

Non-Isolated Unidirectional High Step-Down Converter Based on Stacked DC-DC Buck-Boost Cells for HVDC Gate Unit Supply



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**POWER
ELECTRONICS** 2019

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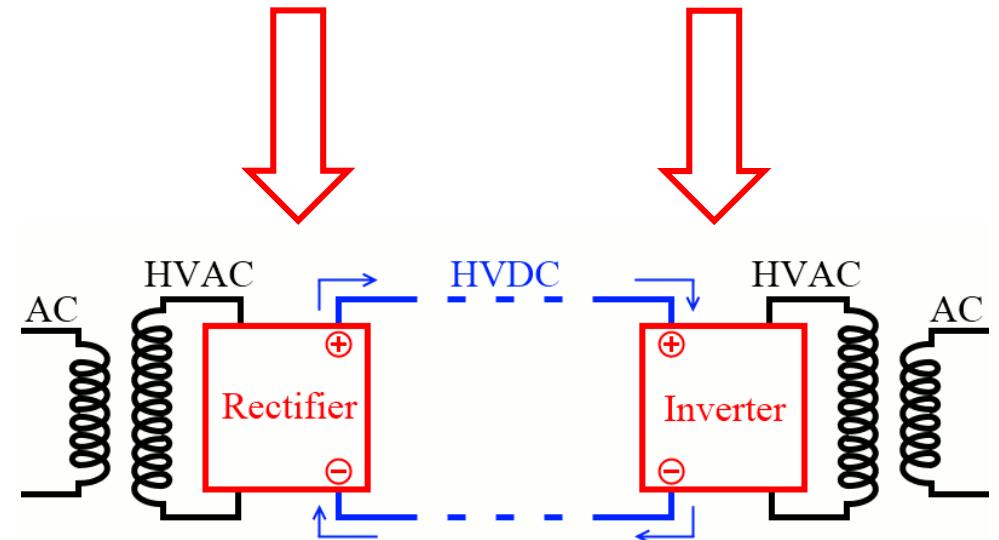
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- Proposed topology
- Principle of operation
- Experimental results
- Conclusion

Introduction

- High Voltage DC (HVDC) Transmission



- Modular Multilevel Converter

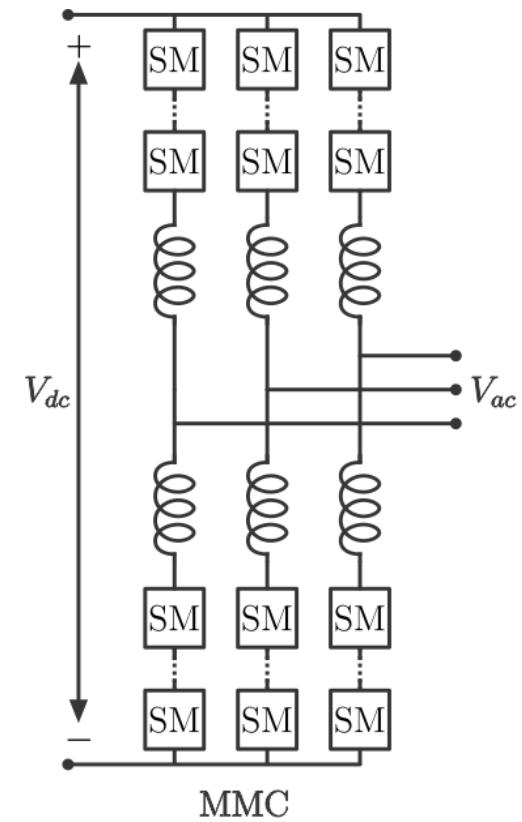


Introduction

- High Voltage DC (HVDC) Transmission

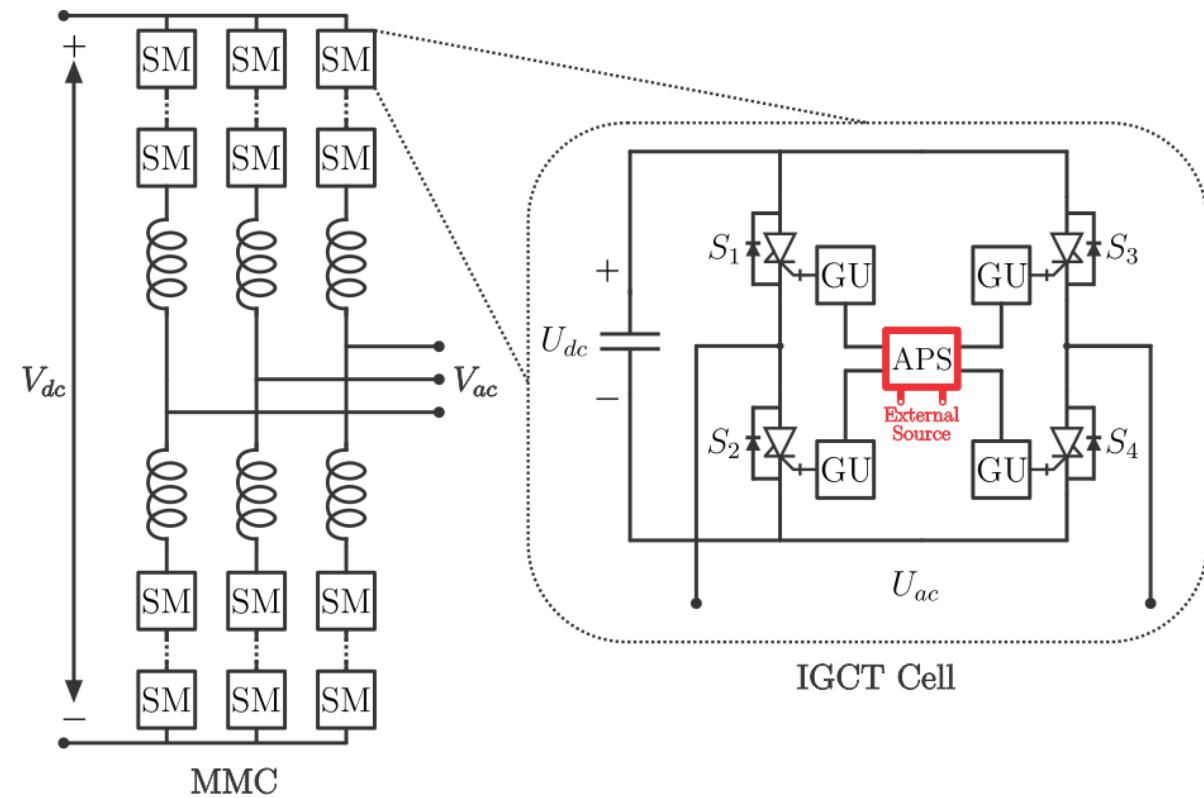


- Modular Multilevel Converter



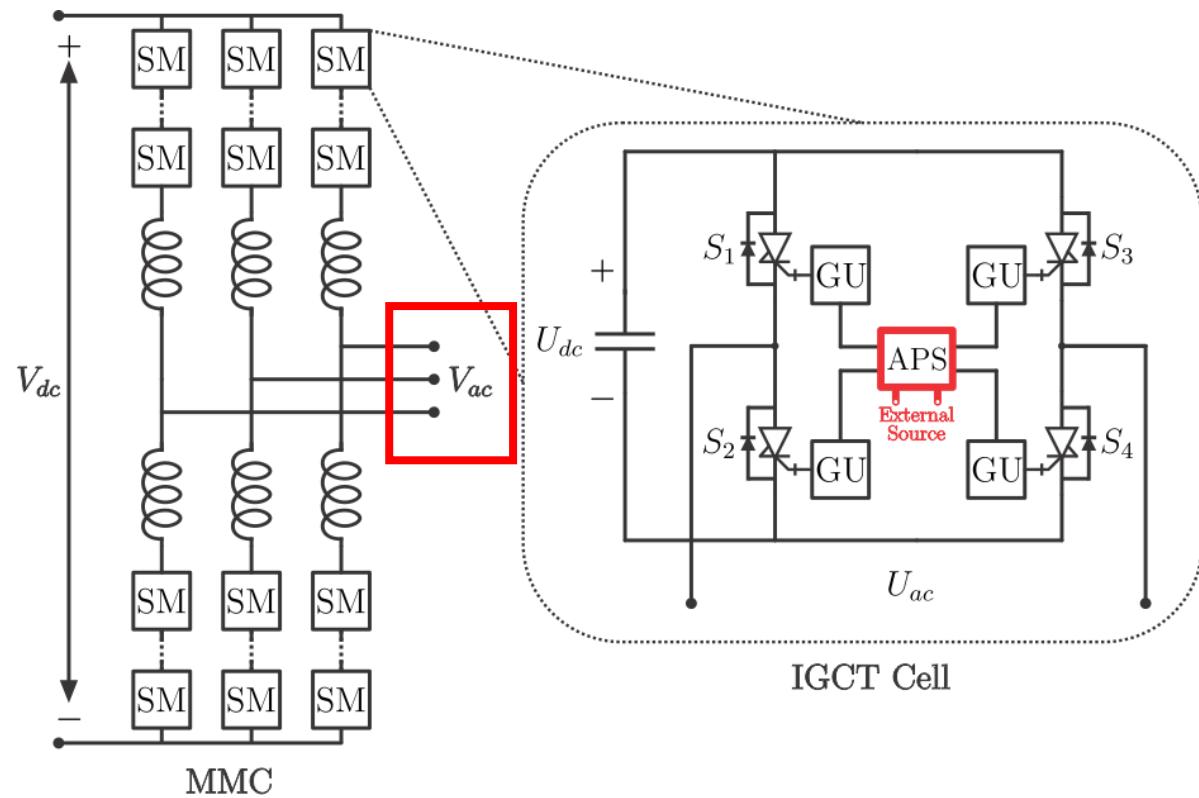
Introduction

- Problem
 - External auxiliary power supply for modular multilevel converters (MMCs)
 - High isolation required



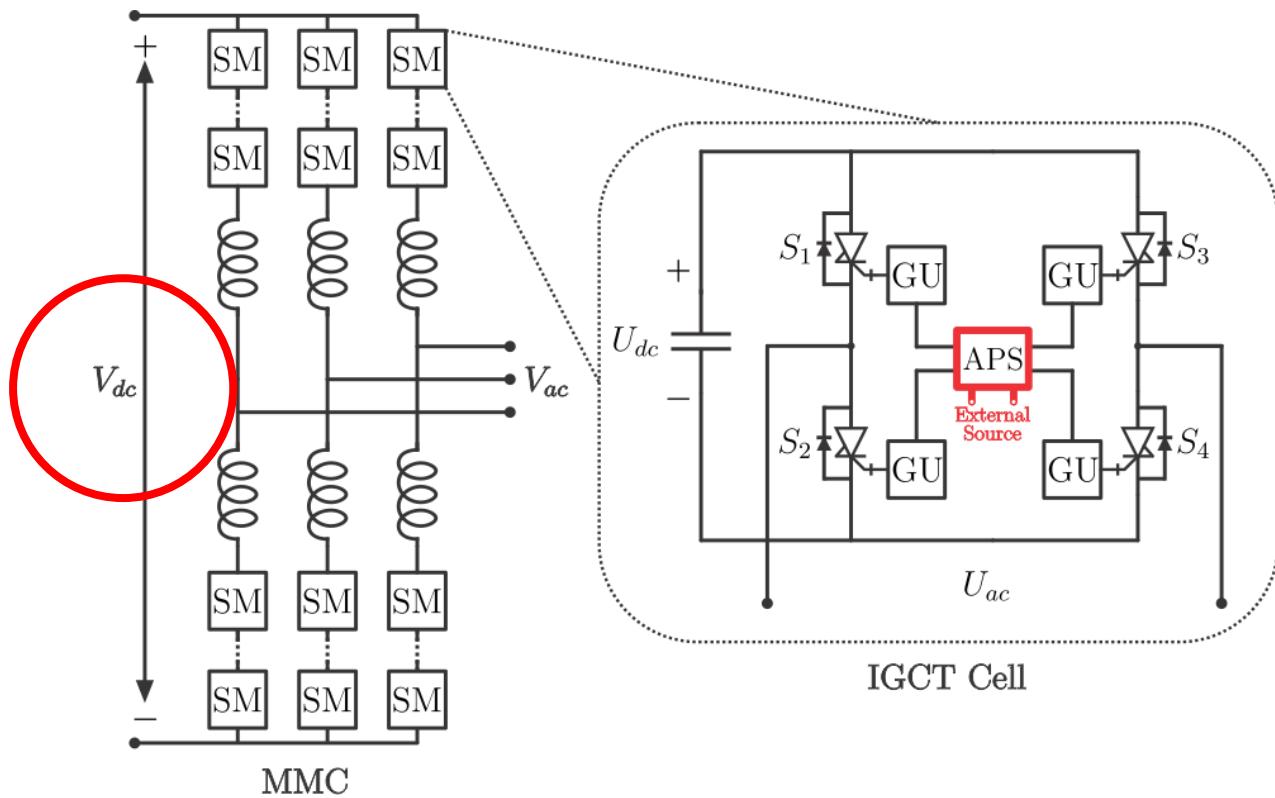
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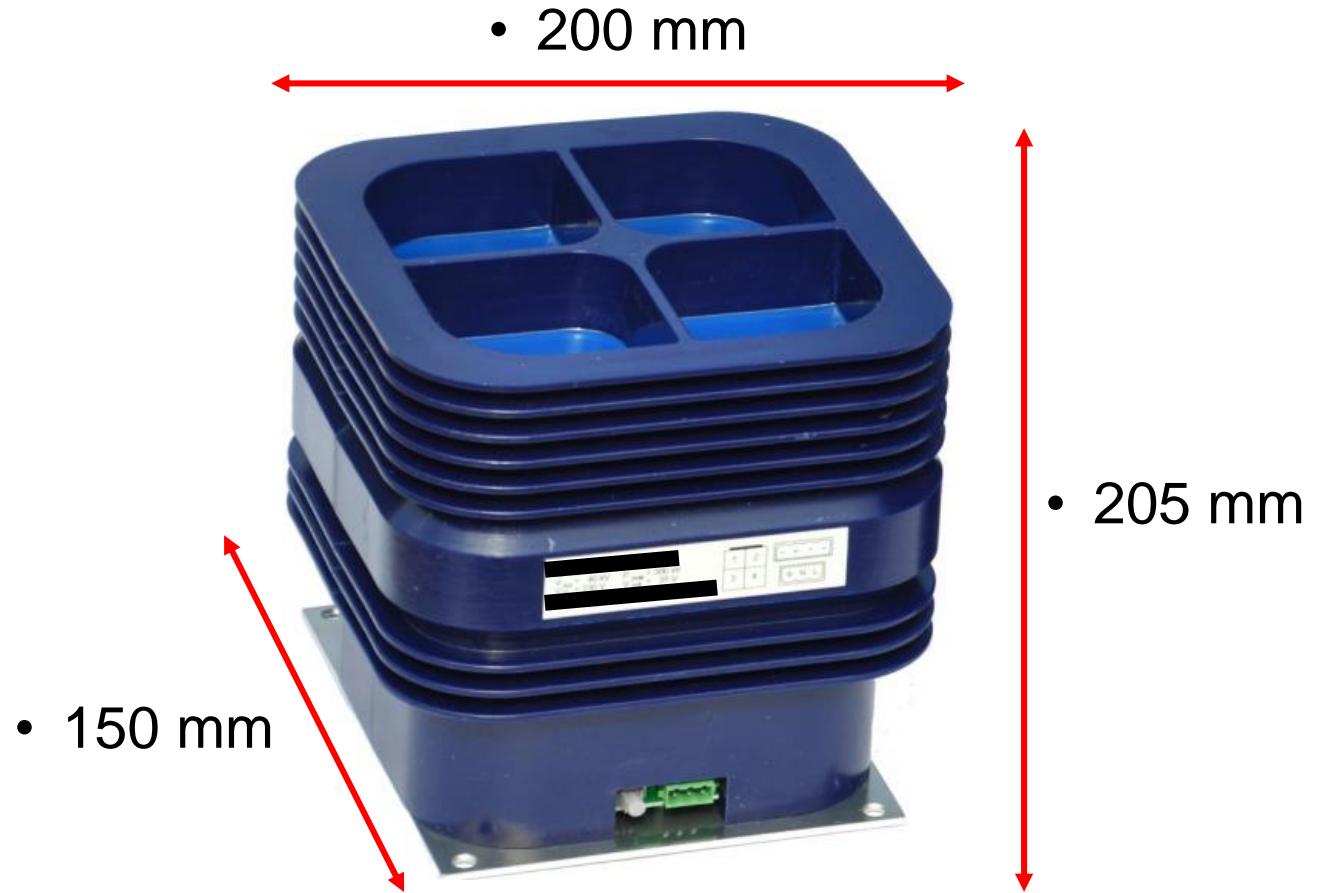
Introduction

- Problem
 - External auxiliary power supply for modular multilevel converters (MMCs)
 - High isolation required
 - ~100 kV



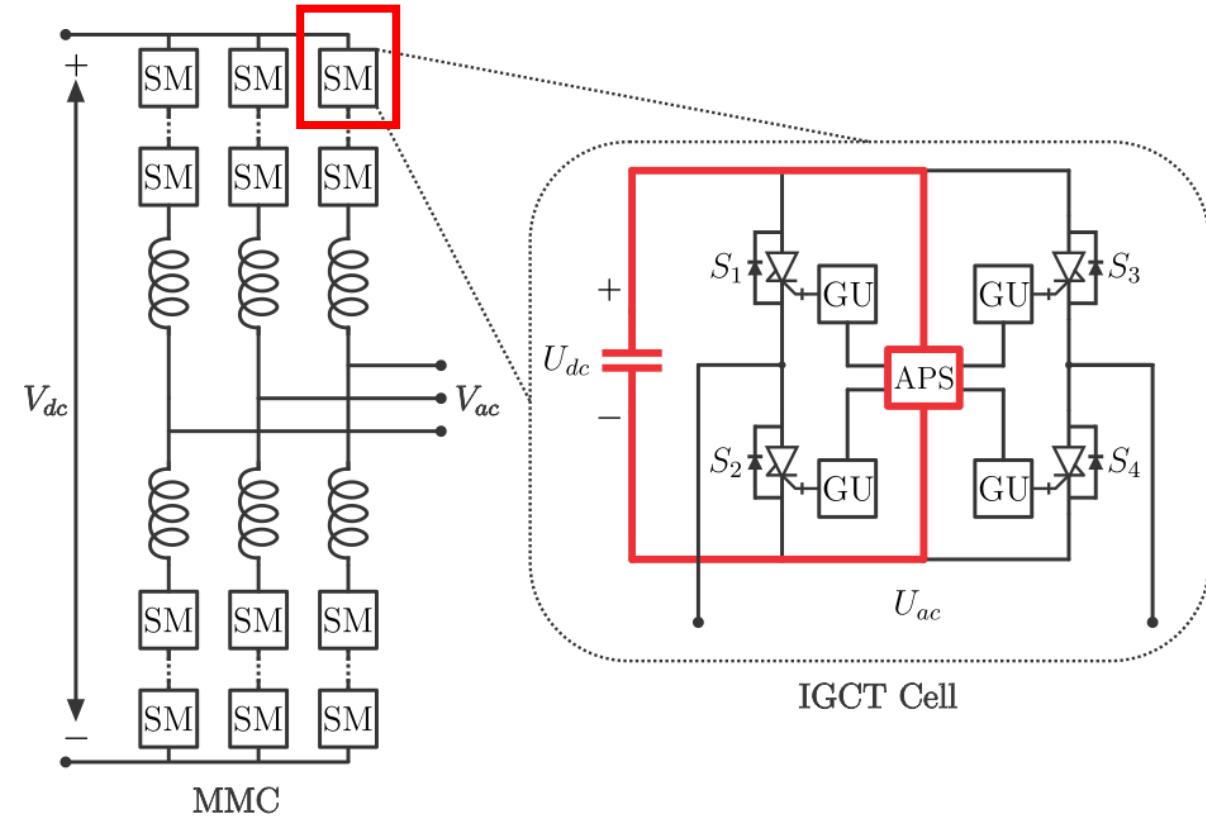
Introduction

- Problem
 - Example
 - Input Voltage = 230 V
 - Output Voltage = 35 V
 - Isolation = **40 kV**
 - Power = 300 W



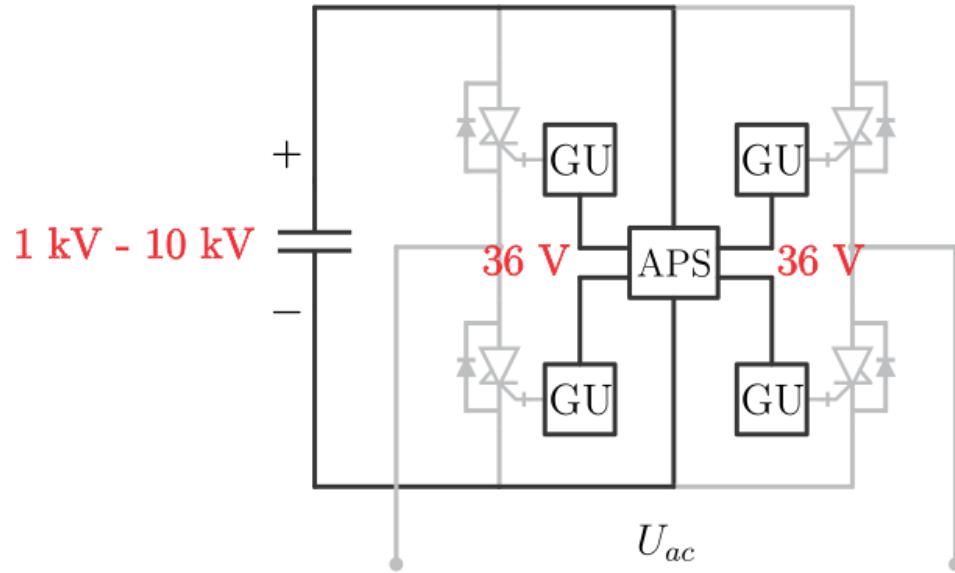
Introduction

- Solution
 - Auxiliary power supply using the capacitor of each MMC module
 - Isolation limited to SM voltage
 - **~10 kV**



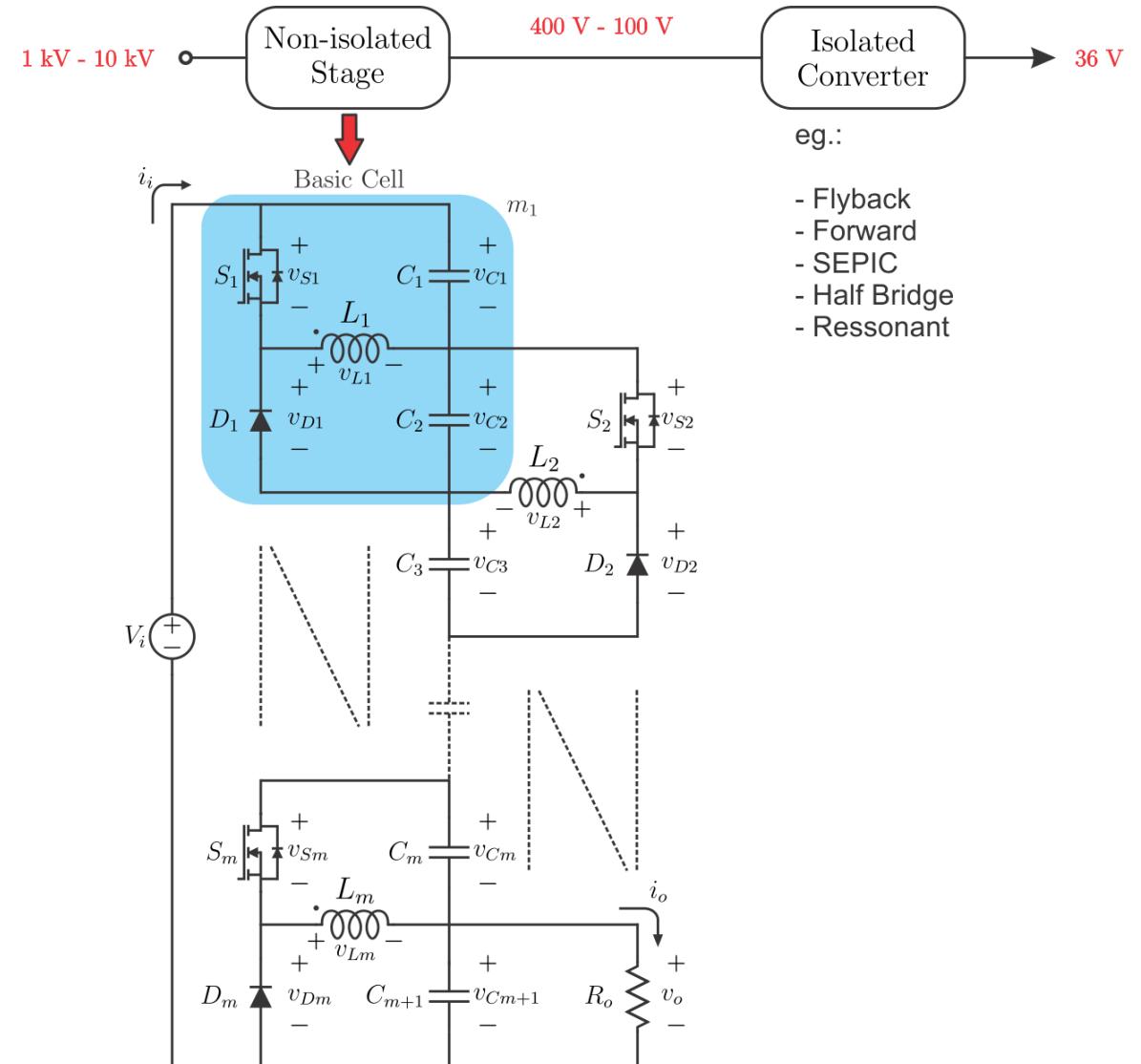
Introduction

- Requirements
 - High step-down voltage ratio
 - Isolation
 - 200 W output
 - Self-starting



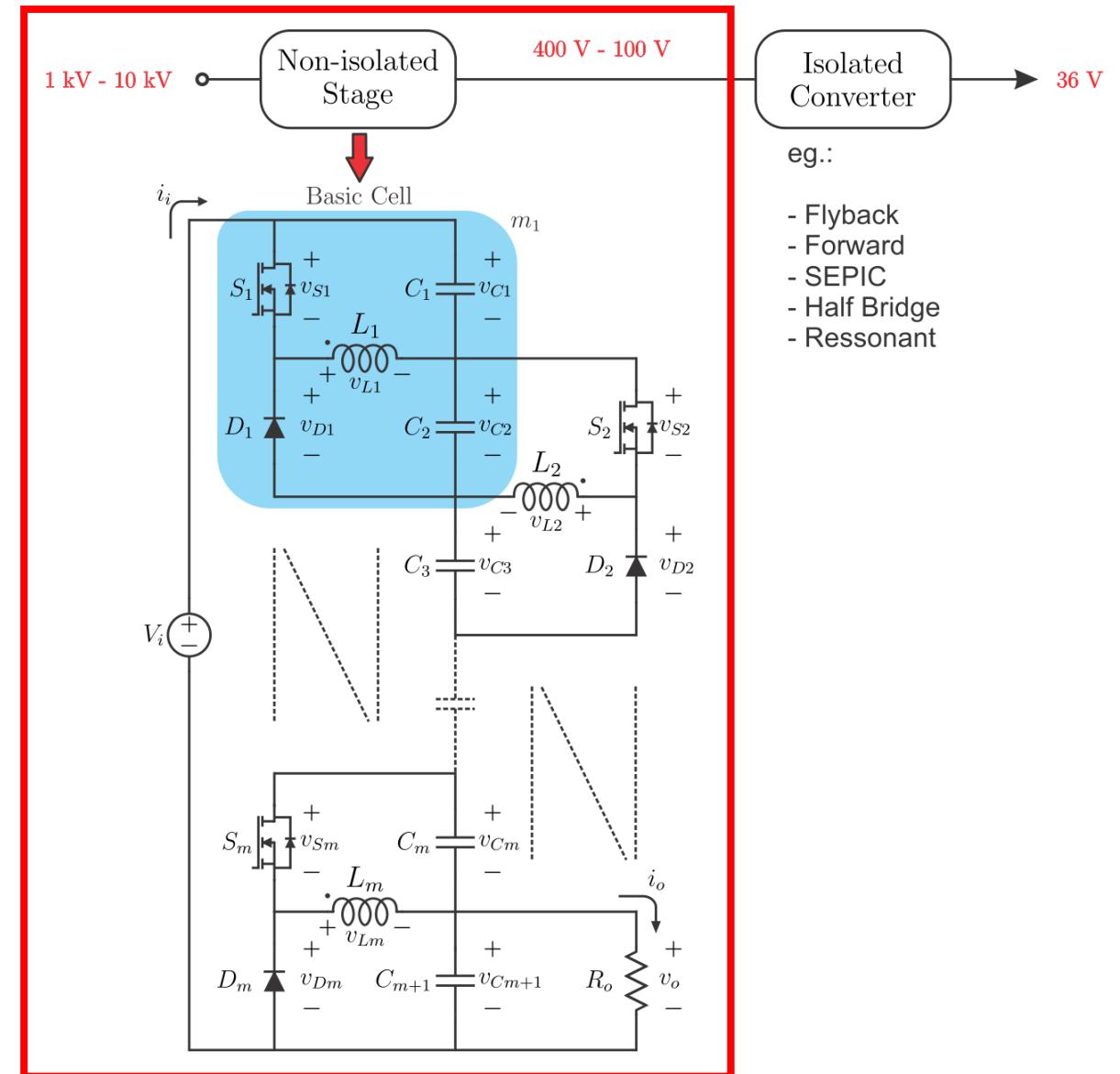
Proposed topology

- Proposal
 - Stage 1: Non-isolated stack of buck-boost cells
 - Stage 2: Isolated converter



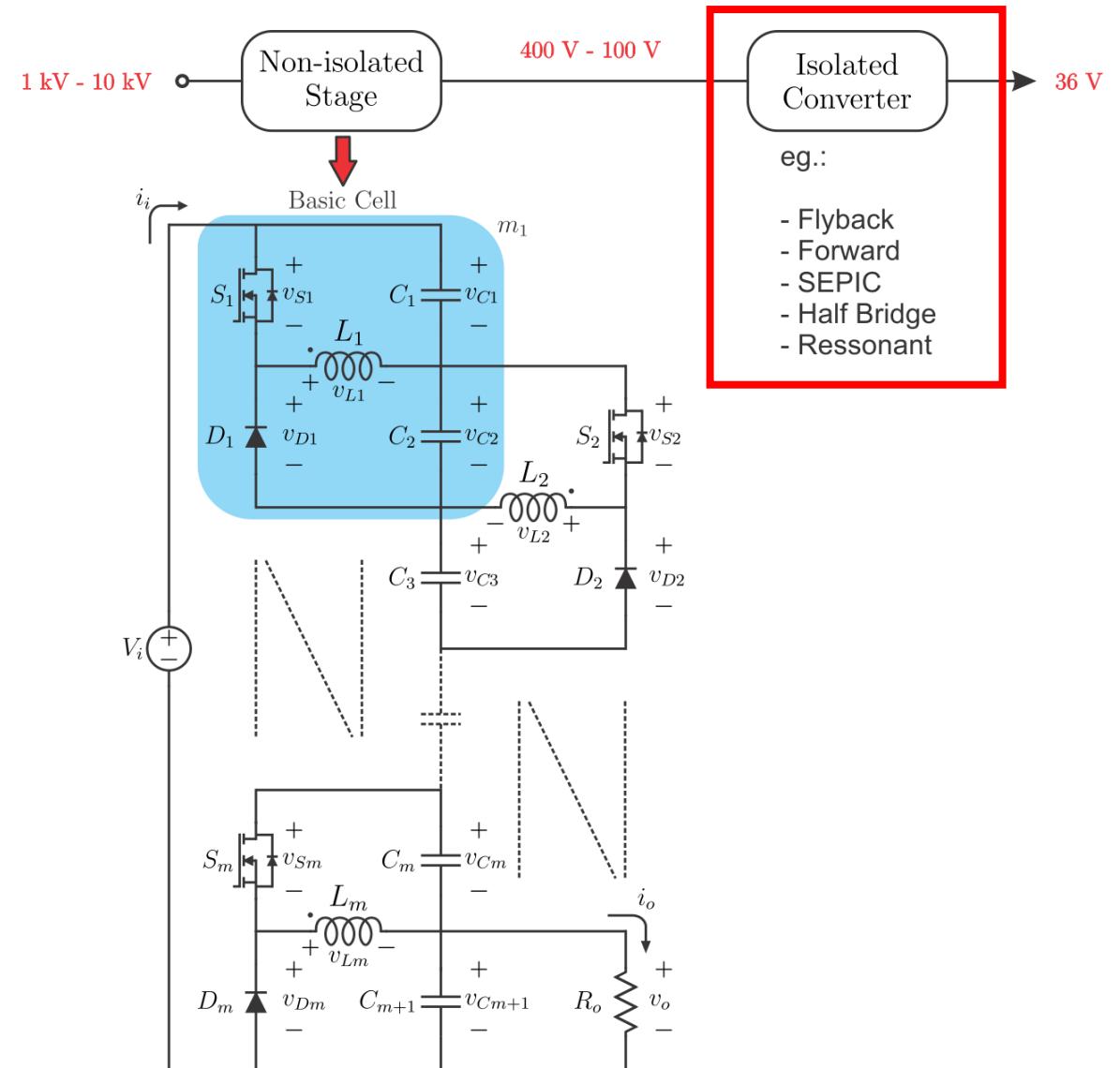
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Proposed topology

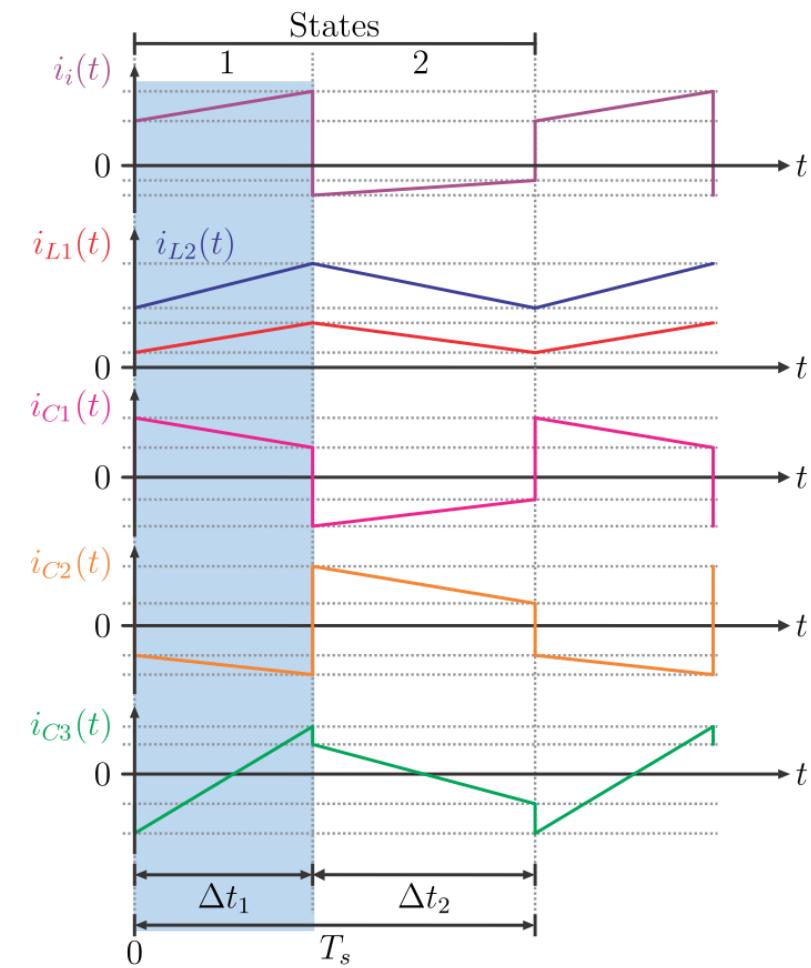
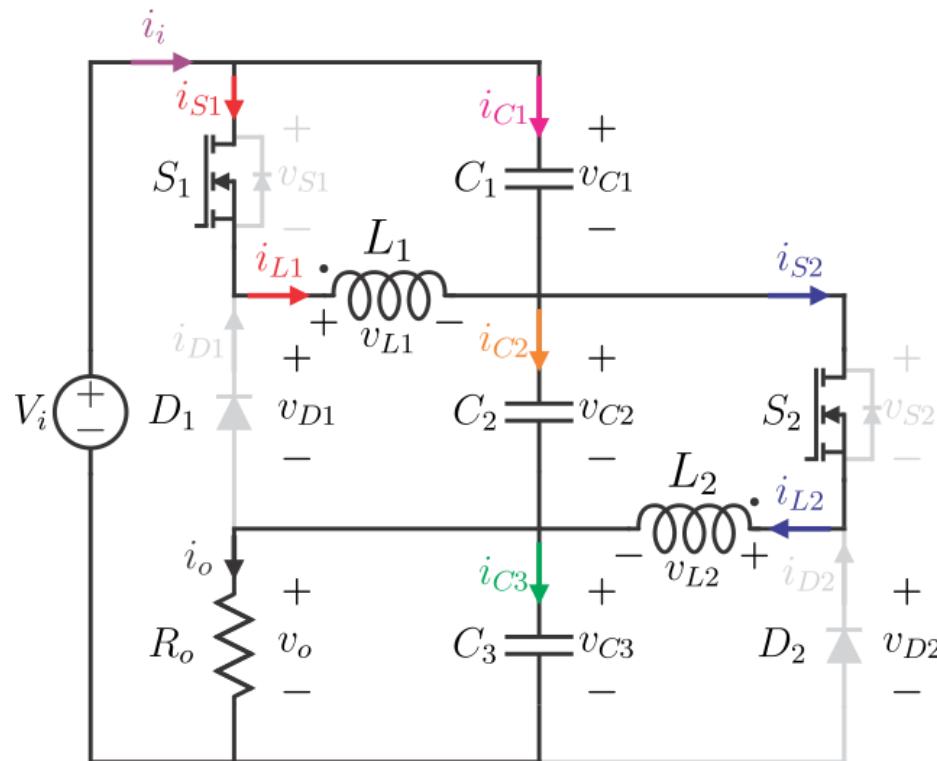
- Proposal
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- Waveforms

Principle of operation (two cells)

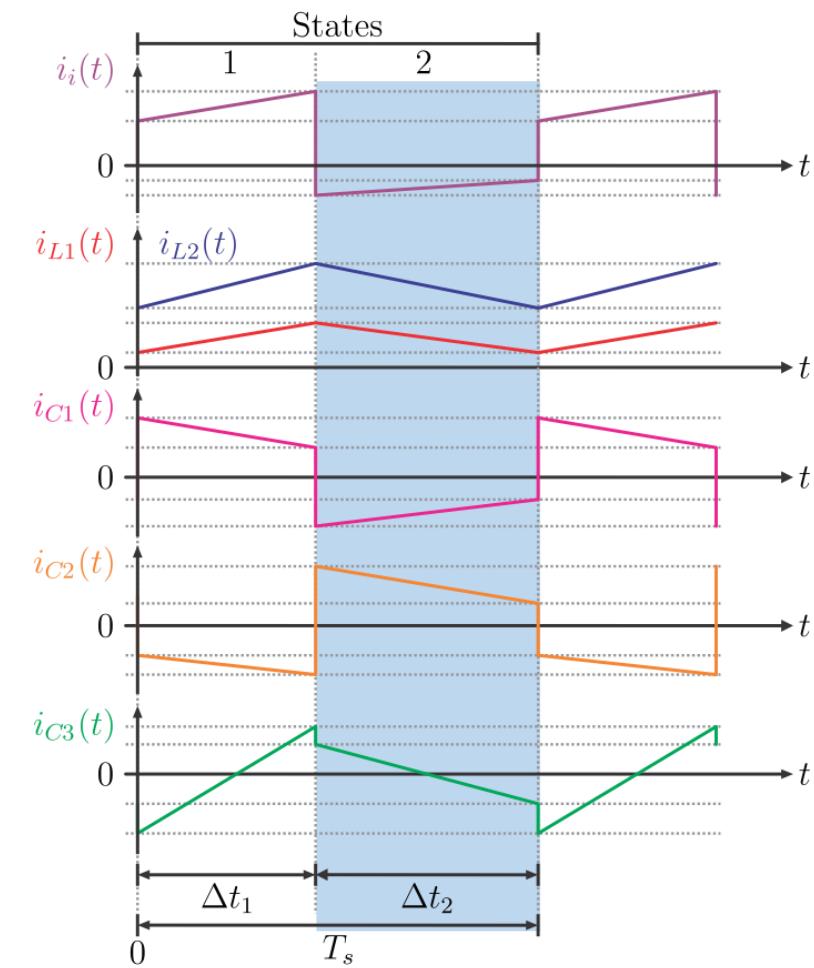
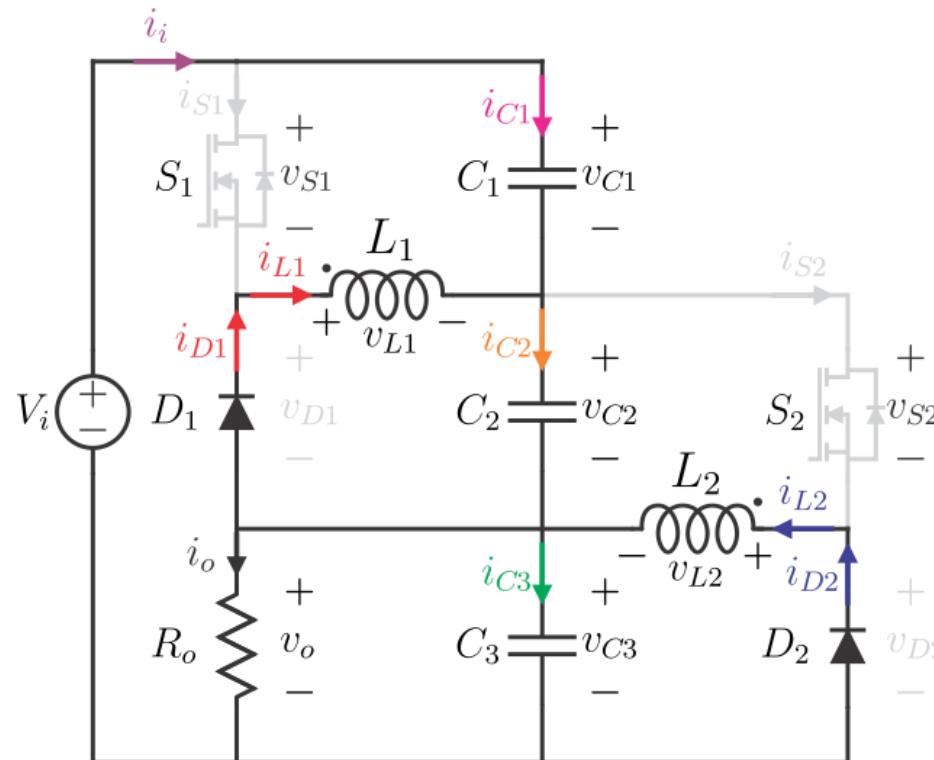
- First State



- Waveforms

Principle of operation (two cells)

- Second State



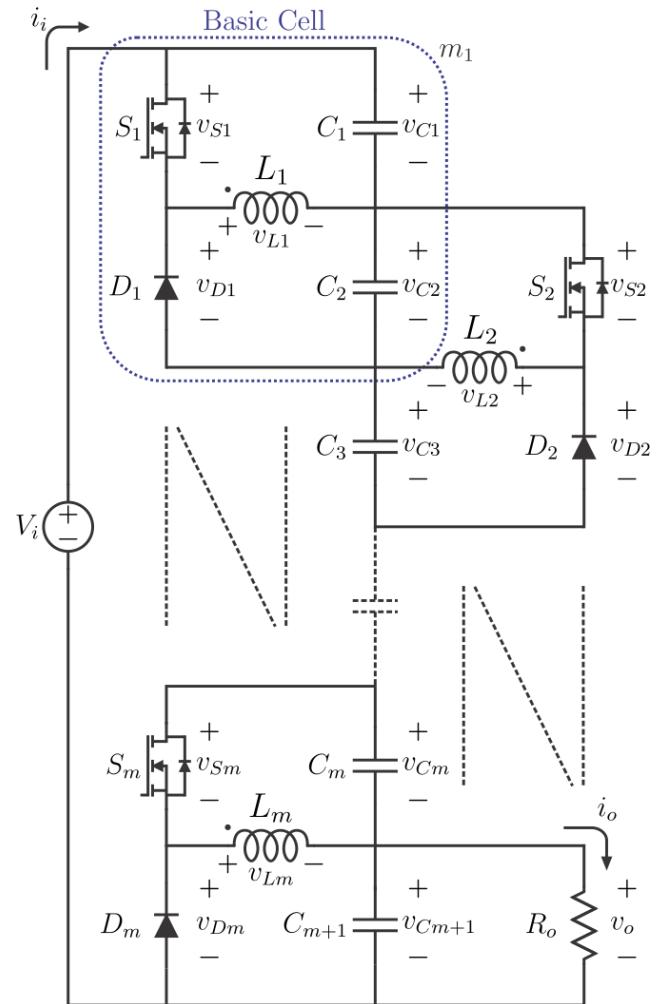
Principle of operation (m cells)

- Voltage gain (two cells)

$$G(\delta, m = 2) = \frac{V_o}{V_i} = \left[\left(\frac{1 - \delta}{\delta} \right)^2 + \left(\frac{1 - \delta}{\delta} \right) + 1 \right]^{-1}$$

- Voltage gain (m cells):

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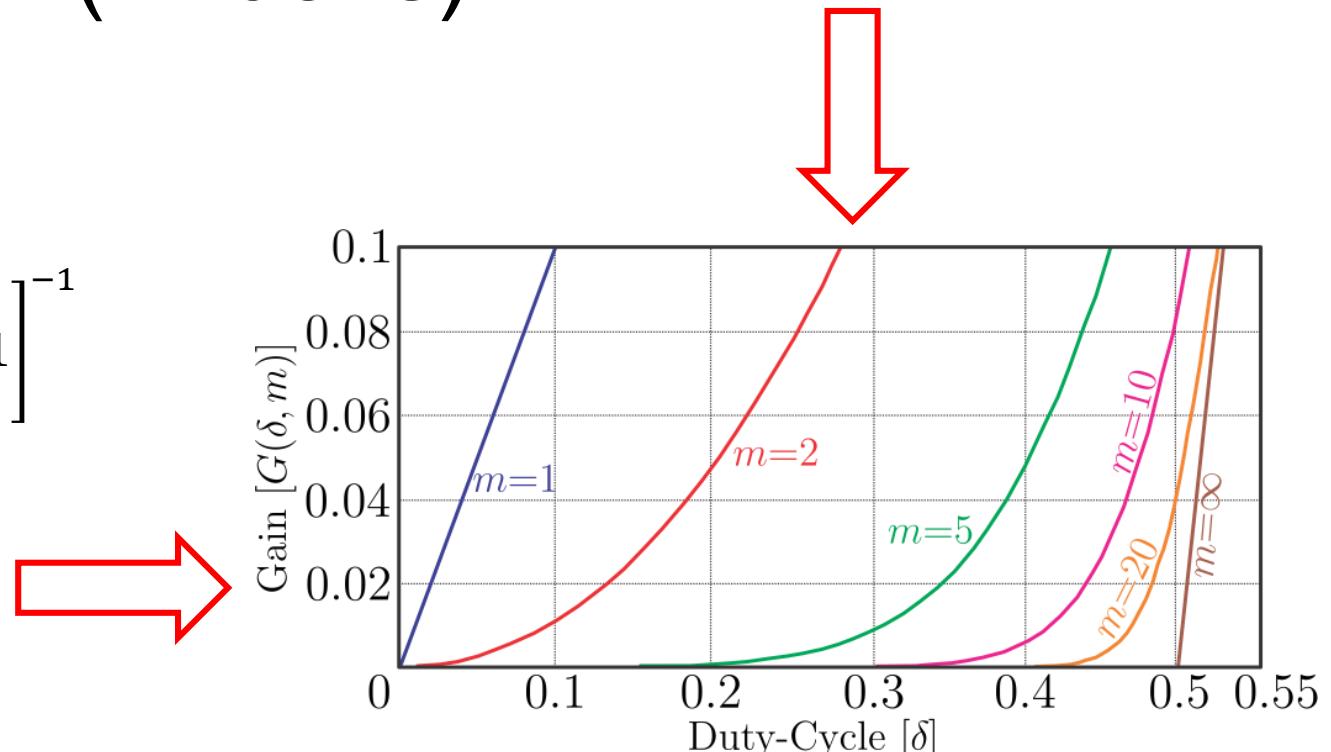
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Principle of operation (m cells)

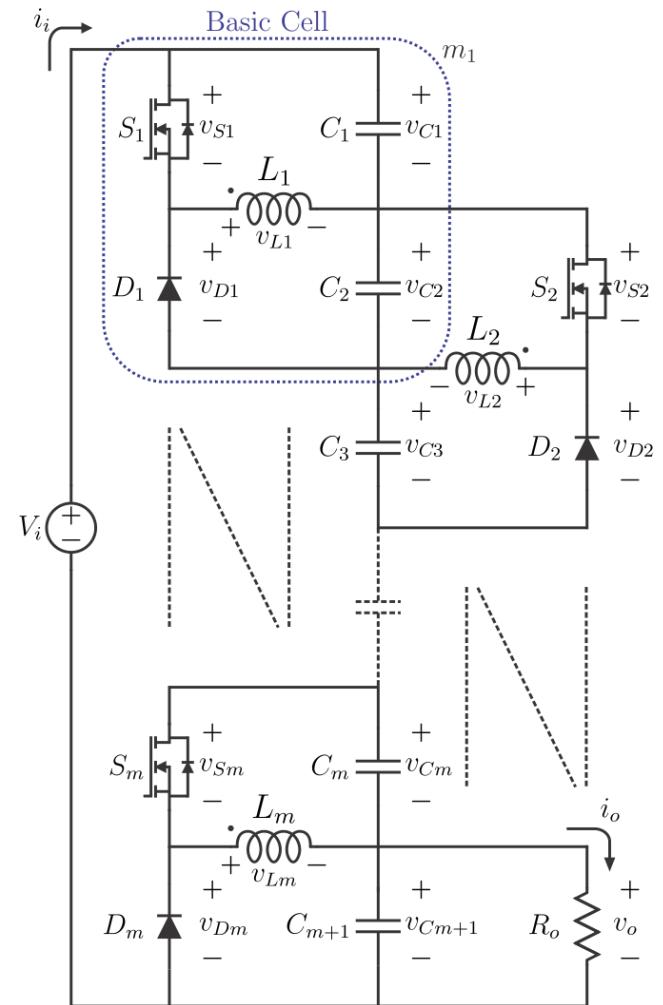
- Voltage across the capacitors

$$V_{Cx} = V_o \left(\frac{1 - \delta}{\delta} \right)^{N-x}$$

- Voltage across the semiconductors

$$V_{Sx} = V_o \sum_{y=0}^{x+1} \left(\frac{1 - \delta}{\delta} \right)^{N-y}$$

$$\begin{cases} x \in \{1, 2, \dots, N\} \\ N = m + 1 \end{cases}$$



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- Characteristic at 50% duty-cycle

$$\frac{V_o}{V_i} = \frac{1}{1 + m} = \frac{1}{N}$$

$$V_{Cx} = V_o$$

$$V_{Sx} = 2V_o$$

$$\begin{cases} x \in \{1, 2, \dots, N\} \\ N = m + 1 \end{cases}$$

Experimental results

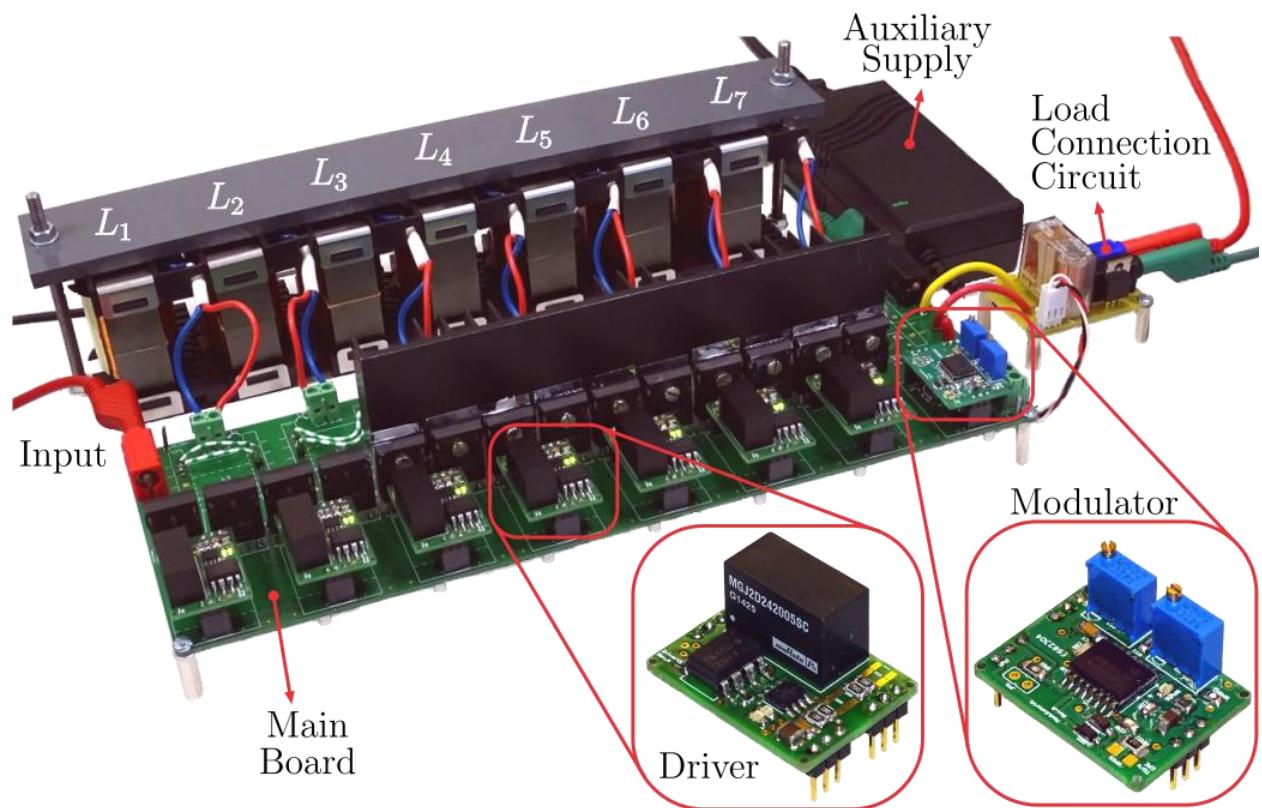
- Prototype specifications

• Rated power	200 W
• Input voltage range	1.5 – 3.0 kV
• Nominal input voltage	2.8 kV
• Nominal output voltage	350 V
• Switching frequency	30 kHz

Experimental results

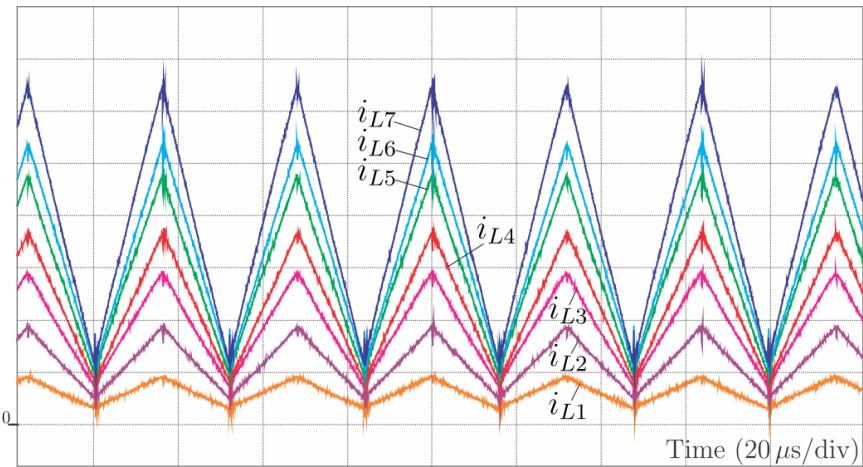
- Converter parameters

- 7 Cells
- 8 Capacitor ($1 \mu\text{F}$)
- 1.7 kV semiconductors
- Inductor values:
[29.3, 14.6, 9.7, 7.3, 5.9, 4.9, 4.2] mH
- Fixed duty cycle (50%)



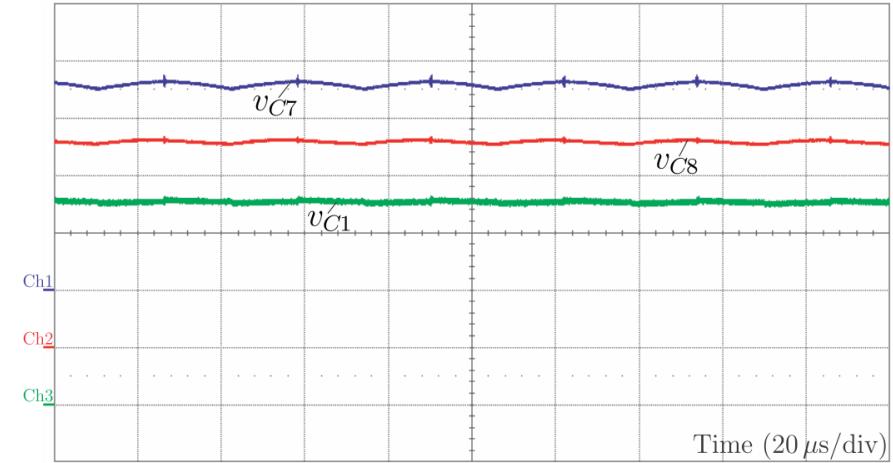
Experimental results

- 2.8 kV Input voltage

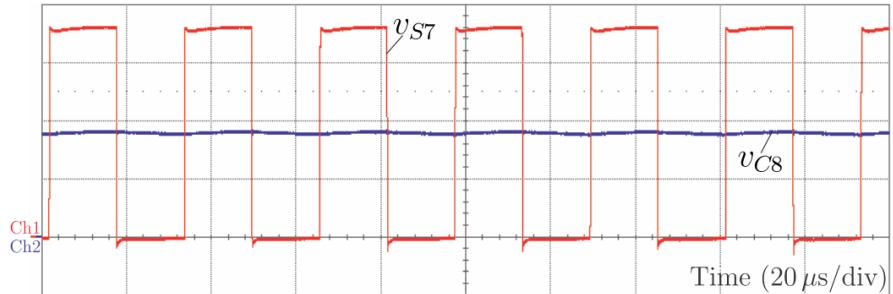


Currents through the inductors (250 mA/div)

$$I_{Lx,\text{avg}} = \frac{x2I_o}{N}$$



Voltage across three capacitors (100 V/div)



Voltage across one switch and output voltage (200 V/div)

Experimental results

- 2.8 kV Input voltage
 - Output voltage (100 V/div)
 - Output current (200 mA/div)
 - Input current (200 mA/div)
 - Output power: ~188 W
 - Efficiency: ~ 90%

Conclusion

- Advantages
 - High step-down voltage ratio
 - Natural voltage balance across the capacitors
 - No control loop and sensors required
 - Simple modulation
 - Modularity
 - HF possible – reduced volume
- Agrees with theoretical results!

Thank You!

<http://www.tue.nl/epe>



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