Acknowledge:
Dr. Pavel Purgat
Dr. Soumya Bandyopadhyay
Dr. Yanfeng Shen

Recent Research on DC Power Conversion

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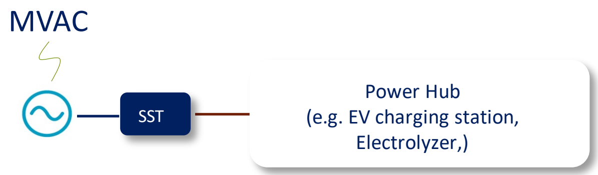
Application scenarios

- V2G charger
  - ✓ Mobile batteries
  - ✓ Ancillary service to grid

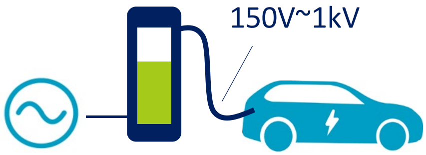
- DC house and distribution system
  - ✓ Higher efficiency
  - ✓ Easier control



- MV grid integration of power hub
  - ✓ More controllability & flexibility
  - ✓ Medium frequency transformer, lighter and smaller

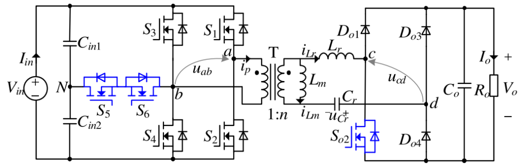
Scenario I – EV charging

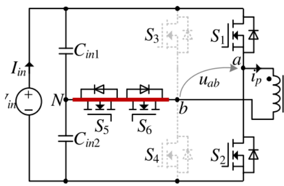
How to maintain high efficiency at a wide voltage range?



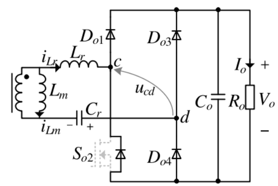
- Battery voltage of different EV models may vary a lot
- Typically, peak efficiency only at one operation point

▶ Structure Reconfigurable Resonant converter - I

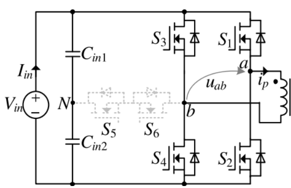




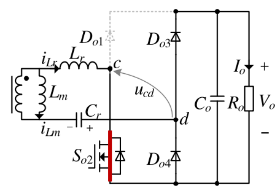
- Input voltage is high (Hi)



- Output voltage is low (Lo)



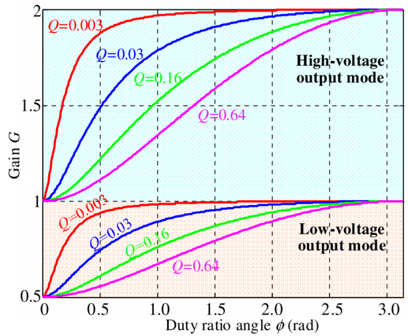
- Input voltage is low (Li)



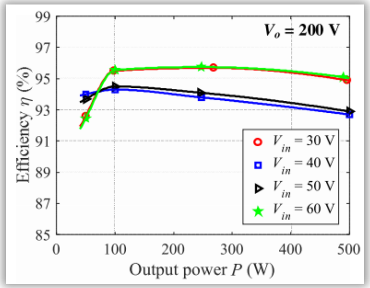
- Output voltage is high (Ho)

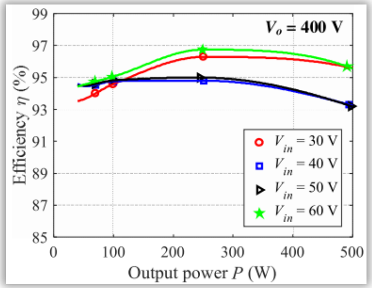
“A Structure-Reconfigurable Series Resonant DC–DC Converter With Wide-Input and Configurable-Output Voltages,” IEEE TIA, 2019

▶ Structure Reconfigurable Resonant converter - I



- LiHo
- LiLo or HiHo
- HiLo

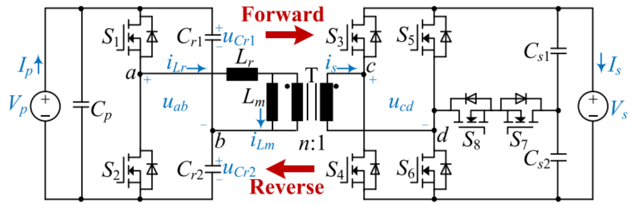


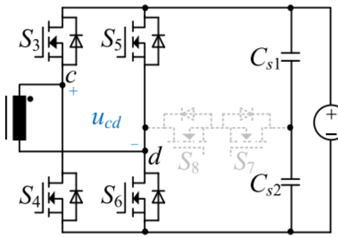


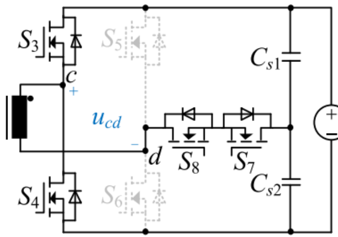
- By combining different operation modes, a broad voltage gain and high efficiency region is achieved

"A Structure-Reconfigurable Series Resonant DC–DC Converter With Wide-Input and Configurable-Output Voltages," IEEE TIA, 2019

▶ Structure Reconfigurable Resonant converter - II







- Output voltage is low (Lo)
- Output voltage is high (Ho)

"A Bidirectional Resonant DC–DC Converter Suitable for Wide Voltage Gain Range," IEEE TPEL, 2018

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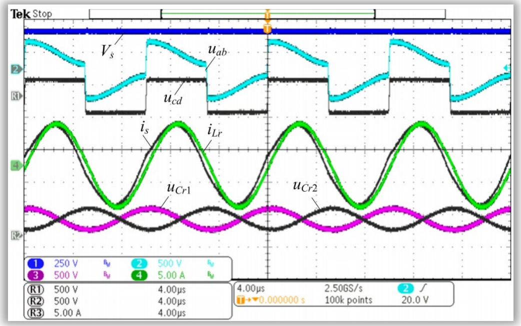
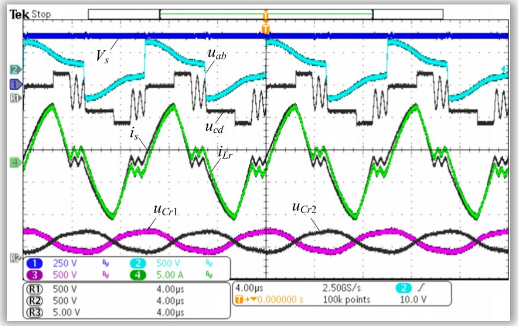
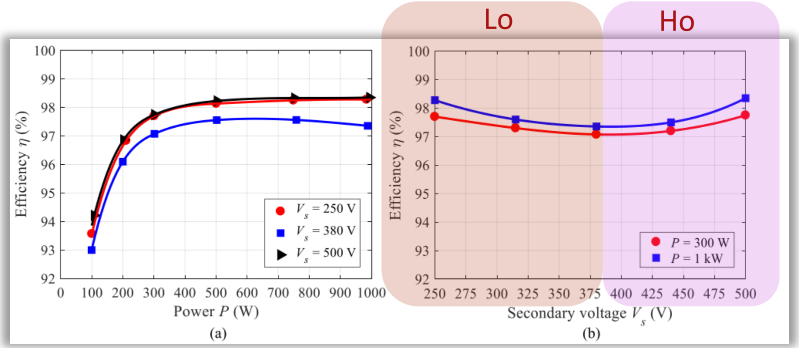
► Structure Reconfigurable Resonant converter - II

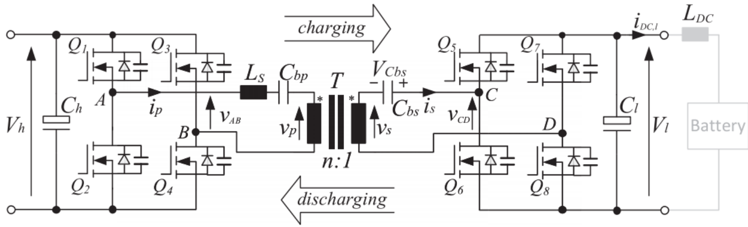


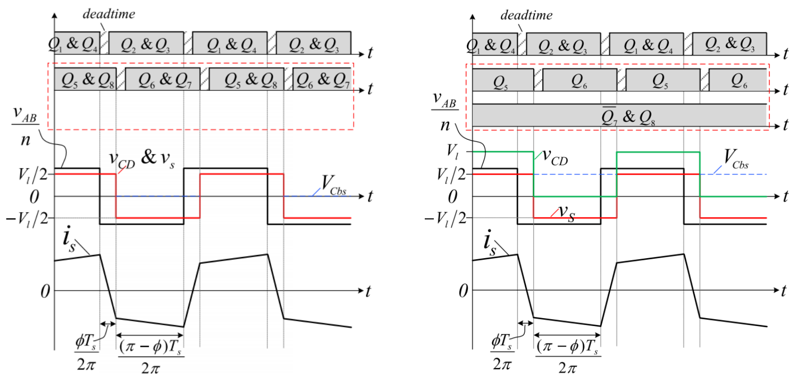




"A Bidirectional Resonant DC–DC Converter Suitable for Wide Voltage Gain Range," IEEE TPEL, 2018

▶ DAB with dc bias voltage control



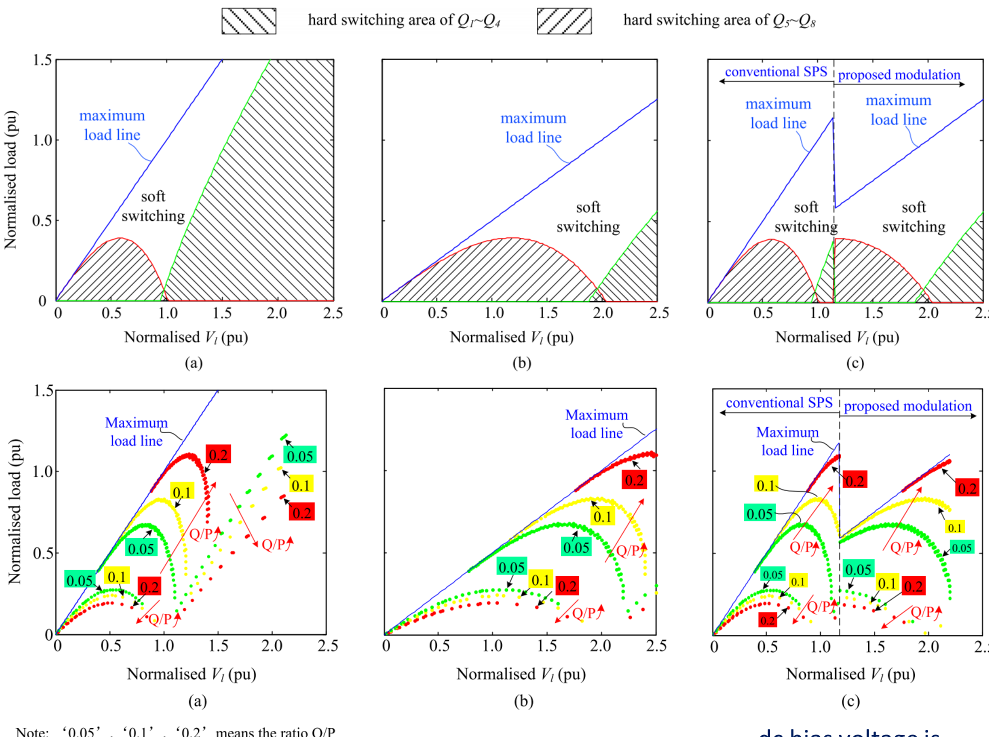


(a) (b)

- When battery voltage is low, dc bias voltage = 0
- When battery voltage is high, dc bias voltage = $V_l/2$

“A Dual Active Bridge Converter With an Extended High-Efficiency Range by DC Blocking Capacitor Voltage Control,” IEEE TPEL, 2018

▶ DAB with dc bias voltage control



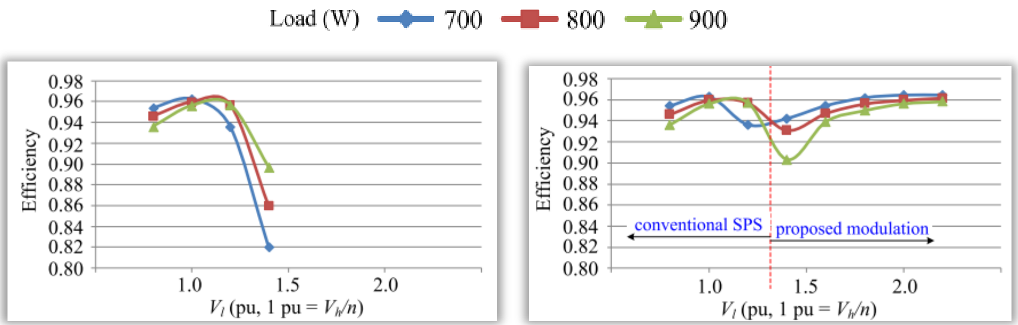
dc bias voltage = 0

dc bias voltage = $V_l/2$

dc bias voltage is controlled according to V_l

"A Dual Active Bridge Converter With an Extended High-Efficiency Range by DC Blocking Capacitor Voltage Control," IEEE TPEL, 2018

▶ DAB with dc bias voltage control



w/o dc bias voltage control

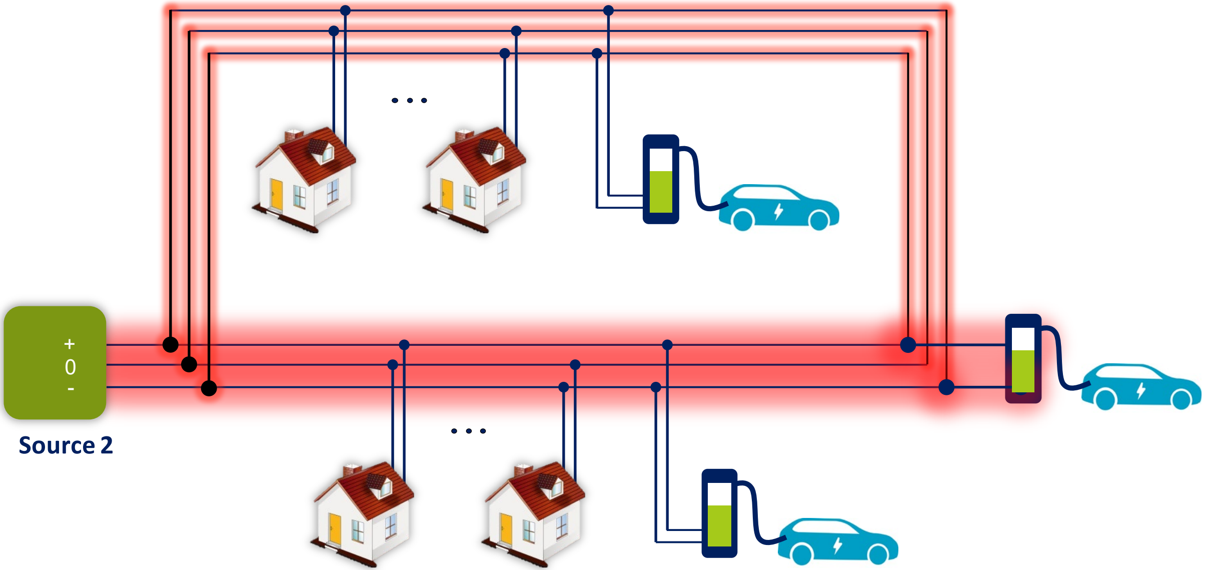
with dc bias voltage control

“A Dual Active Bridge Converter With an Extended High-Efficiency Range by DC Blocking Capacitor Voltage Control,” IEEE TPEL, 2018

Scenario II – DC house and distribution system

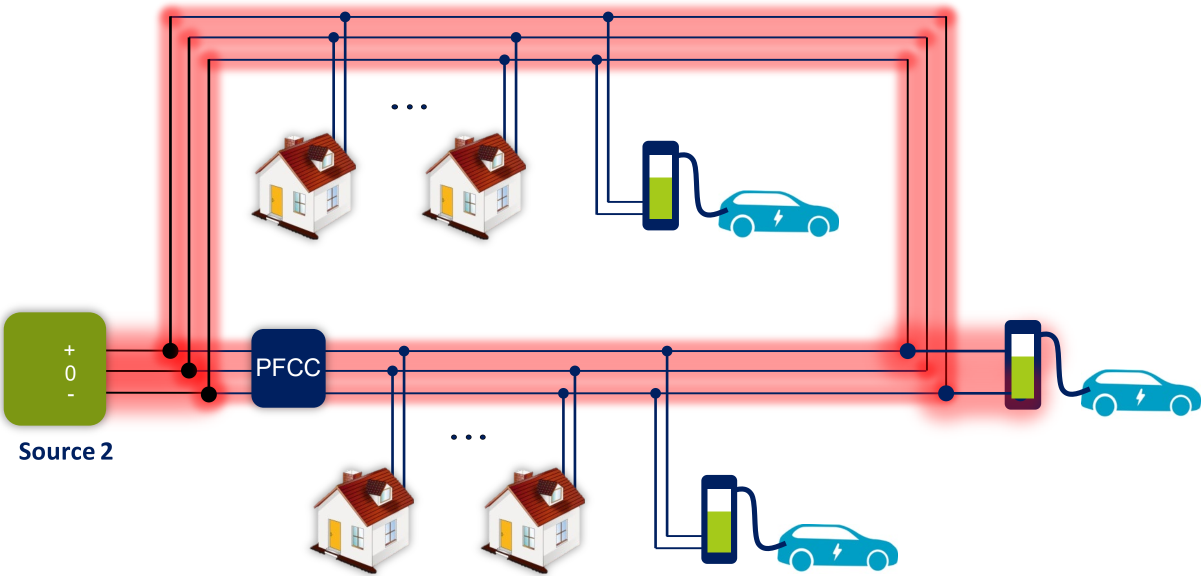
- ✓ Higher efficiency
- ✓ Easier control

▶ Partially load power flow controller



- Meshed grid to enhance the availability of the electricity during fault ☺
- Wire utilization might be low due to uneven power flow distribution ☹

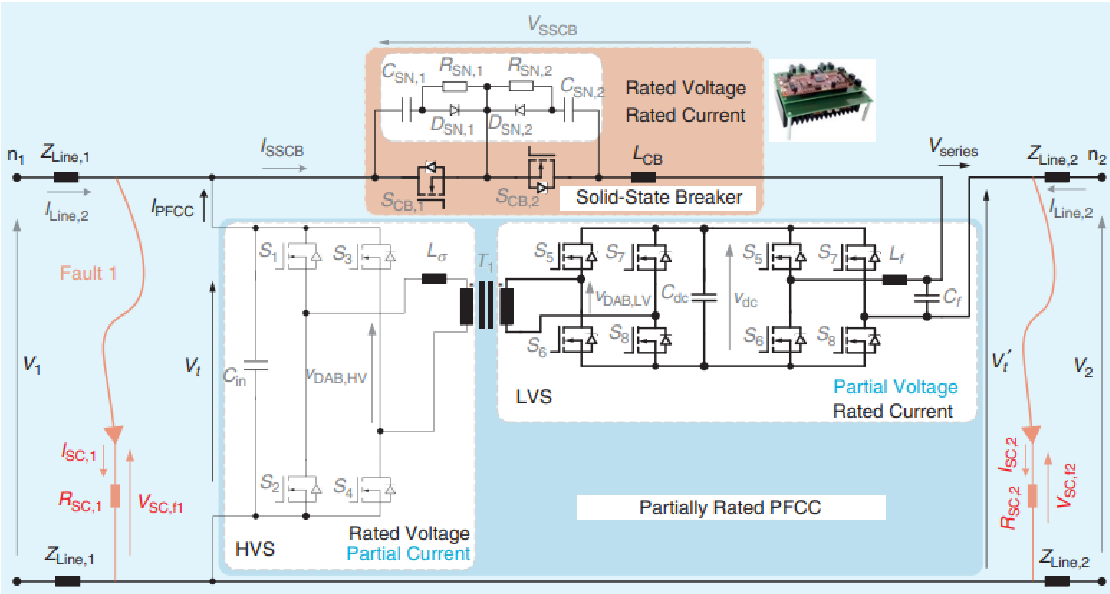
▶ Partially load power flow controller



- Meshed grid to enhance the availability of the electricity during fault ☺
- Wire utilization might be low due to uneven power flow distribution ☹
- Power flow control is needed to more evenly share the load in wires

"Zero Voltage Switching Criteria of Triple Active Bridge Converter," IEEE TPEL, 2020

Partially load power flow controller



"Low-Voltage dc System Building Blocks - Integrated Power Flow Control and Short Circuit Protection," IEEE IEM, 2021

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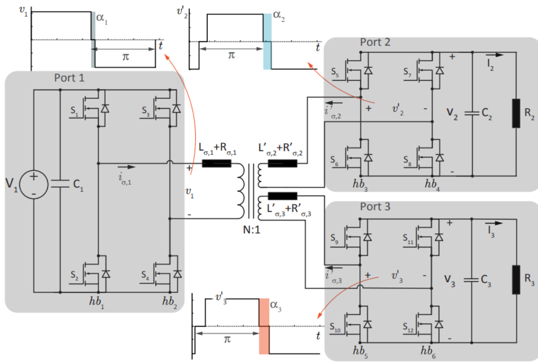
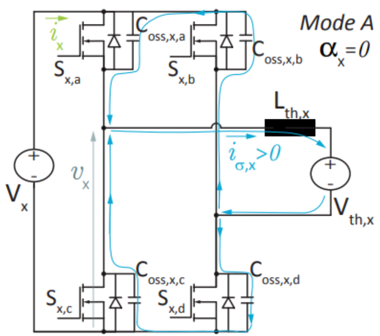
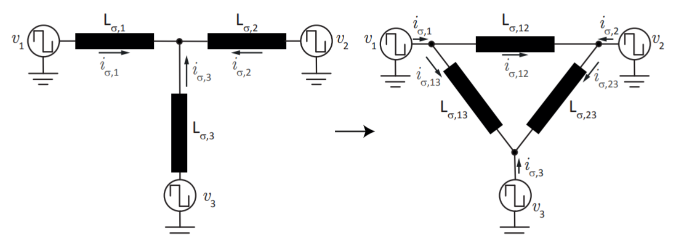
▶ ZVS criteria of triple active bridge (TAB)







ZVS condition:

$$|i_{\sigma,x}(\tau_j)| \geq 2V_x \sqrt{\frac{C_{\text{oss},x}}{L_{\text{th},x}} \frac{V_{\text{th},x}}{V_x}}$$

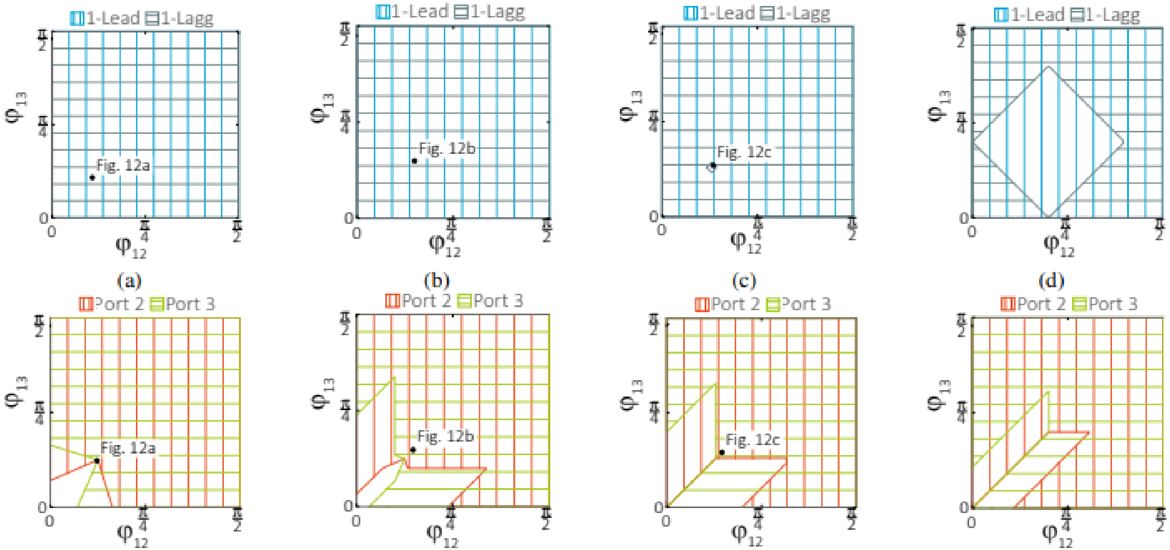
$$L_{\text{th},x} \rightarrow \frac{L_{\sigma,13} L_{\sigma,12}}{L_{\sigma,13} + L_{\sigma,12}}$$

$$V_{\text{th},x} \rightarrow V_2(\tau_1)\frac{L_{\sigma,13}}{L_{\sigma,13} + L_{\sigma,12}} + V_3(\tau_1)\frac{L_{\sigma,12}}{L_{\sigma,13} + L_{\sigma,12}}$$

"Zero Voltage Switching Criteria of Triple Active Bridge Converter," IEEE TPEL, 2021

▶ ZVS criteria of triple active bridge (TAB)

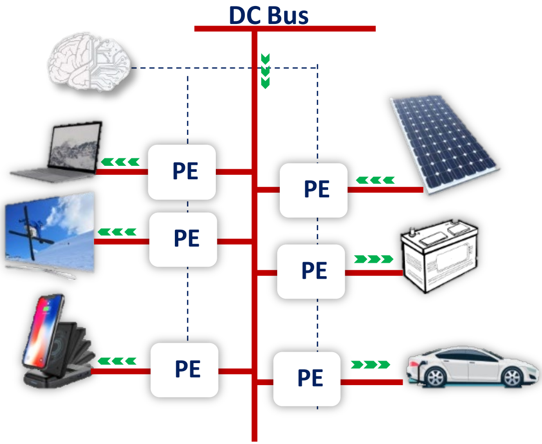
Map of ZVS

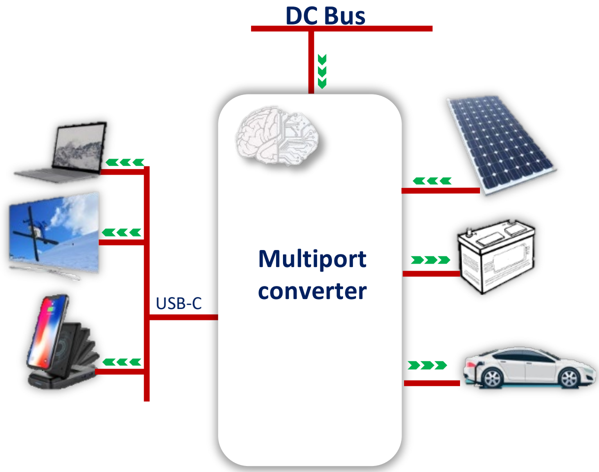


"Zero Voltage Switching Criteria of Triple Active Bridge Converter," IEEE TPEL, 2021

An MAB with inherently decoupled power flows

In a DC house or power hub





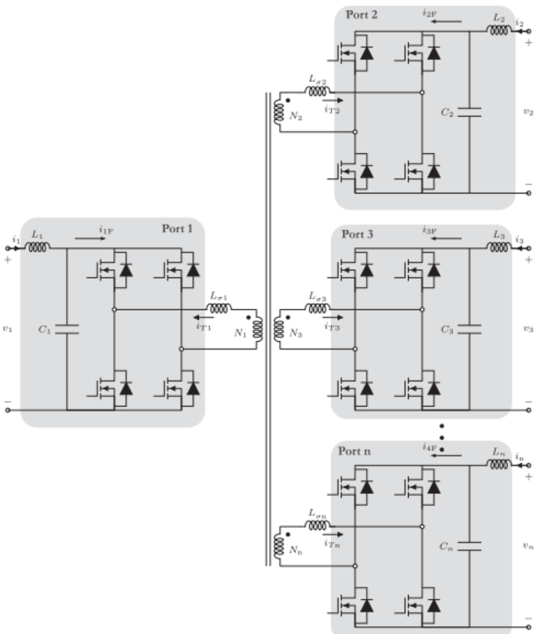
Distributed solution

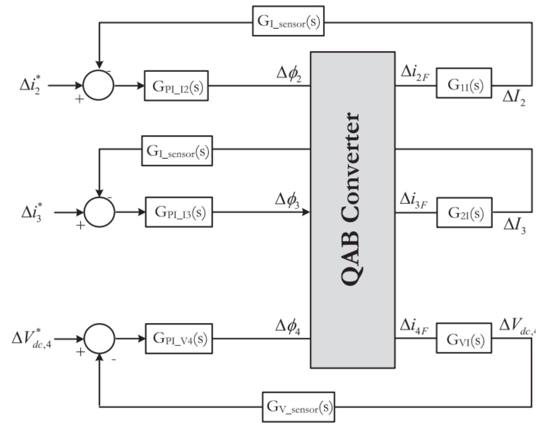
- ✓ Isolated power conversion for each unit
  - -> more power stage, higher efficiency
- ✓ Power management based on communication
  - -> more cyber vulnerability

All-in-One solution

- ✓ Single converter with multi-winding HF transformer
  - -> less power stage, higher efficiency
- ✓ Power management in one converter
  - -> less communication, more cyber secure
- ✓ How to decouple the power flow between ports?

► An MAB with inherently decoupled power flows





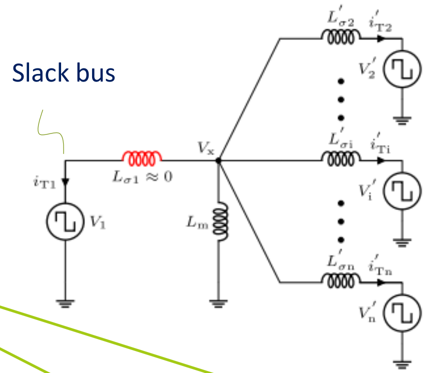
$$\begin{bmatrix} \Delta i_{2F} \\ \Delta i_{3F} \\ \Delta i_{4F} \end{bmatrix} = \begin{bmatrix} G_{22} & G_{23} & G_{23} \\ G_{32} & G_{33} & G_{34} \\ G_{42} & G_{43} & G_{44} \end{bmatrix} \begin{bmatrix} \Delta \phi_2 \\ \Delta \phi_3 \\ \Delta \phi_4 \end{bmatrix}$$

Model of QAB

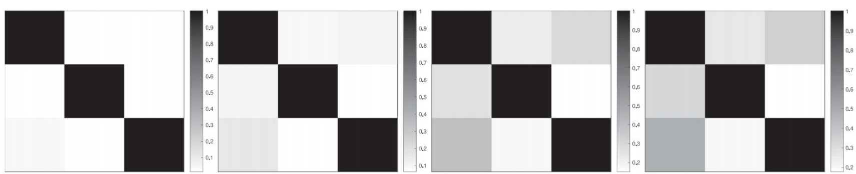
"A Multiactive Bridge Converter With Inherently Decoupled Power Flows," IEEE TPEL, 2021

▶ An MAB with inherently decoupled power flows

$$\begin{bmatrix} \Delta i_{2F} \\ \Delta i_{3F} \\ \Delta i_{4F} \end{bmatrix} = \begin{bmatrix} G_{22} & G_{23} & G_{23} \\ G_{32} & G_{33} & G_{34} \\ G_{42} & G_{43} & G_{44} \end{bmatrix} \begin{bmatrix} \Delta \phi_2 \\ \Delta \phi_3 \\ \Delta \phi_4 \end{bmatrix}$$



Lσ1 = 0.04 pu → Lσ1 = 1 pu



weak coupling

strong coupling

Patent Filed

- Power flow between the ports are decoupled by minimizing the leakage inductance of the slack bus

"A Multiactive Bridge Converter With Inherently Decoupled Power Flows," IEEE TPEL, 2021

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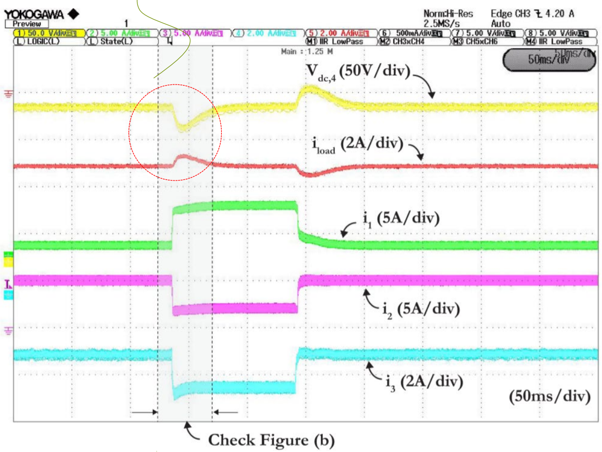
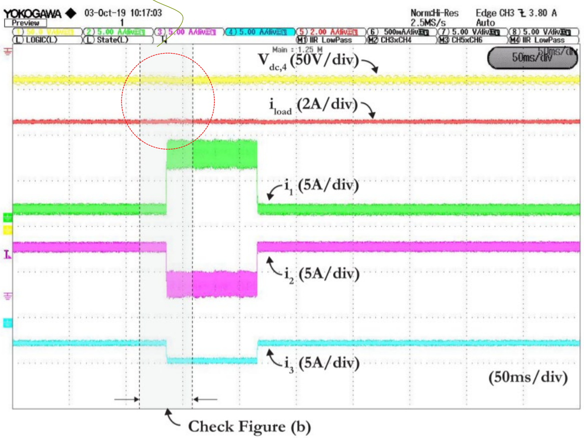
▶ An MAB with inherently decoupled power flows

Port 4 is disturbed



Lσ1 = 0.6 pu

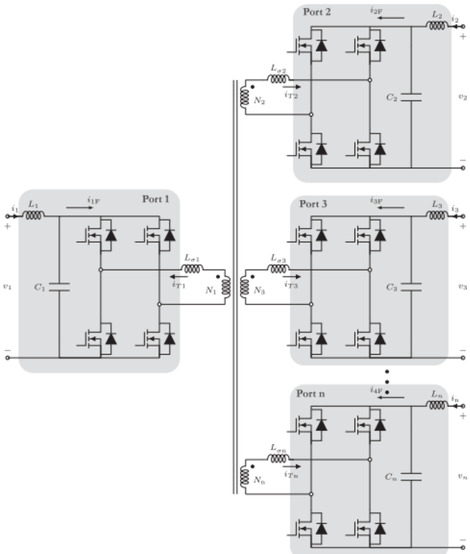
Port 4 is not disturbed

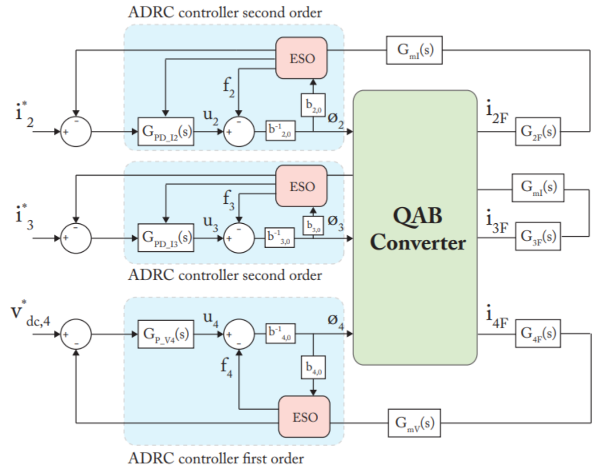


Lσ1 = 0

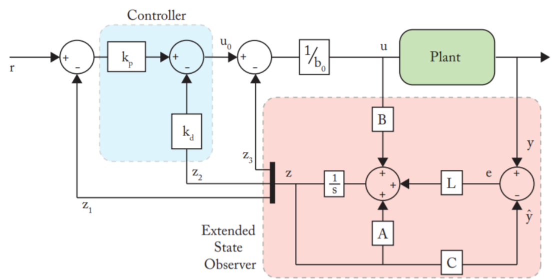
"A Multiactive Bridge Converter With Inherently Decoupled Power Flows," IEEE TPEL, 2021

▶ ADRC based power flow decoupling control (QAB)



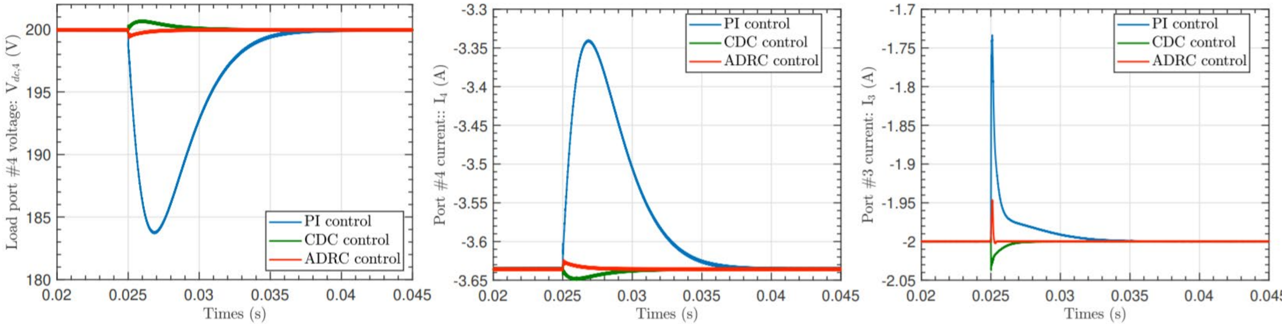


- QAB as a MIMO system with coupling can also be decoupled by applying ADRC control



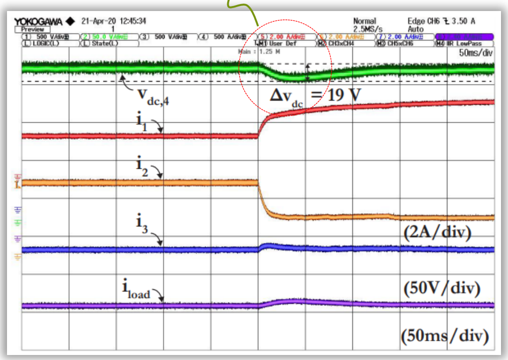
“Decoupling Control of Multi-Active Bridge Converters using Linear Active Disturbance Rejection,” IEEE TIE, 2021

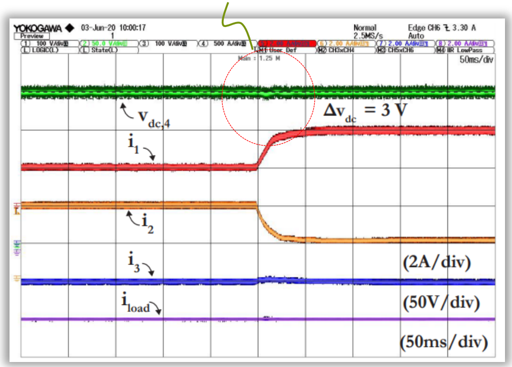
► ADRC based power flow decoupling control (QAB)



Port 4 is disturbed

Port 4 is not disturbed



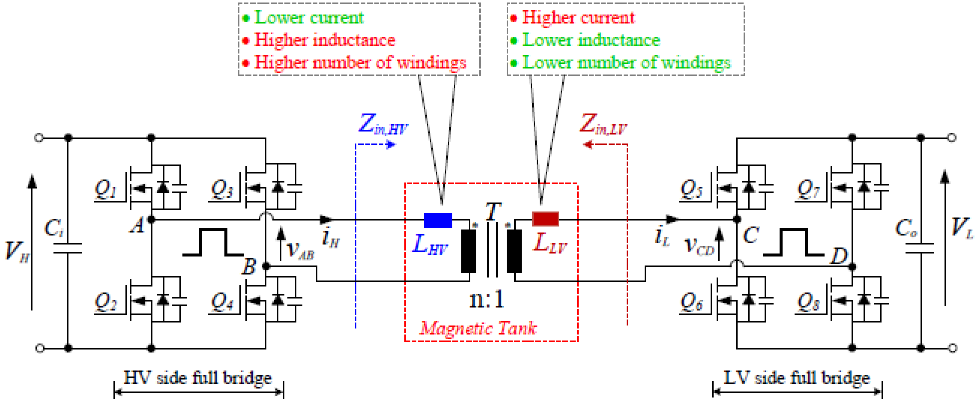


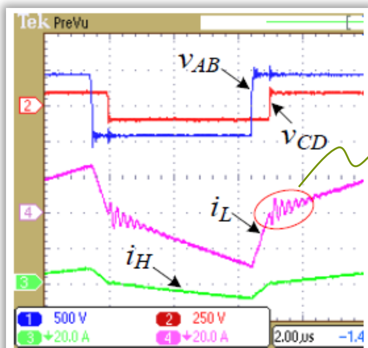
w/o ADRC

with ADRC

"Decoupling Control of Multi-Active Bridge Converters using Linear Active Disturbance Rejection," IEEE TIE, 2021

▶ Transformer current ringing in DAB





Reasons:

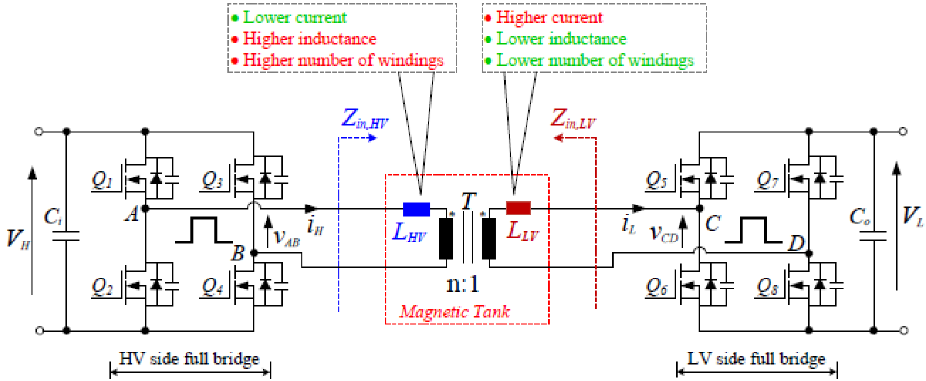
- High dv/dt during switching
- Low impedance due to parasitic cap

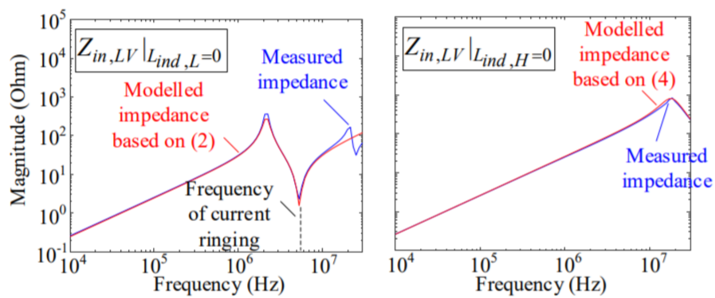
Solution:

- Reducing dv/dt would limit switching freq
- Increase the impedance?

"Transformer Current Ringing in Dual Active Bridge Converters," IEEE TIE, 2021

▶ Transformer current ringing in DAB

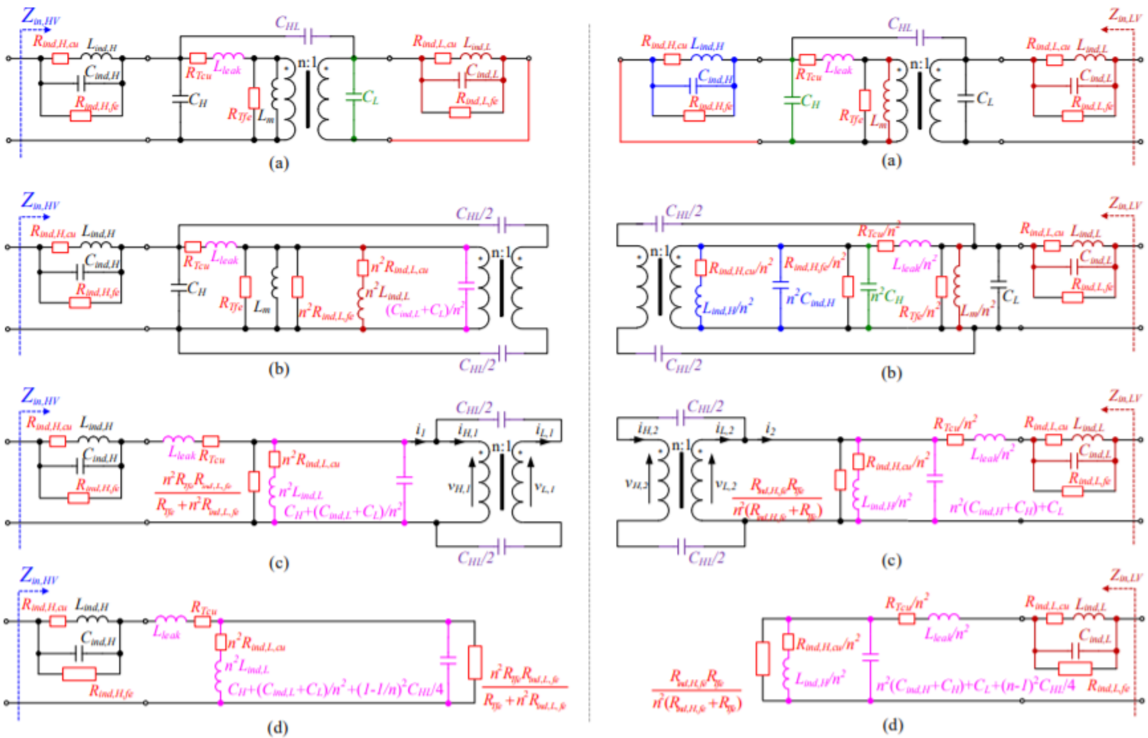




- Parasitic cap of the inductor is weighed differently whether being connecting on high or low voltage side

“Transformer Current Ringing in Dual Active Bridge Converters,” IEEE TIE, 2021

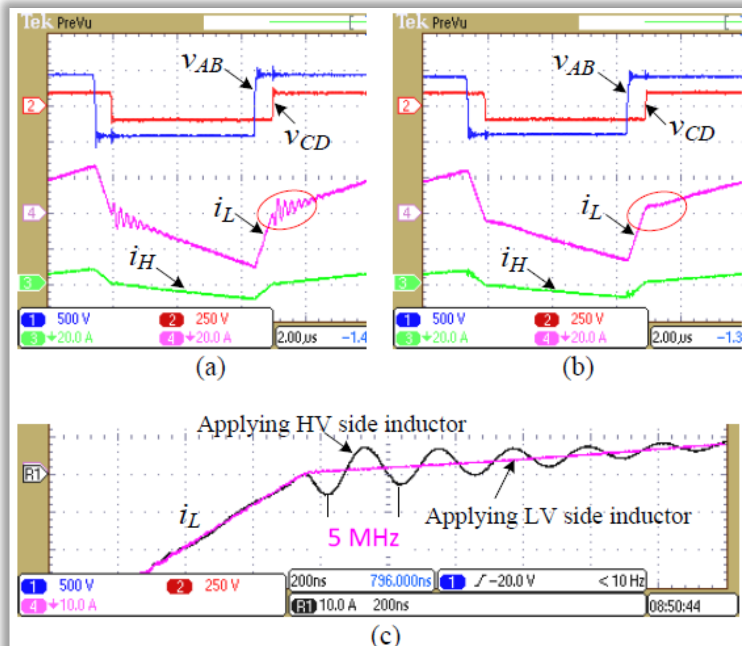
▶ Transformer current ringing in DAB



Impedance model of the magnetic tank

“Transformer Current Ringing in Dual Active Bridge Converters,” IEEE TIE, 2021

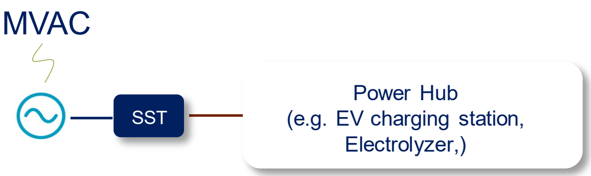
▶ Transformer current ringing in DAB



- Transformer current ringing is significantly reduced by connecting the inductor on LV side assuming the inductor always has single layer winding no matter on HV or LV side

"Transformer Current Ringing in Dual Active Bridge Converters," IEEE TIE, 2021

Scenario III – MV grid integration of power hub



- ✓ More controllability & flexibility
- ✓ Medium frequency transformer, lighter and smaller

The FlexH2 project is starting soon…

谢谢!
欢迎批评指正!

秦子安
z.qin-2@tudelft.nl