state	1	0	0	1	V_{DC}
Medium state 1	1	0	1	0	$V_{DC}/2$
Medium state 2	0	1	0	1	$V_{DC}/2$
Zero state	0	1	1	0	0



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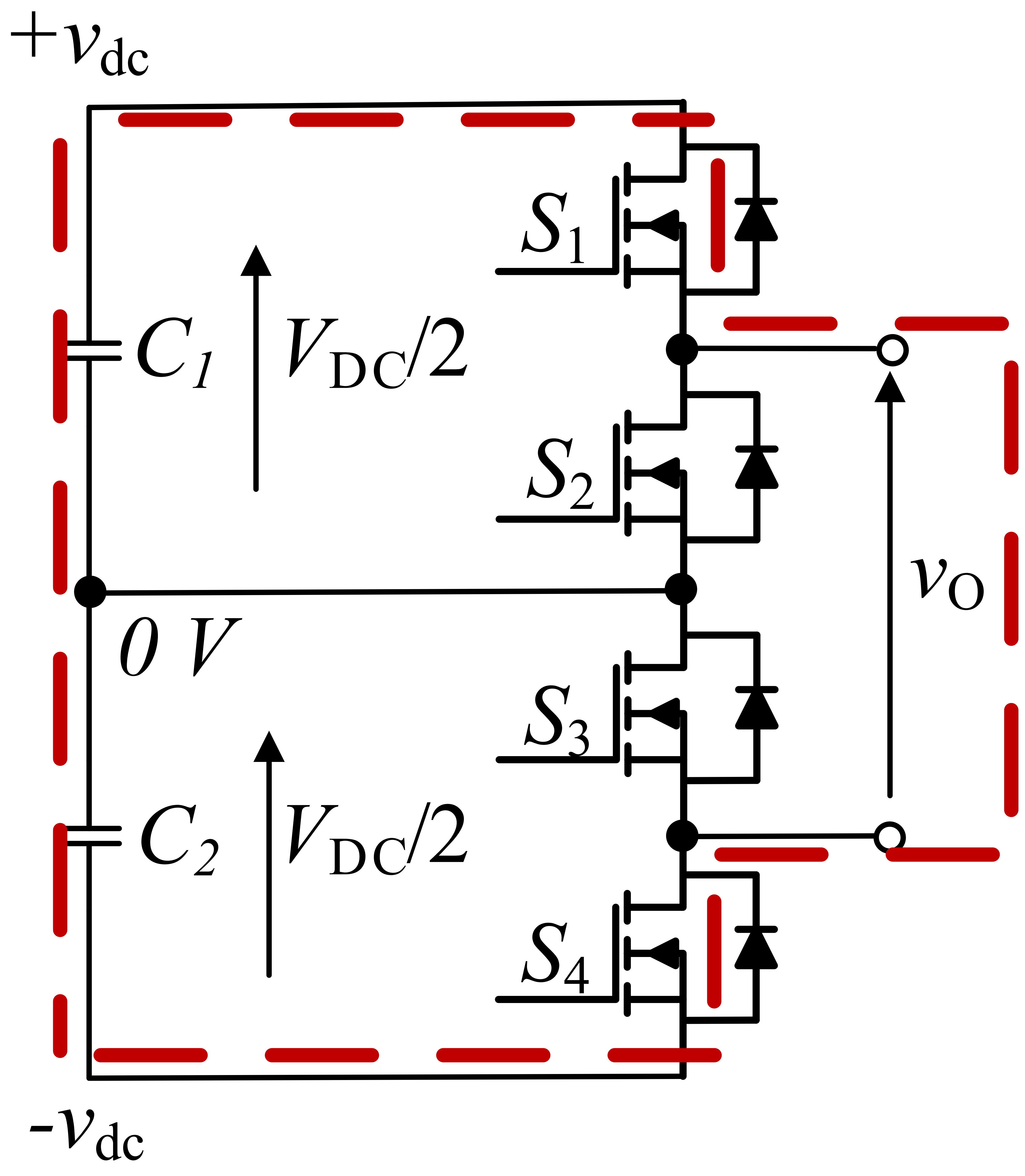

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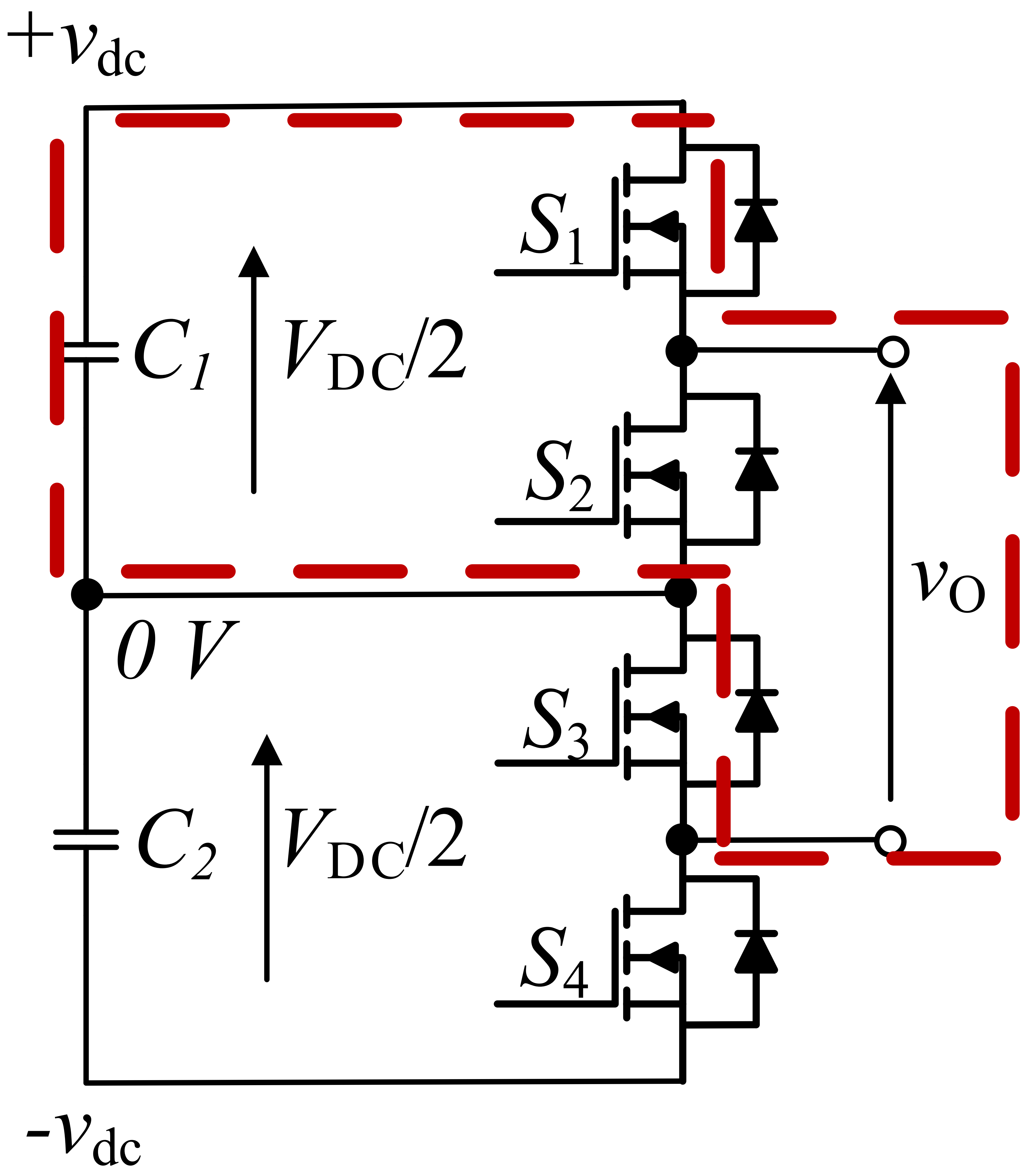

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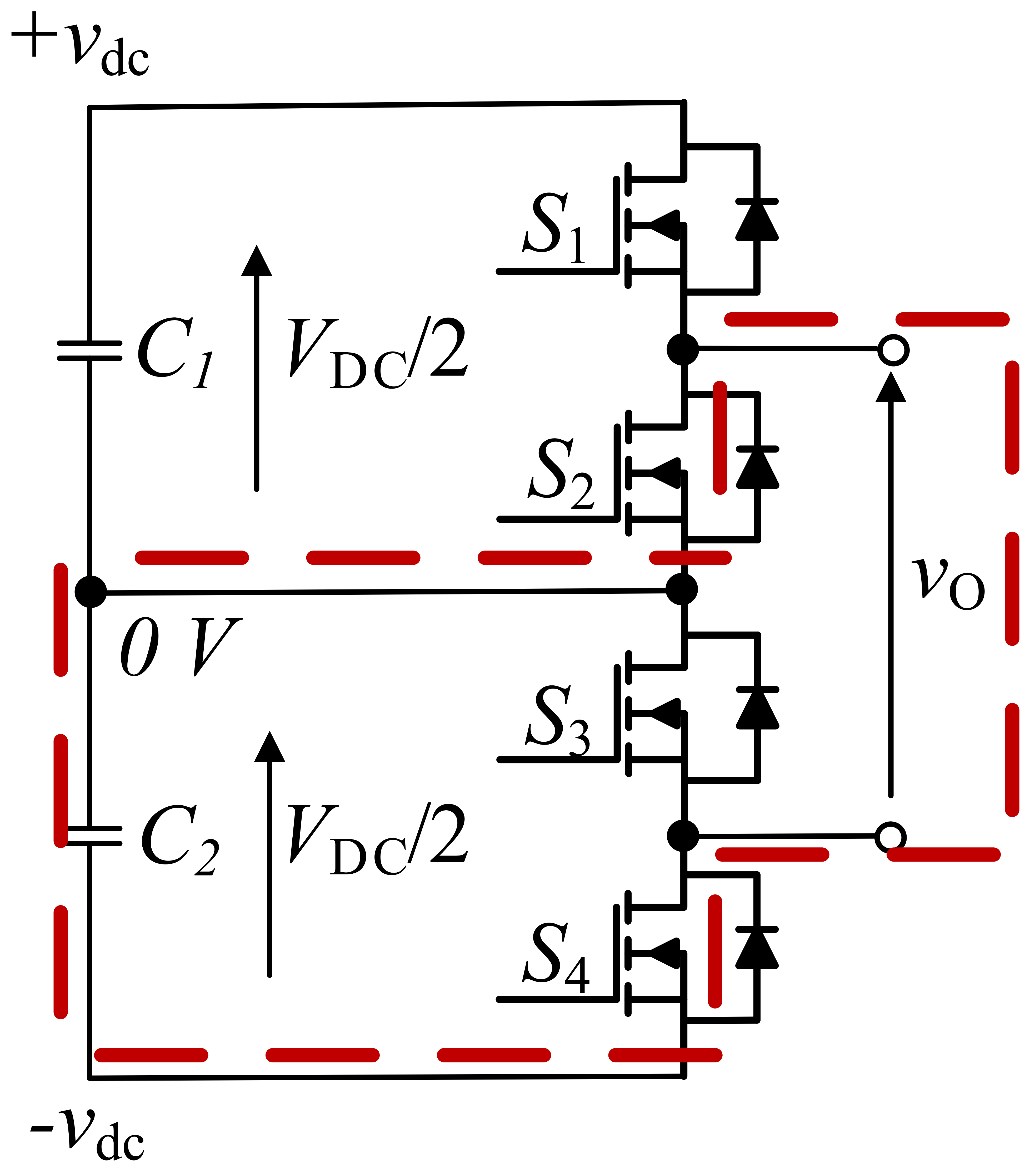

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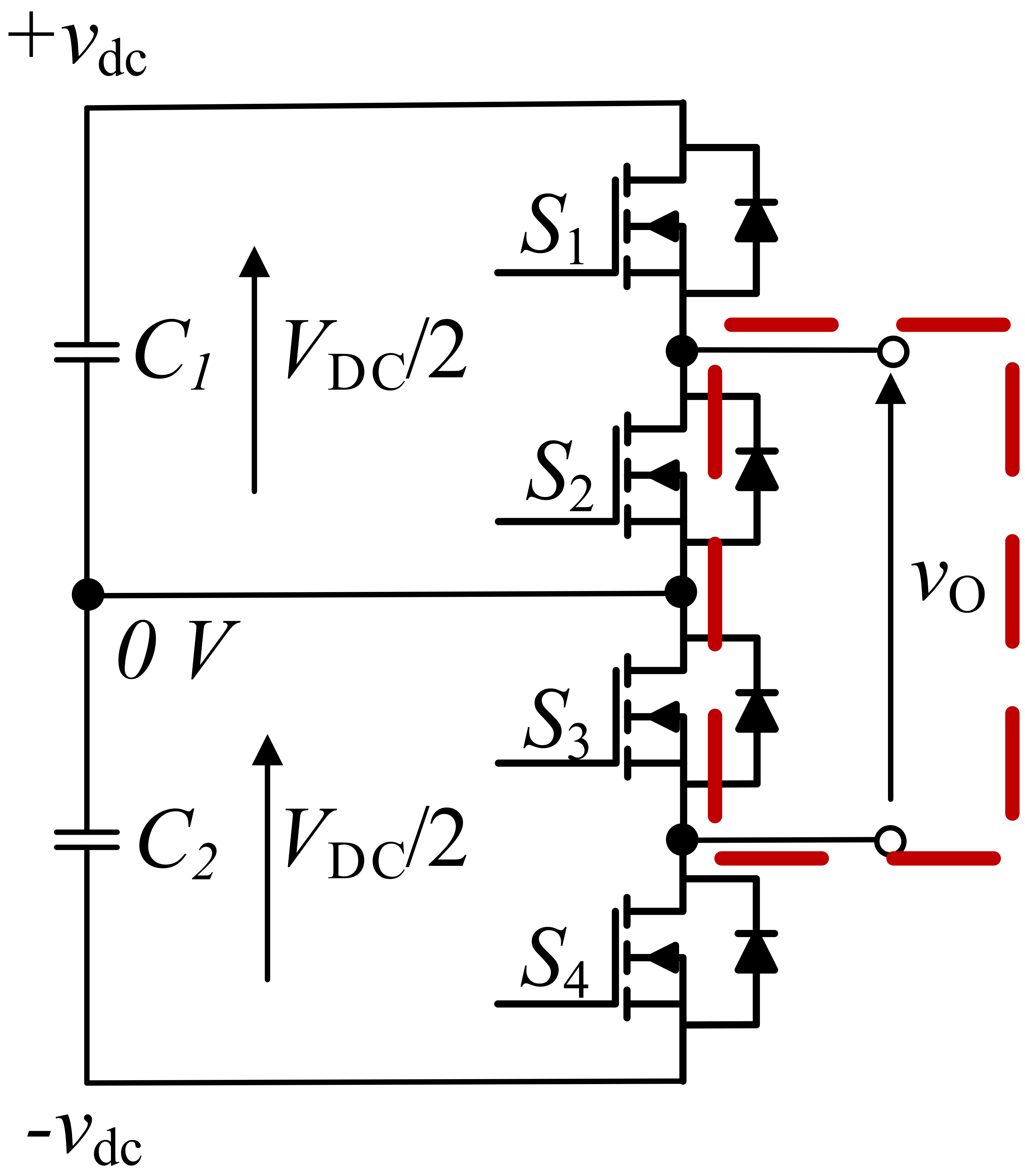
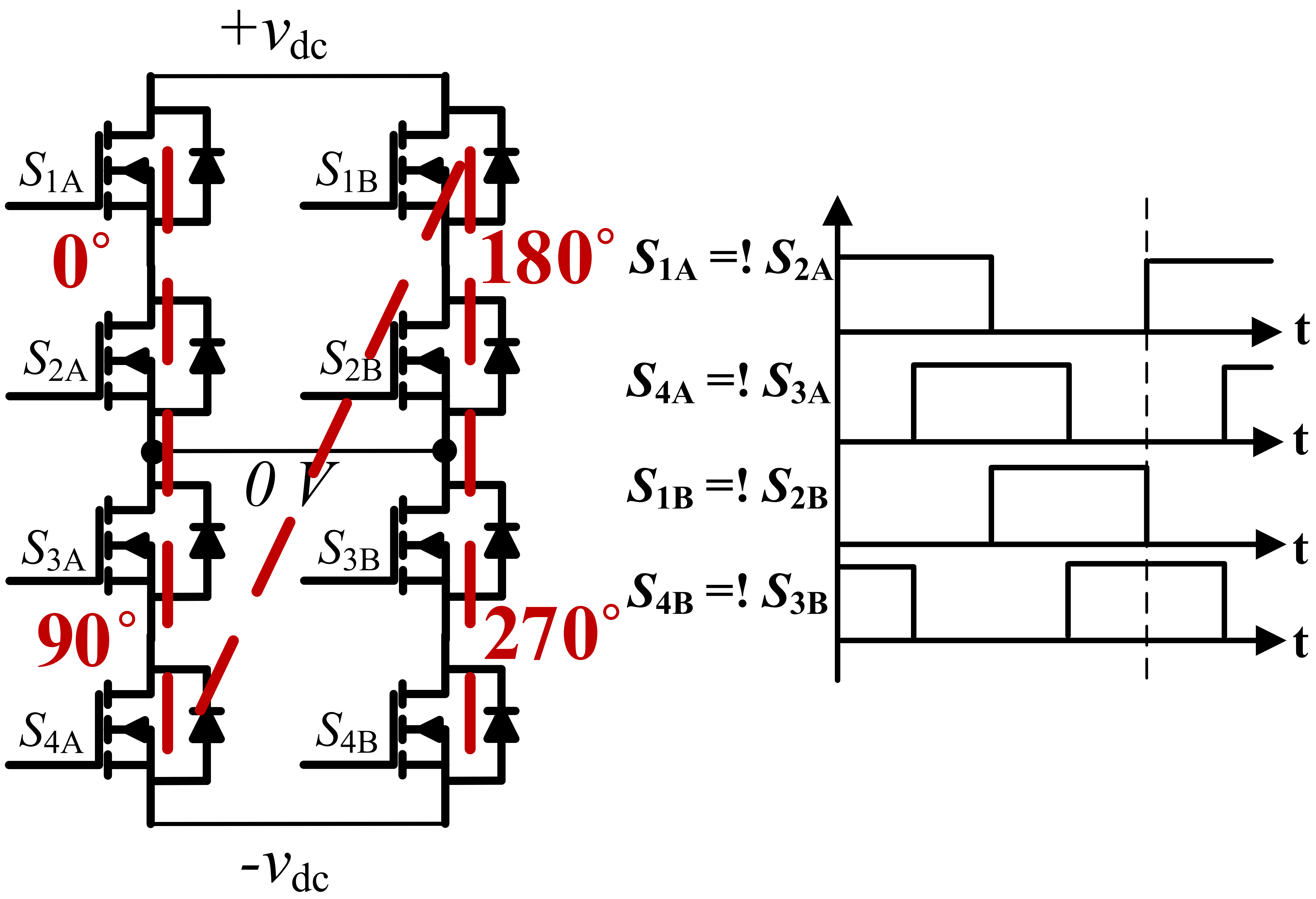


3L DC/DC converter – N-type interleaving control

Characteristics:

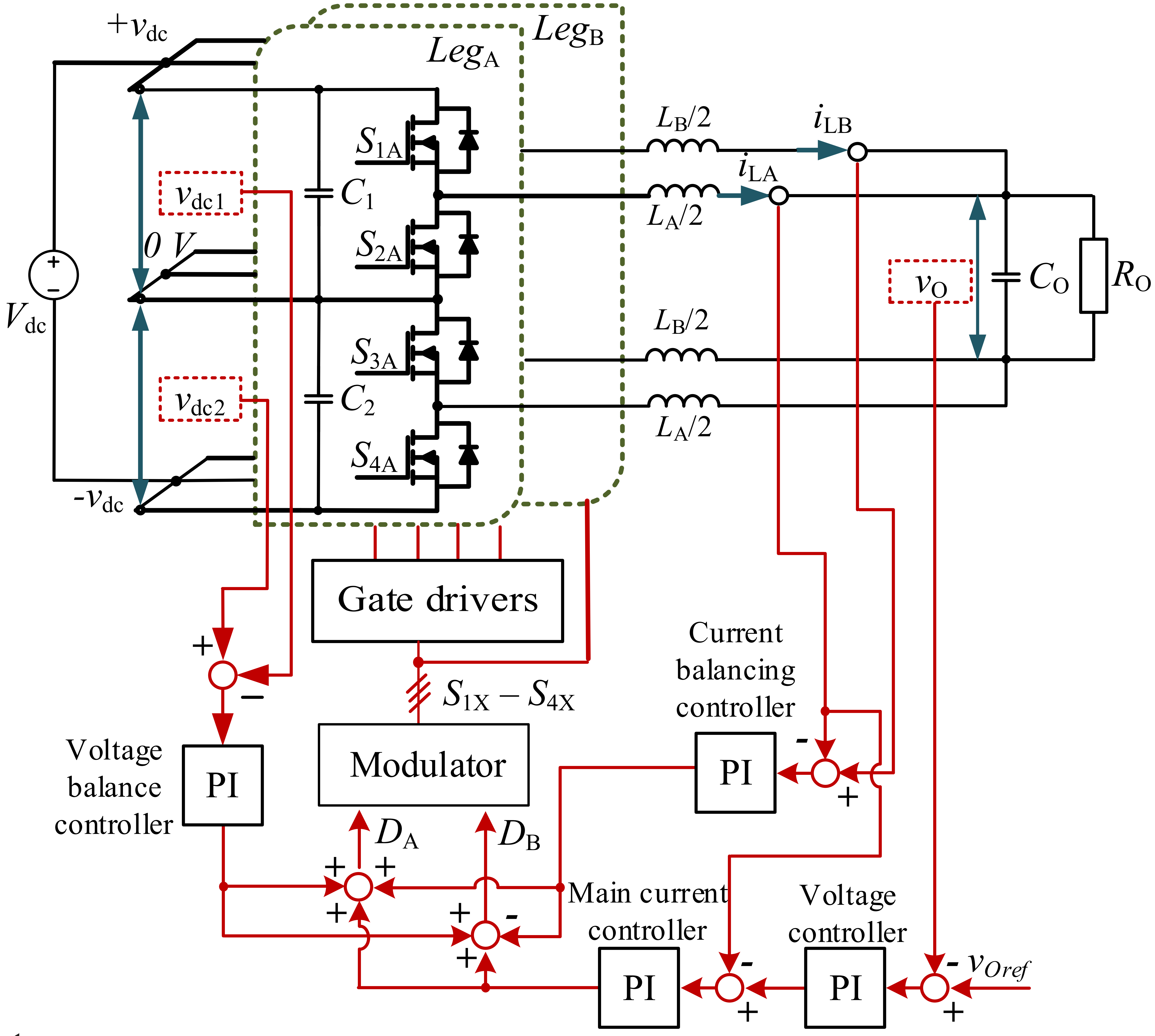
- Lower output ripples compared to a conventional interleaving approach (H)
- Lower EMI generation compared to Z-type interleaving scheme



3L DC/DC converter – control system

Characteristics:

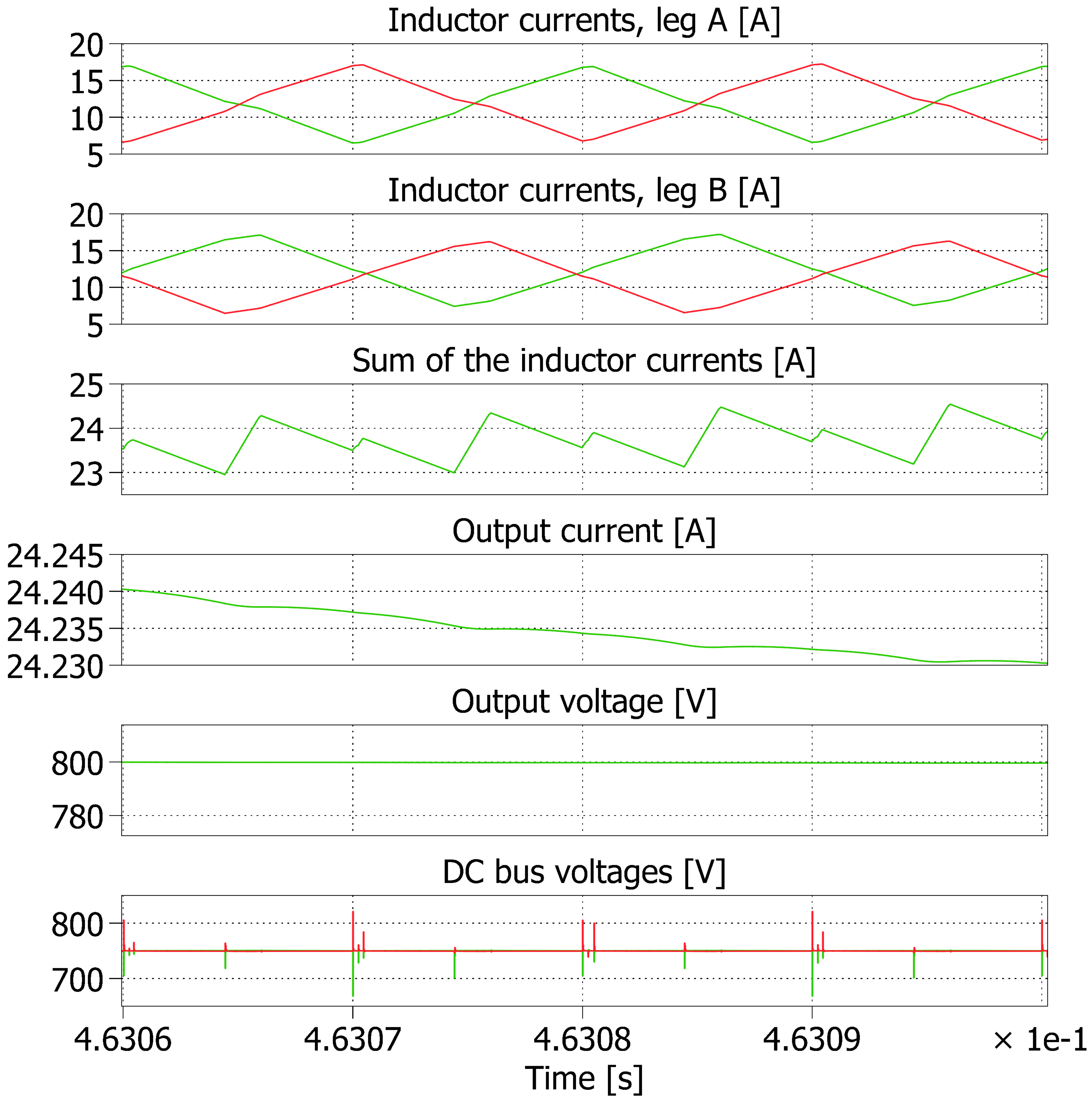
- Core loop – controlling the output voltage/inductor current
- Voltage balancing loop – 3-pole DC grid voltage leveling
- Current balancing loop – inductor current leveling



Simulation study - nominal

Parameters

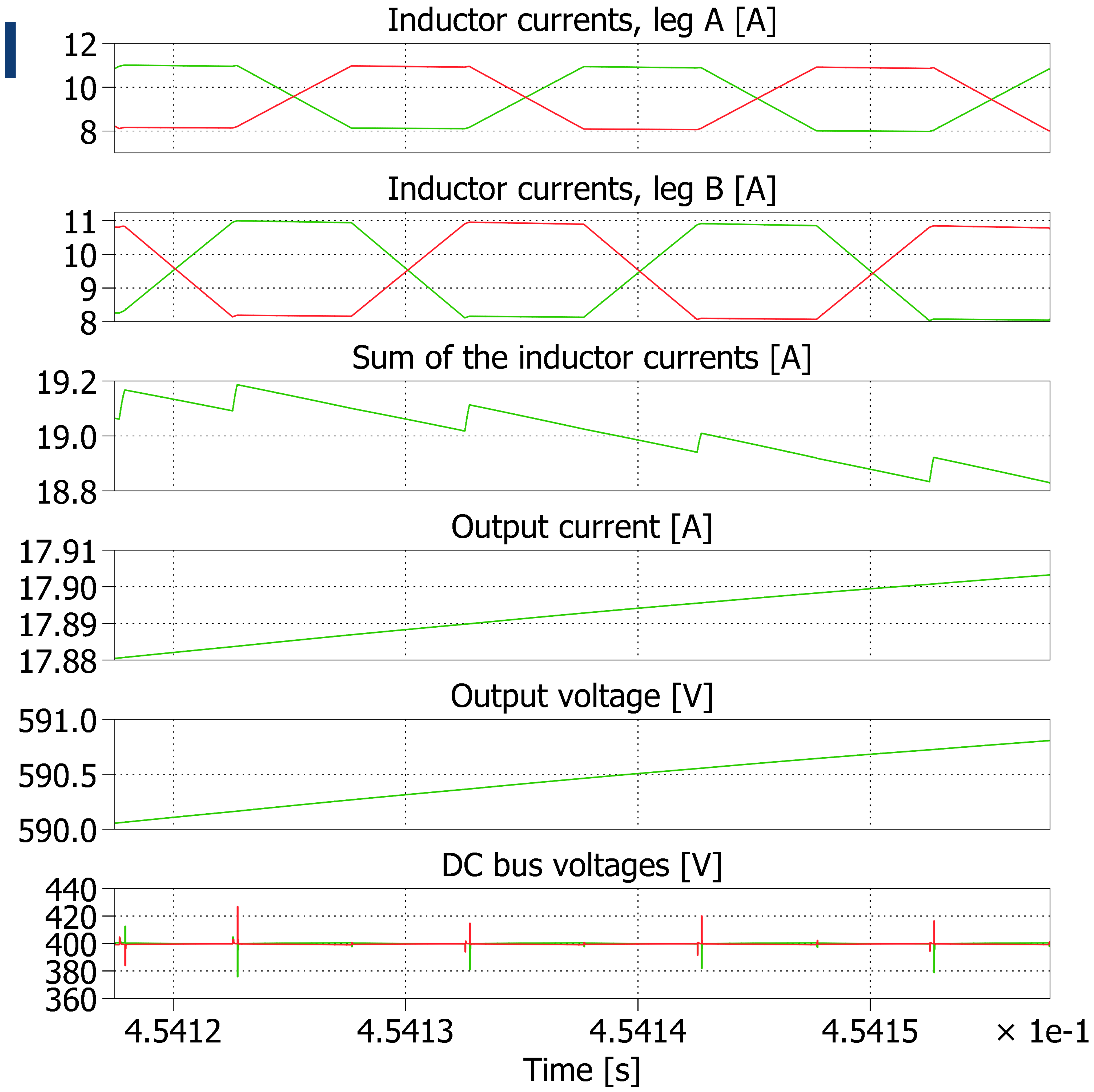
Battery-side (output) voltage	800 V
DC bus-side voltage	1.5 kV DC
Switching frequency	50 kHz
Filter inductors	4 x 150 µH
Battery-side capacitor	60 µF
DC-link capacitors	4 x 60 µF
Power transistors	8 x NTH4L040N120SC1
Maximum output power	20 kW



Simulation study – non-nominal

Parameters

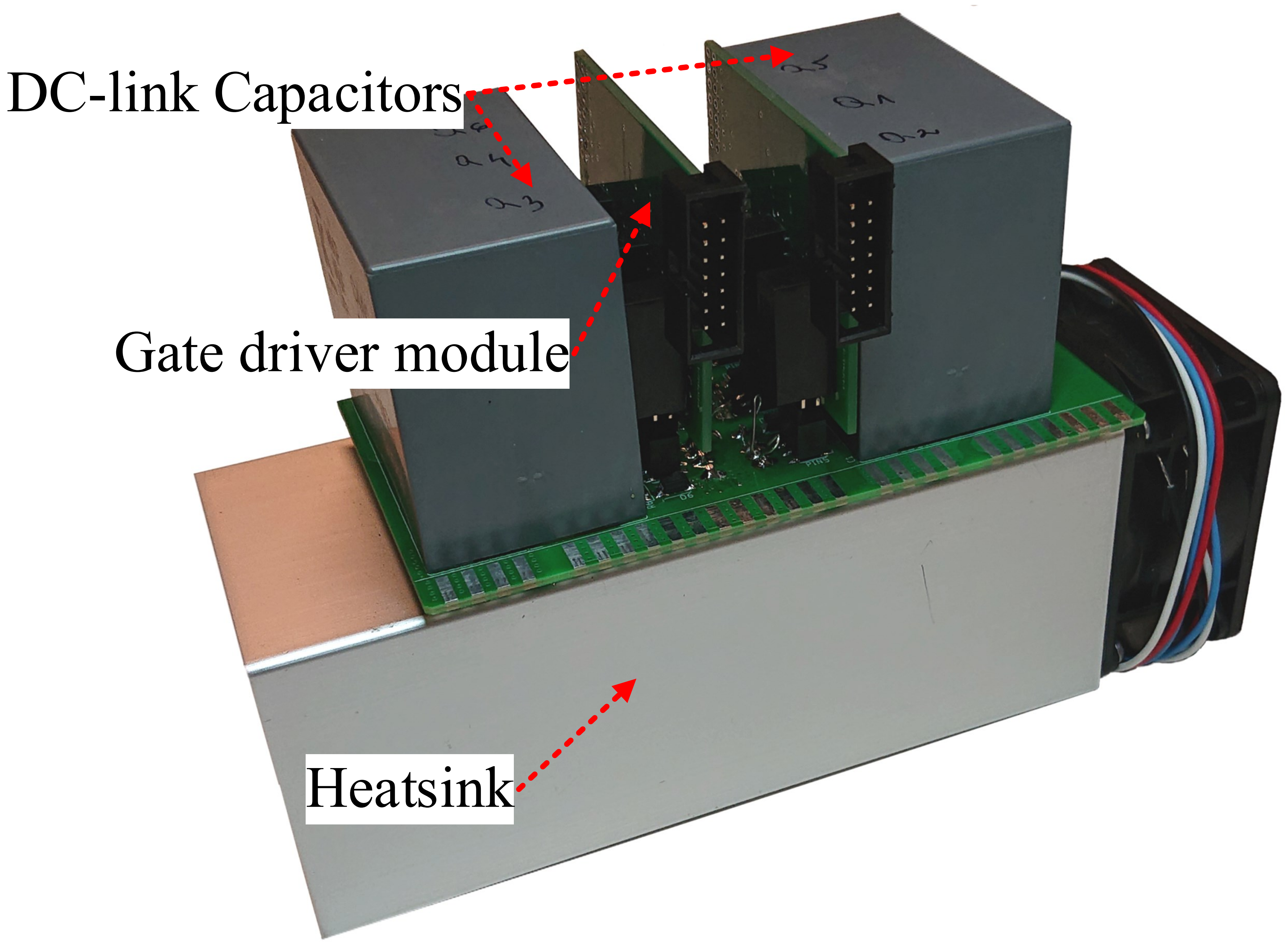
Battery-side (output) voltage	590 V
DC bus-side voltage	800 V DC
Switching frequency	50 kHz
Filter inductors	4 x 150 µH
Battery-side capacitor	60 µF
DC-link capacitors	4 x 60 µF
Power transistors	8 x NTH4L040N120SC1
Maximum output power	10 kW



Experimental model – the universal submodule as a converter leg

Characteristics:

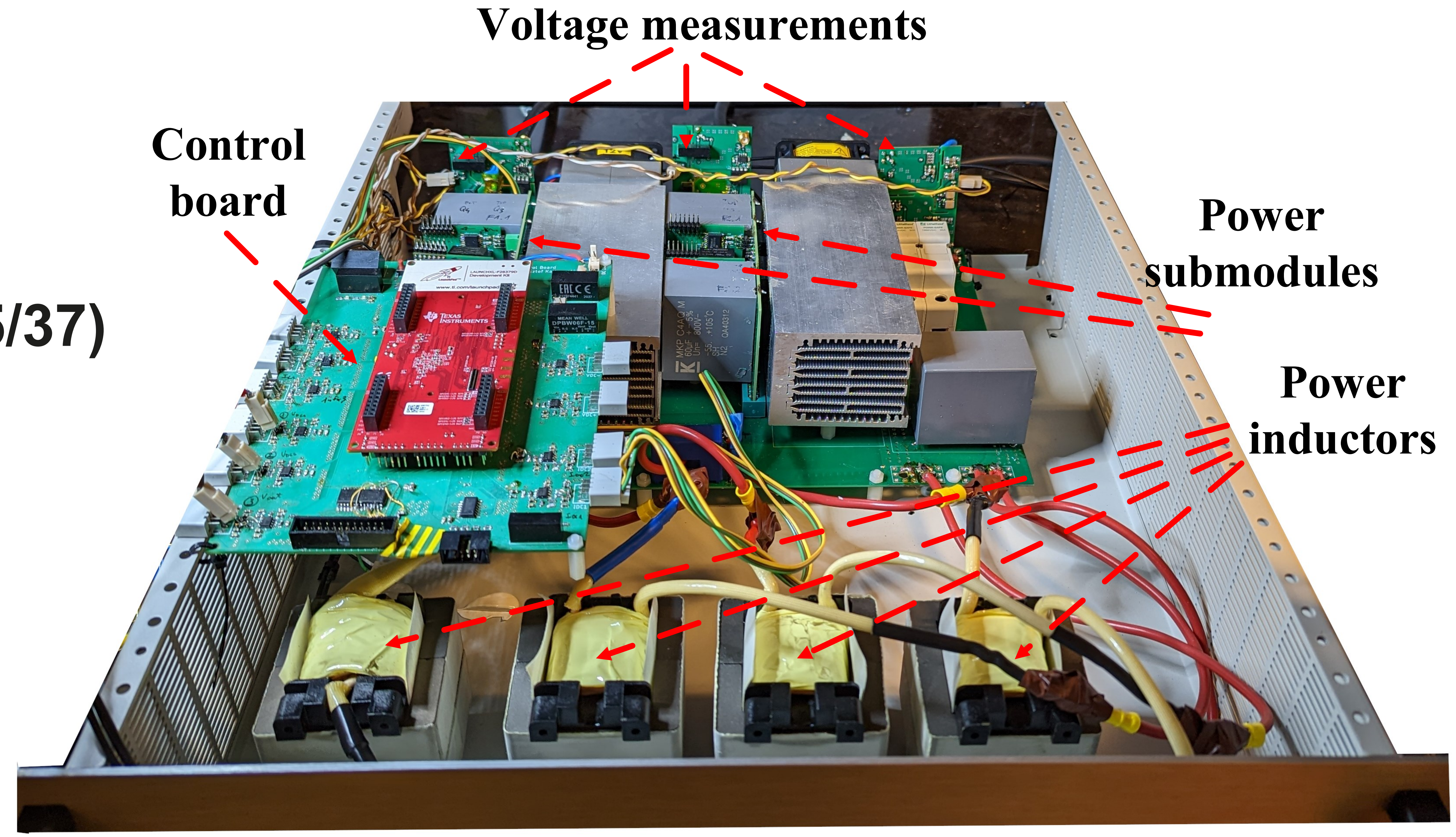
- Four NTH4L040N120SC1 power transistors
- Two 60 µF DC-link capacitors
- Two gate driver modules with protection measures
- Four-layer PCB for power connections
- Highly-performant heatsink with forced air cooling (Fischer Elektronik LAM6)



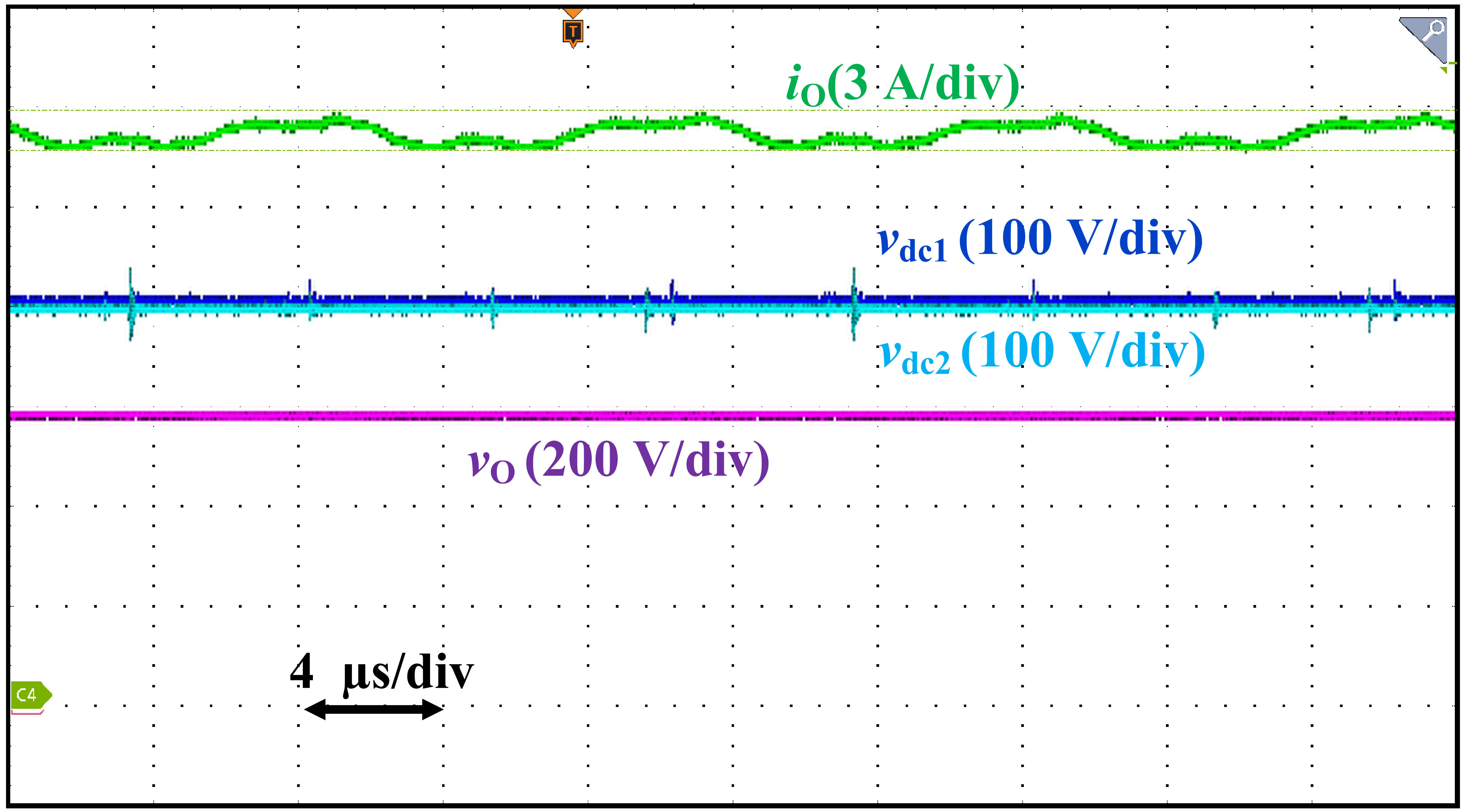
Experimental model – full prototype

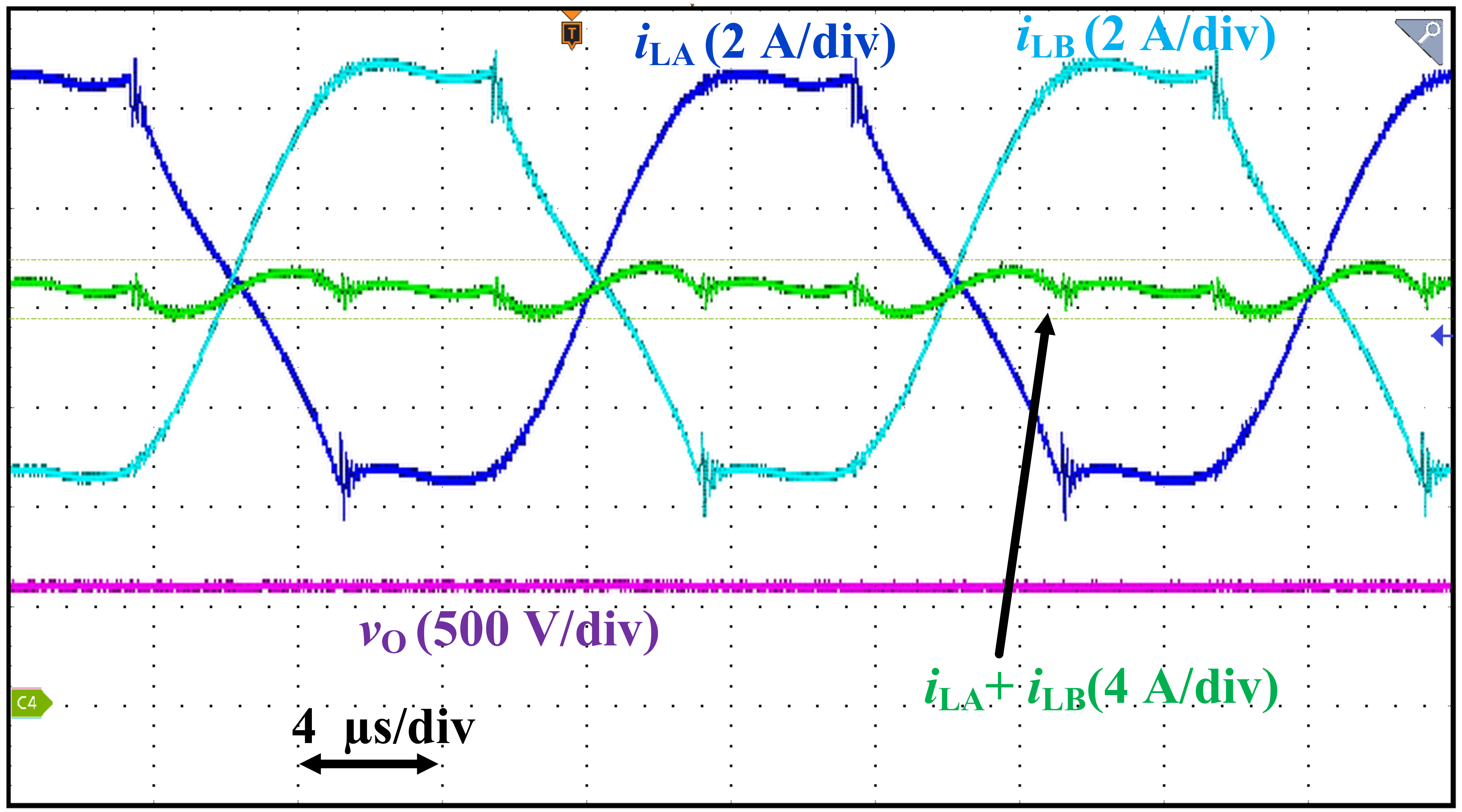
Characteristics:

- Two power submodules
- Four 150 µH inductors (DEMS-65X54/0,15/37)
- Output capacitor (800 V/60 µF)
- Control board based on a DSP, including peripherials for measurements
- Enclosed in a 3U rack case



Initial experimental results – exemplary case





Test performed at 10 kW, 800 V DC, voltage gain of roughly 0.74 with a load of 32 ohms.

Conclusion & further works

The converter can be effectively used as a battery interface for the EV fast-charging system with a bipolar DC grid:

- **Satisfactory performance at various operating points**
- **Low output ripples**
- **Balanced DC bus voltages**
- **Leveled inductor current**

Further works:

- **Full experimental study at rated current/voltage levels, in both directions**
- **Analysis of different inductor configurations, including coupled structures**
- **Experiments with the converter operating in the full EV charging station**

Norway grants

Thank you!

1st Workshop on Advanced Charging Systems

Gdynia 2022

moresic-project

https://www.ee.pw.edu.pl/moresic-project/

Warsaw University of Technology

NTNU Norwegian University of Science and Technology

MARKEL energoelektronika to nasza pasja

AREX GRUPA WB