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POWER ELECTRONICS 2017

Electromechanics and Power Electronics Group

3–5 Level Bidirectional Dual Active Bridge DC–DC Converter

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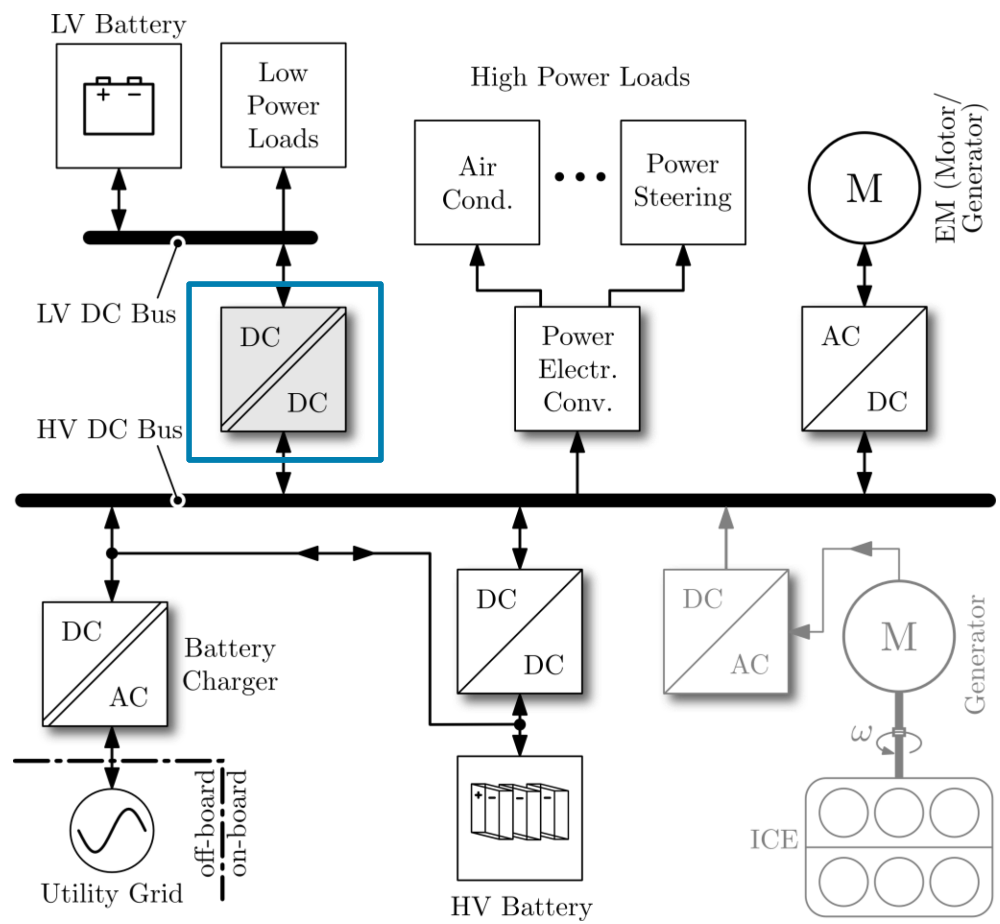
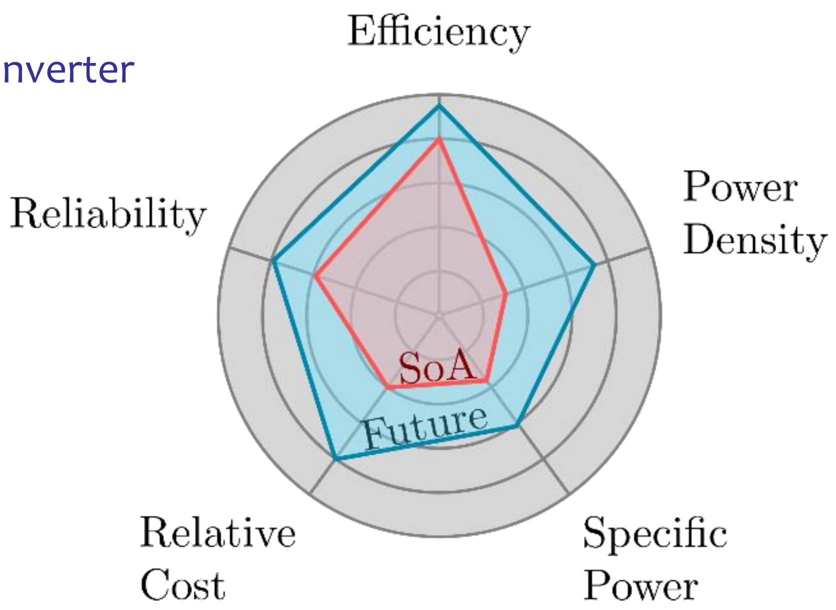


Introduction

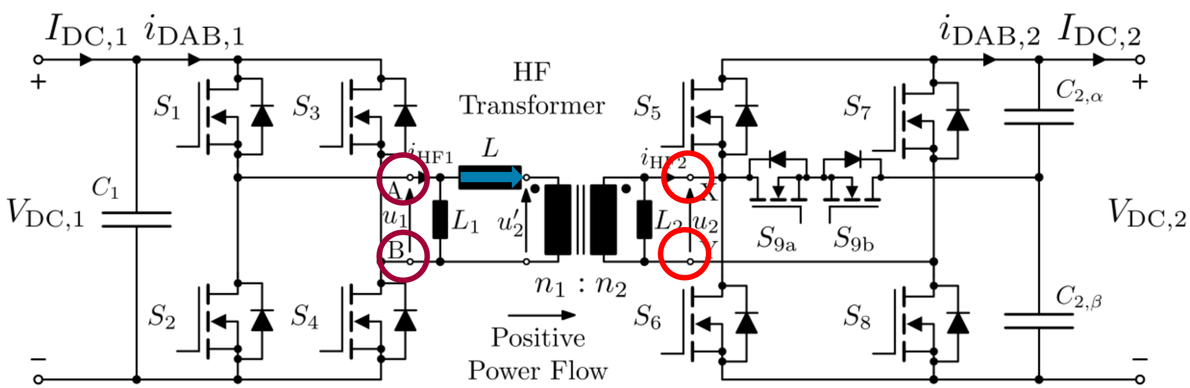
- Specifications
  - 8-16 V_{DC} (LV Side)
  - 175-450 V_{DC} (HV Side)
  - 200 A (LV DC current)
- Motivation
  - Single Stage implementation
  - Multi Objective Optimization (MOO) of the converter
  - Comparison with Dual Stage implementation
- Dual Active Bridge
  - Soft-Switching
  - Galvanic Isolation



Content

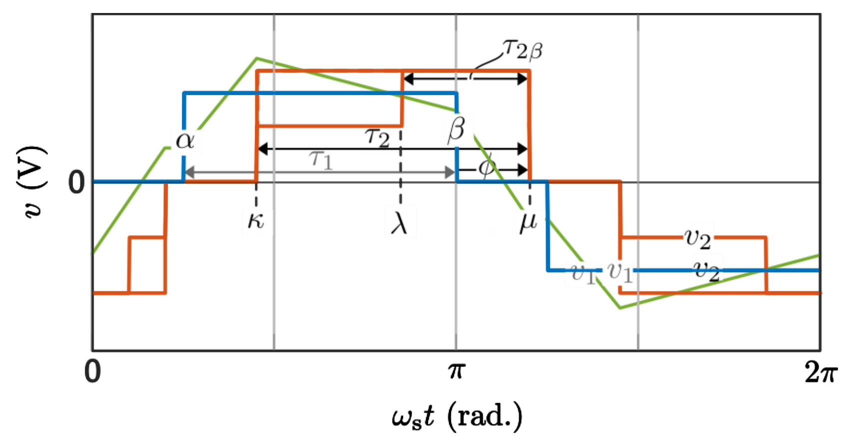
- The Dual Active Bridge (DAB)
  - Operating Principle
  - 3-5L DAB
- Switching Control Analysis
  - Zero voltage switching (ZVS)
  - Piecewise linear analysis
  - Switching modes and mode selection
- Modulation Strategy
- Experimental Results: Proof of concept
- Comparative Evaluation (3-3L vs 3-5L DAB)
- Conclusions

The Dual Active Bridge



Control Variables

$\tau_1,\ \tau_2,\ \tau_{2B}$ and ϕ



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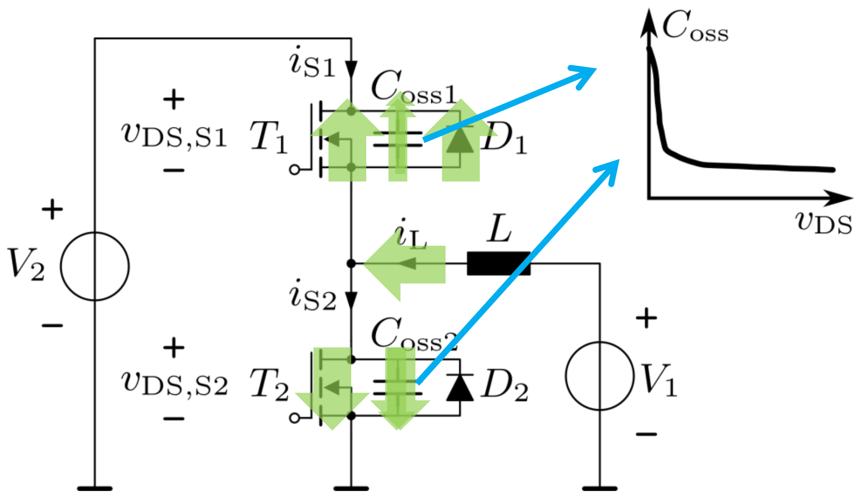
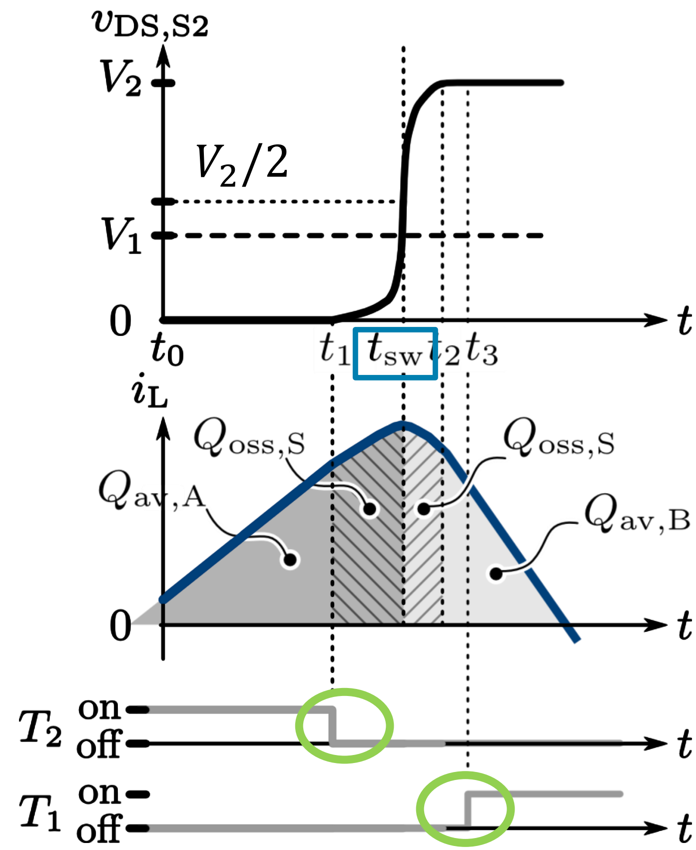
$T2$: ZVS turn-off

$T1$: ZVS turn-on





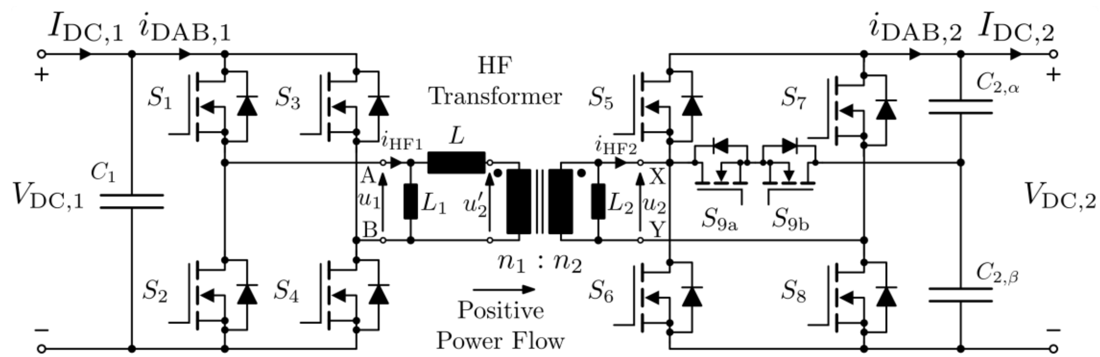
$$Q_{av,A} \geq Q_{oss,S}$$
$$Q_{av,B} \geq Q_{oss,S}$$

Switching Control Analysis

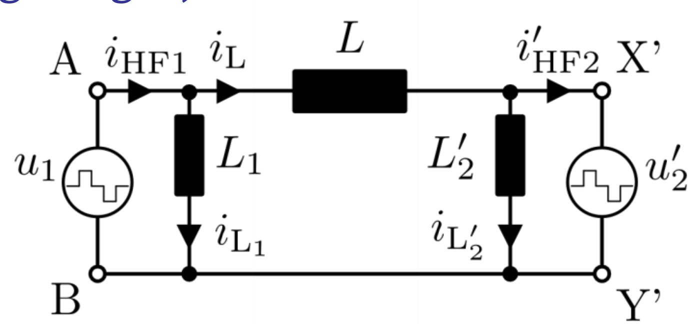
- Piecewise linear

$$\frac{\mathrm{d}i_{\mathrm{L}}(t)}{\mathrm{d}t} = \frac{v_1(t) - v_2'(t)}{L}$$

$$\frac{\mathrm{d}i_{\mathrm{L}_1}(t)}{\mathrm{d}t} = \frac{v_1(t)}{L_1} \qquad \frac{\mathrm{d}i_{\mathrm{L}_2'}(t)}{\mathrm{d}t} = \frac{v_2'(t)}{L_2'}$$

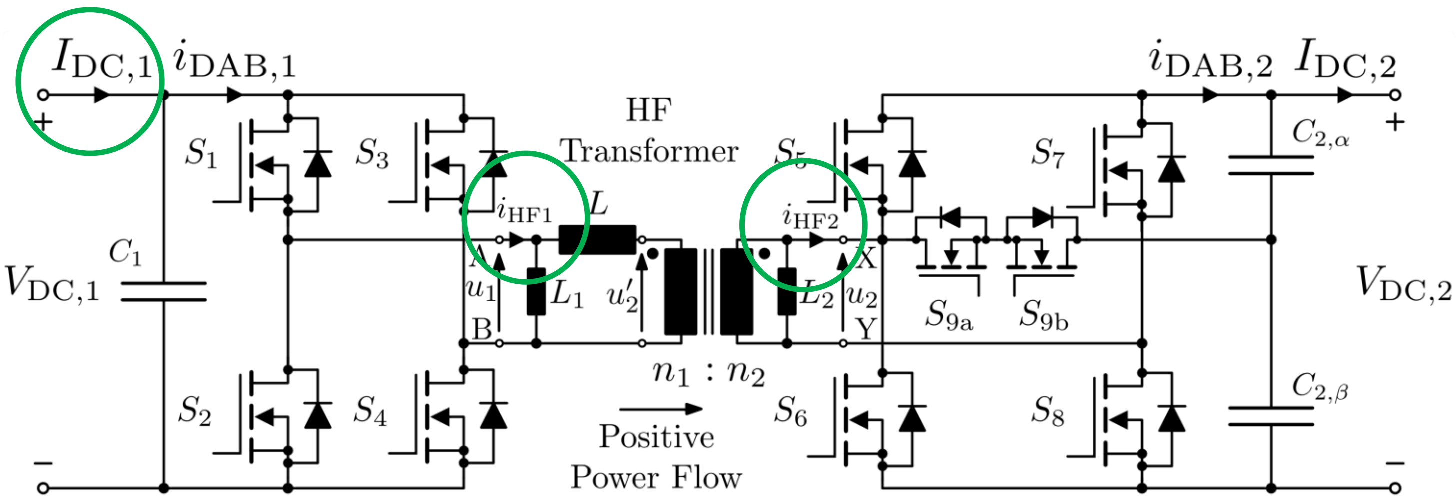


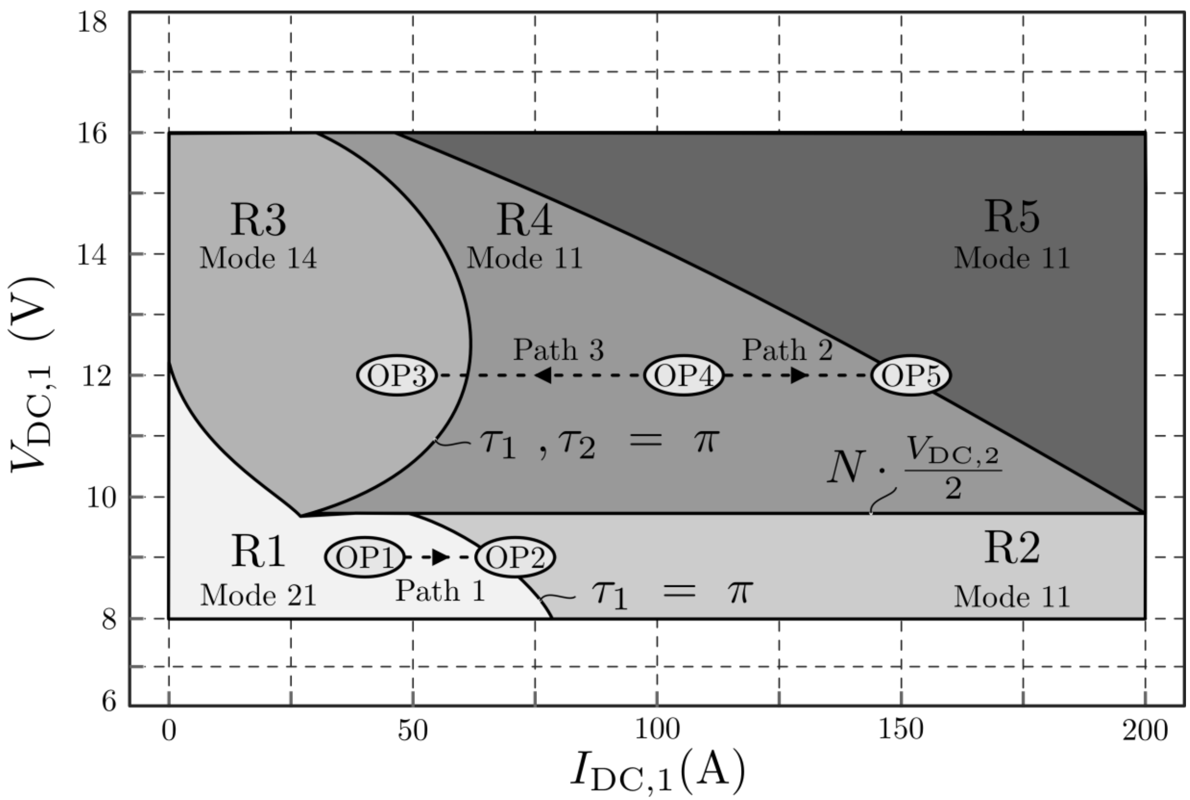
- 24 possible modes
(i.e. different sequences of the voltage edges)



- Mode selection (non linear constrained minimization)
  - Soft-switching constraints
  - Input current
  - Objective function:

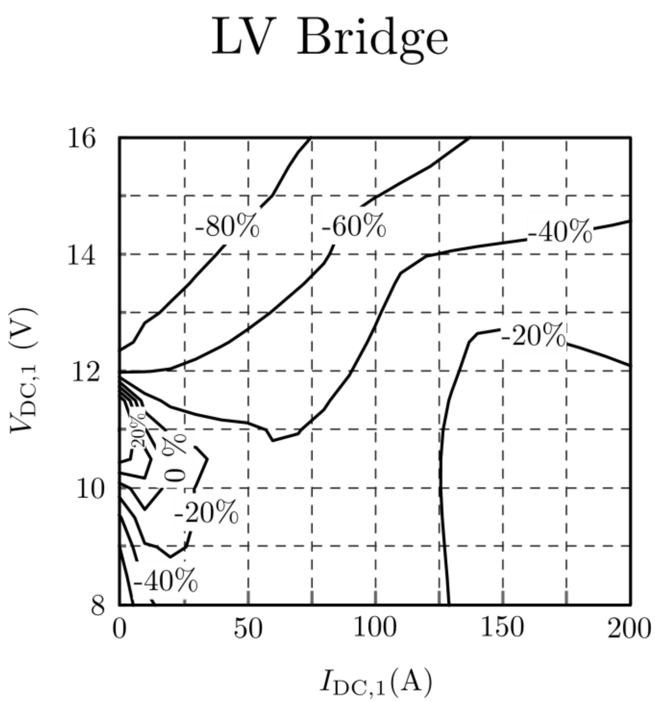
$$f_{\mathrm{obj}} = I^2_{\mathrm{RMS,HF1}} + \frac{I^2_{\mathrm{RMS,HF2}}}{N^2}$$

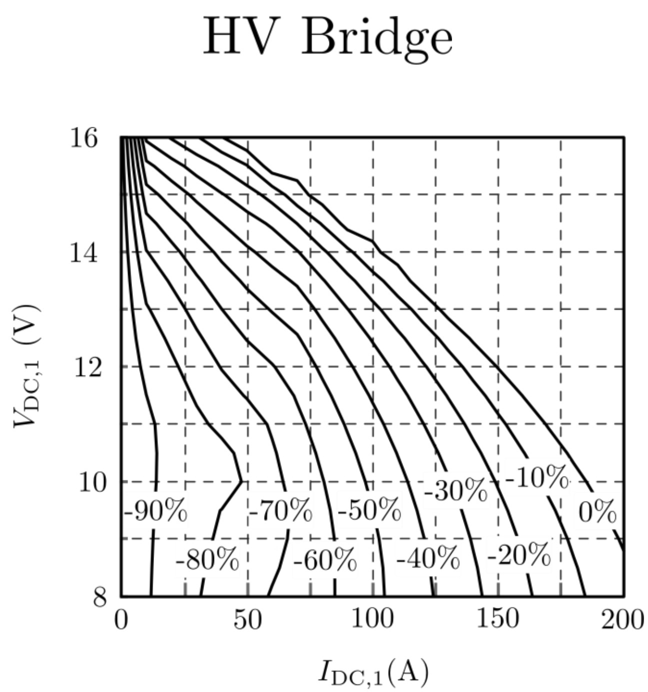




18
16
14
12
10
8
6
0
50
100
150
200
$V_{DC,1}$ (V)
$I_{DC,1}$(A)
R3
Mode 14
R4
Mode 11
R5
Mode 11
R1
Mode 21
R2
Mode 11
OP1
OP2
OP3
OP4
OP5
Path 1
Path 2
Path 3
$\tau_1, \tau_2 = \pi$
$\tau_1 = \pi$
$N \cdot \frac{V_{DC,2}}{2}$

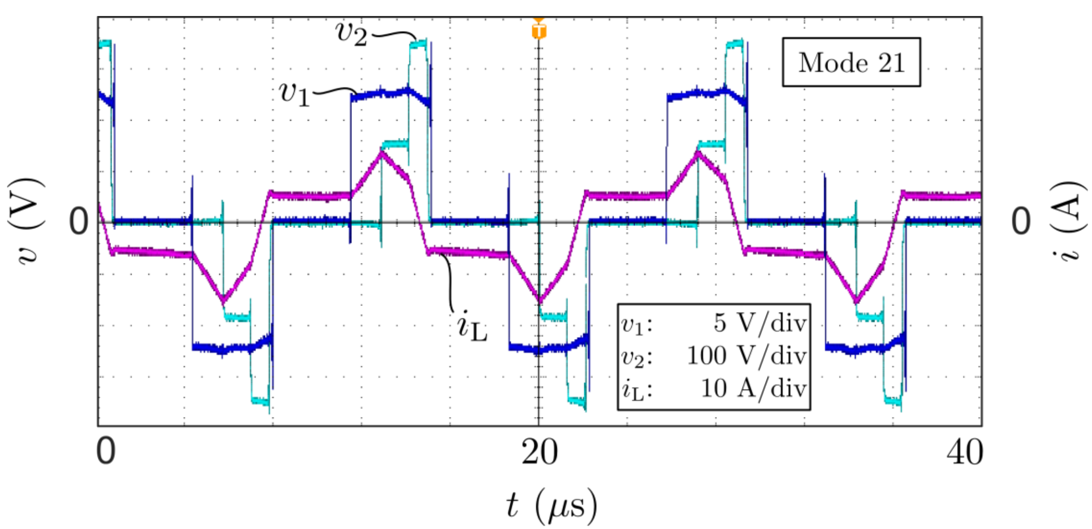
- ZVS achieved in the entire operating region

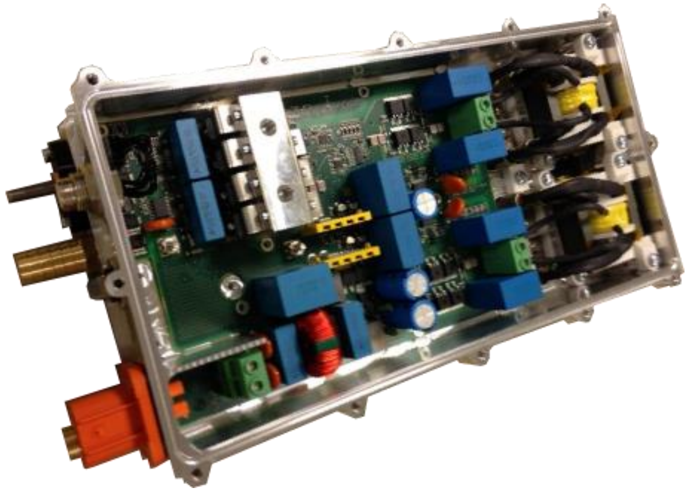




$$RMS_{\%} = 100\% \cdot \frac{I^2_{\mathrm{RMS,HFx,3-5L}}(v,i) - I^2_{\mathrm{RMS,HFx,3-3L}}(v,i)}{I^2_{\mathrm{RMS,HFx,3-3L}}(v,i)}.$$

Experimental Results: Proof of Concept

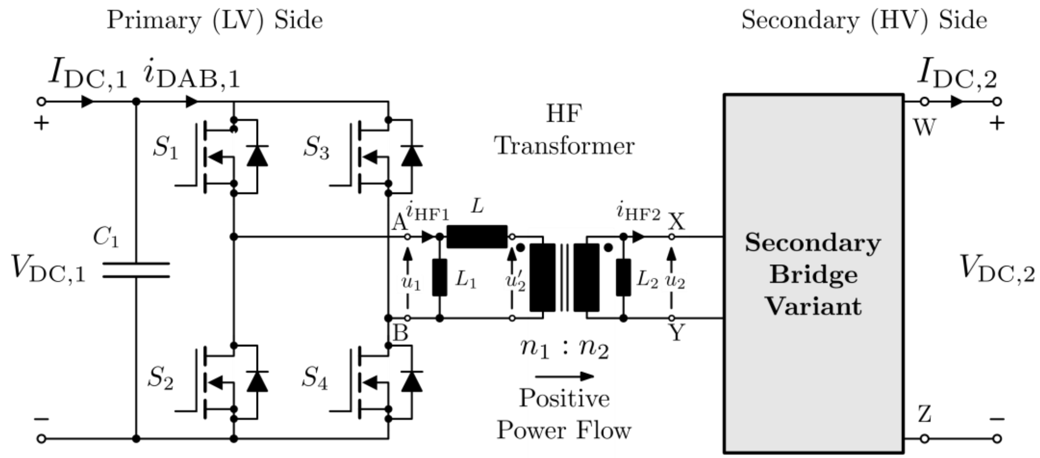




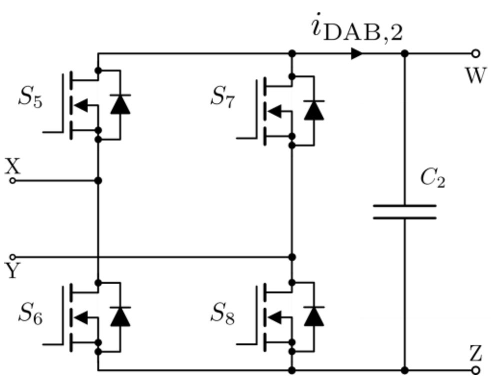
- $V_{DC,1} = 12$ V
- $V_{DC,2} = 350$ V
- $I_{DC,1} = 32.6$ A

Switch (LV)	BUK7Y3R5-40E
Switch (HV)	STW65N65DM2AG
$n_1/n_2 = N$	1/11
L	6.4 μH
f_s	70 kHz

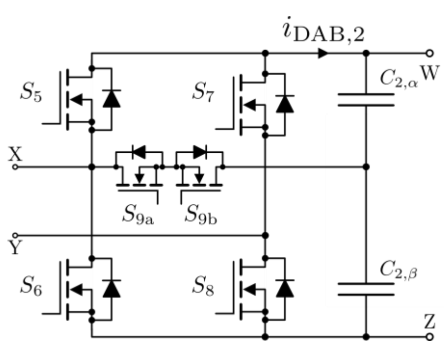
Comparative Evaluation: Dual Active Bridge Variants



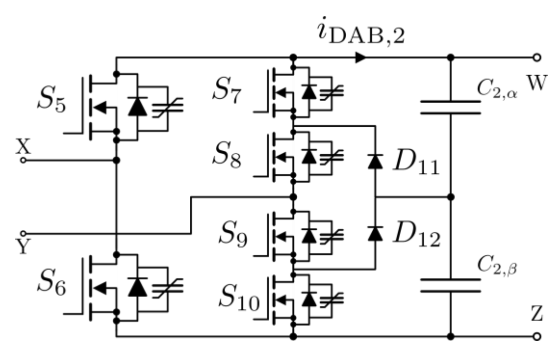
3 Level



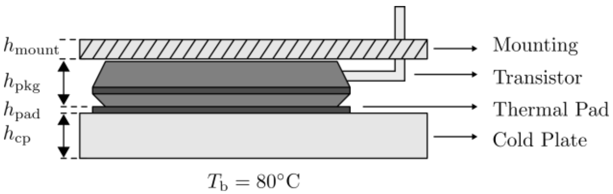
5 Level T-Type

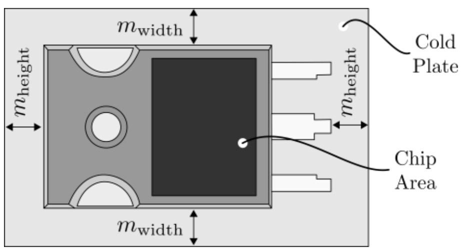


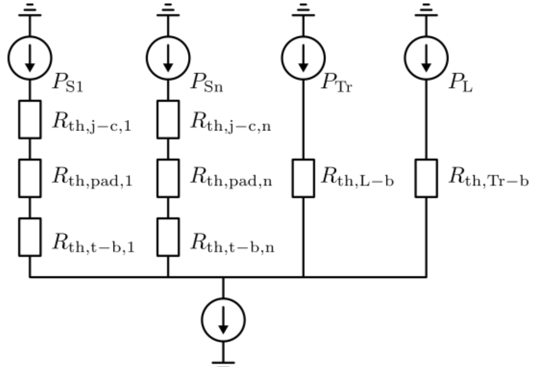
5 Level NPC

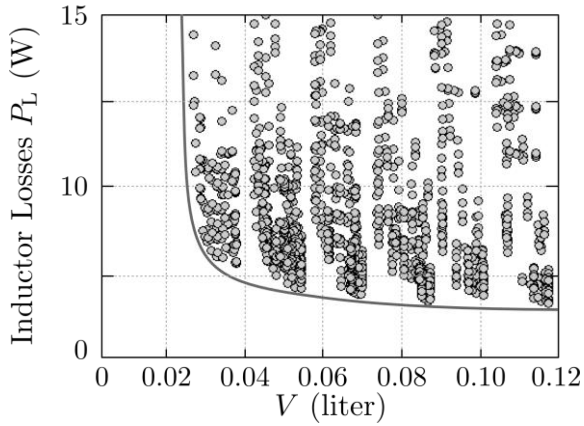


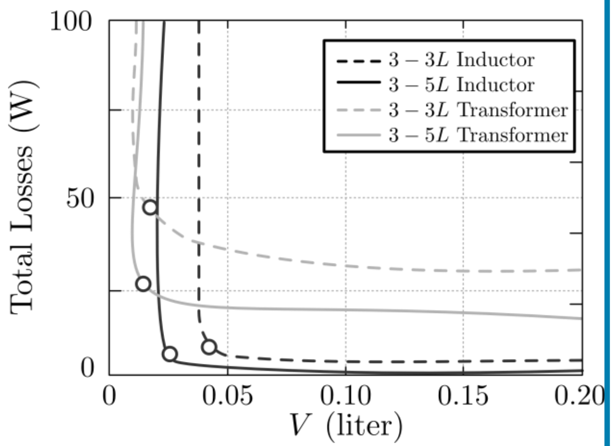
Comparative Evaluation: Loss and Volume Models







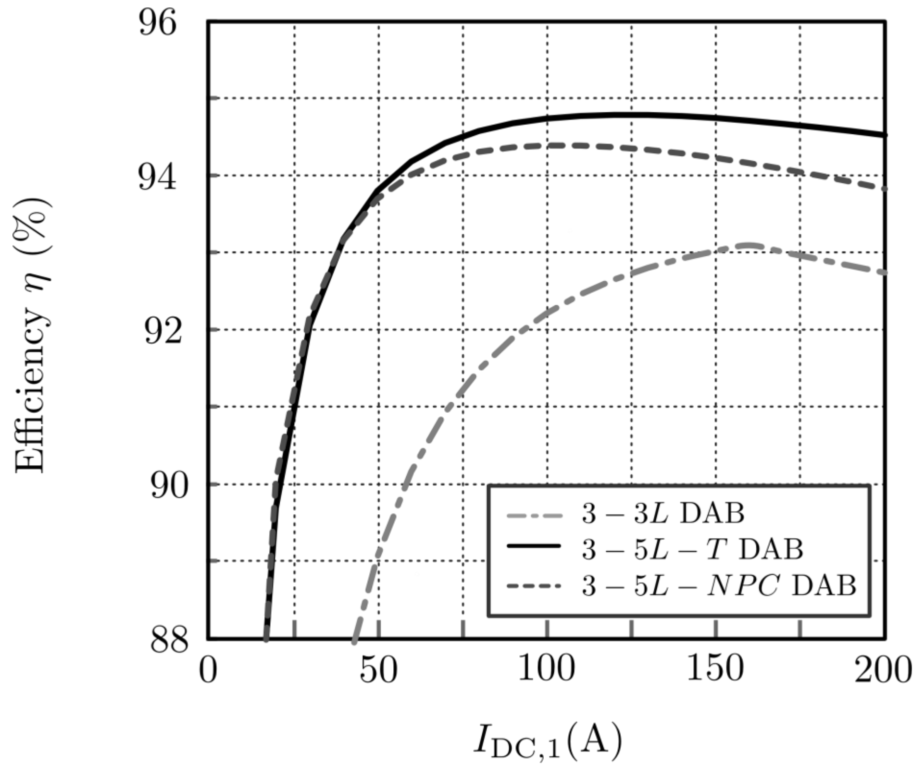




$$Q_x(t) = \int_0^t i_{C_x}(\tau)d\tau$$

$$C_x = \frac{\Delta Q_x}{V_{DC,x} \cdot f_{\text{ripple}}}$$

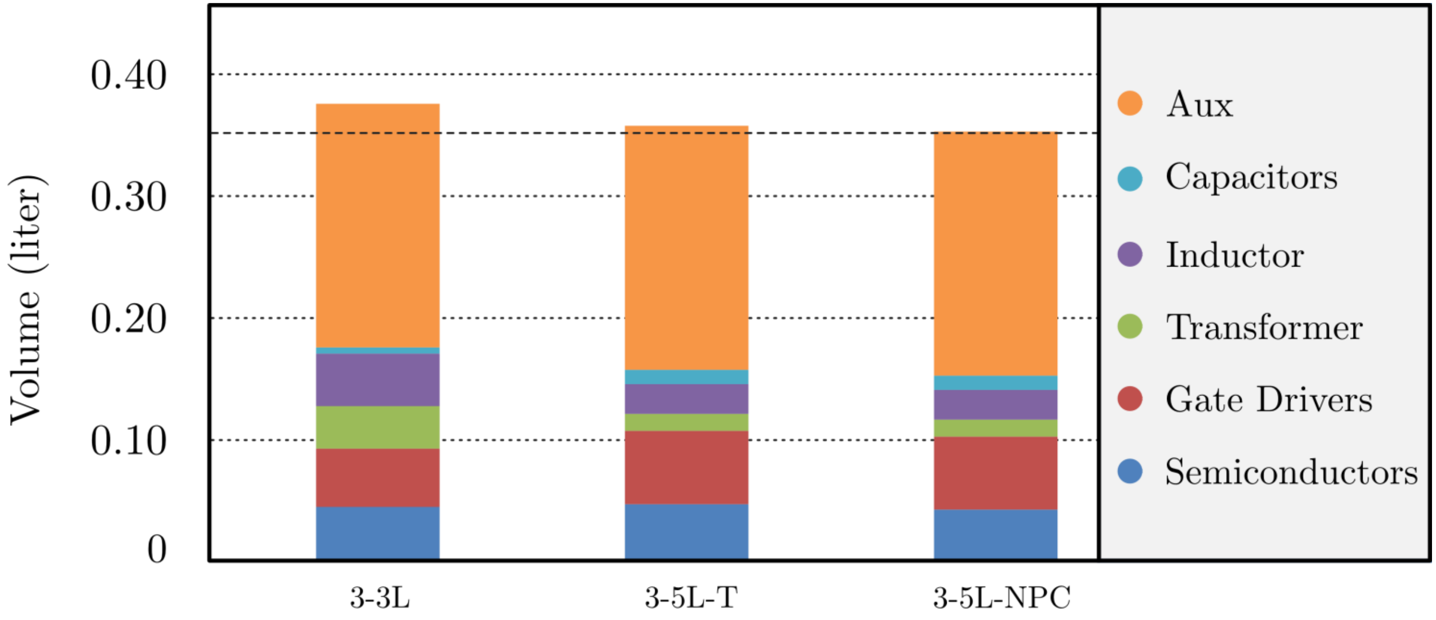
Comparative Evaluation – Efficiency



$$\eta = \frac{P_{\mathrm{DC,in}} - (P_{\mathrm{S}} + P_{\mathrm{Magnetics}})}{P_{\mathrm{DC,in}}}$$

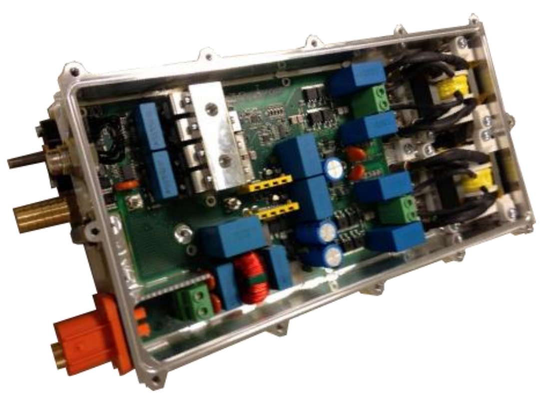
Comparative Evaluation – Power Density

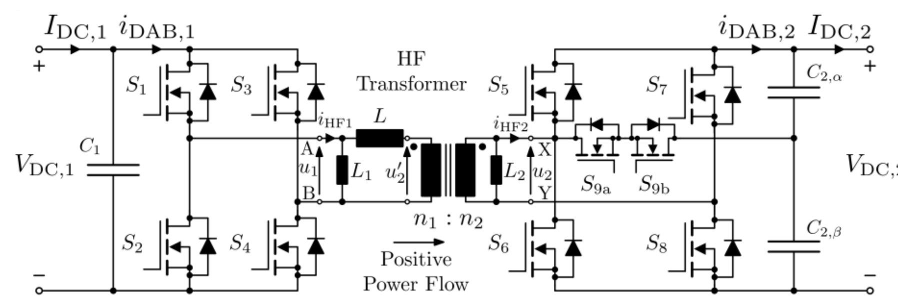
$$\rho = \frac{P_{\mathrm{DC,out}}}{(1 + f_{pack}) \cdot (V_{\mathrm{sem}} + V_{\mathrm{GD}} + V_{\mathrm{Mag}} + V_{\mathrm{C}} + V_{\mathrm{aux}})}$$



Conclusions

- Multilevel secondary bridge with additional degrees of freedom
- Analytical charge-based ZVS modulation strategy
- Comparison of a 3-5L DAB with a 3-3L DAB
- Experimental verification of the concept
- Design and realization of an optimized 3-5L DAB DC-DC converter prototype (ongoing)





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Thank you for your attention !

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