Advanced Control Solutions for Enhanced Power Density of Isolated Multiport Converters in DC Railway

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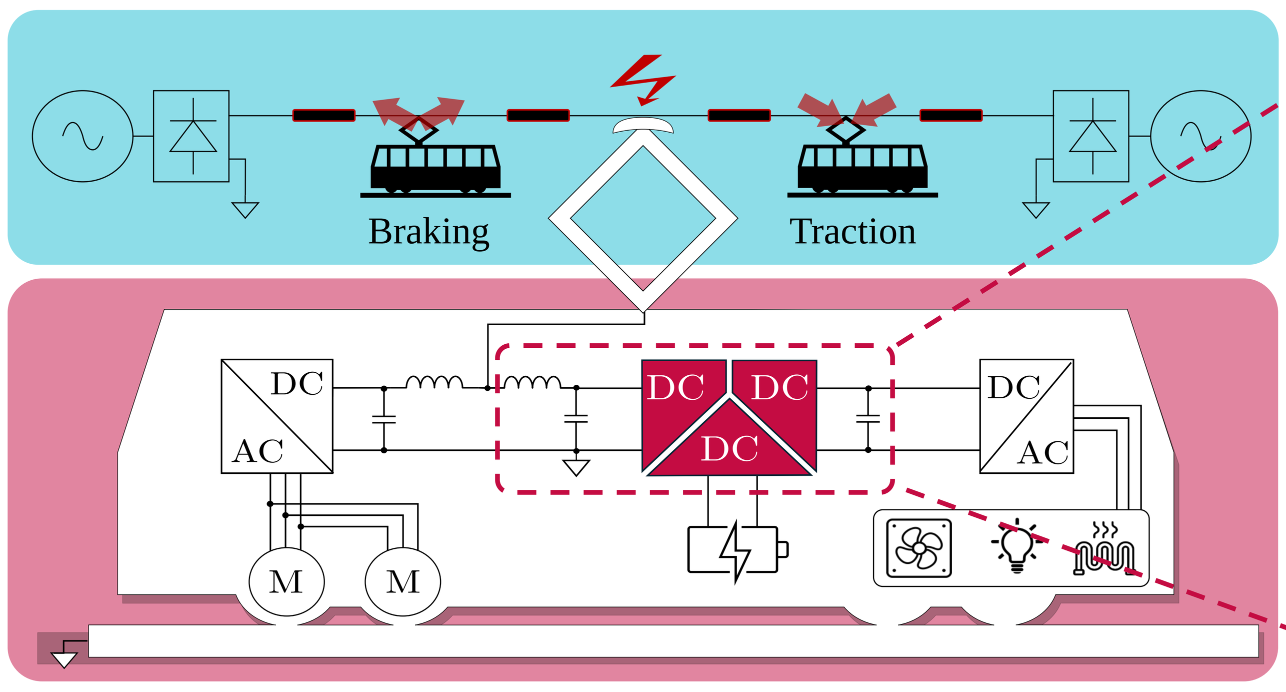
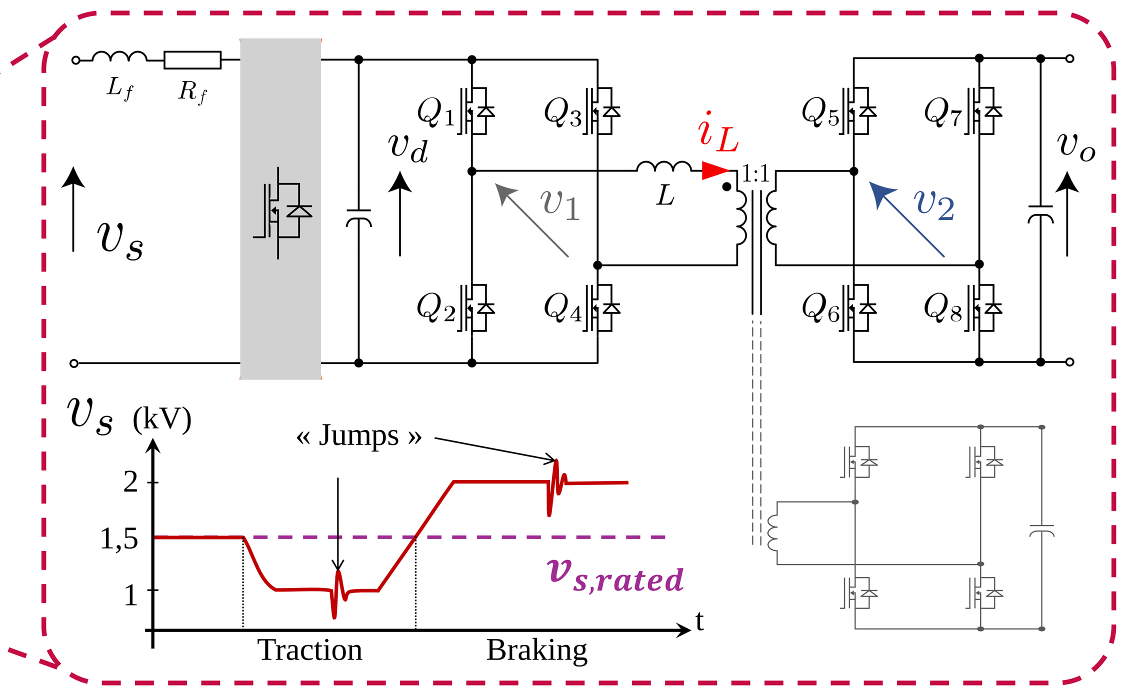
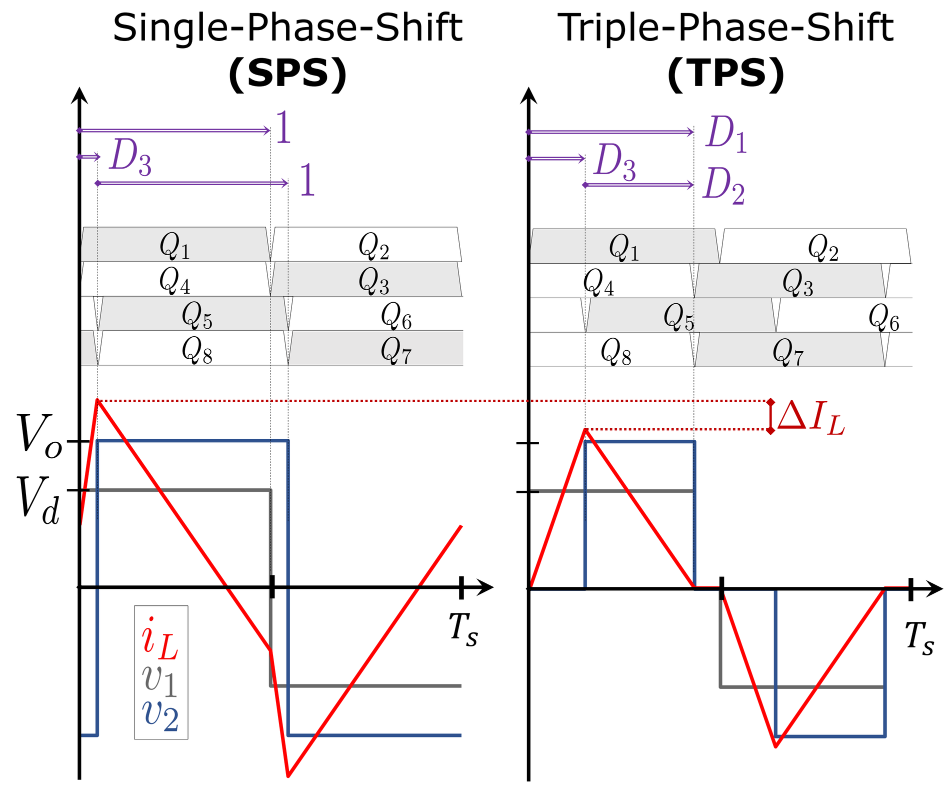
Auxiliary Railway Supply converts the electric power of the catenary into consumer-orientated power for equipment's such as air conditioning, lighting, battery charging, etc. **High power density**, bidirectional power flow and galvanic isolation are required. A Triple-Active-Bridge (TAB) converter with a simple Single-Phase-Shift (SPS) modulation is best suited if the ports DC voltages match the transformer turn ratio. However, due to the varying position on the line and the powering state of the vehicles, supply conditions vary greatly. A **front-end converter** is therefore used to regulate and stabilize the supply voltage.



Typical configuration of a DC railway power conversion chain.



Isolated multiport converter; Triple-Active-Bridge (TAB)



DAB modulation strategy.

Objective :
Gain **weight** and **simplicity** by removing the front-end converter.

Challenge :
Input side of the TAB faces :
- Voltage spikes and permanent deviations from V_{rated} (±33%).
- Unknown line impedance.

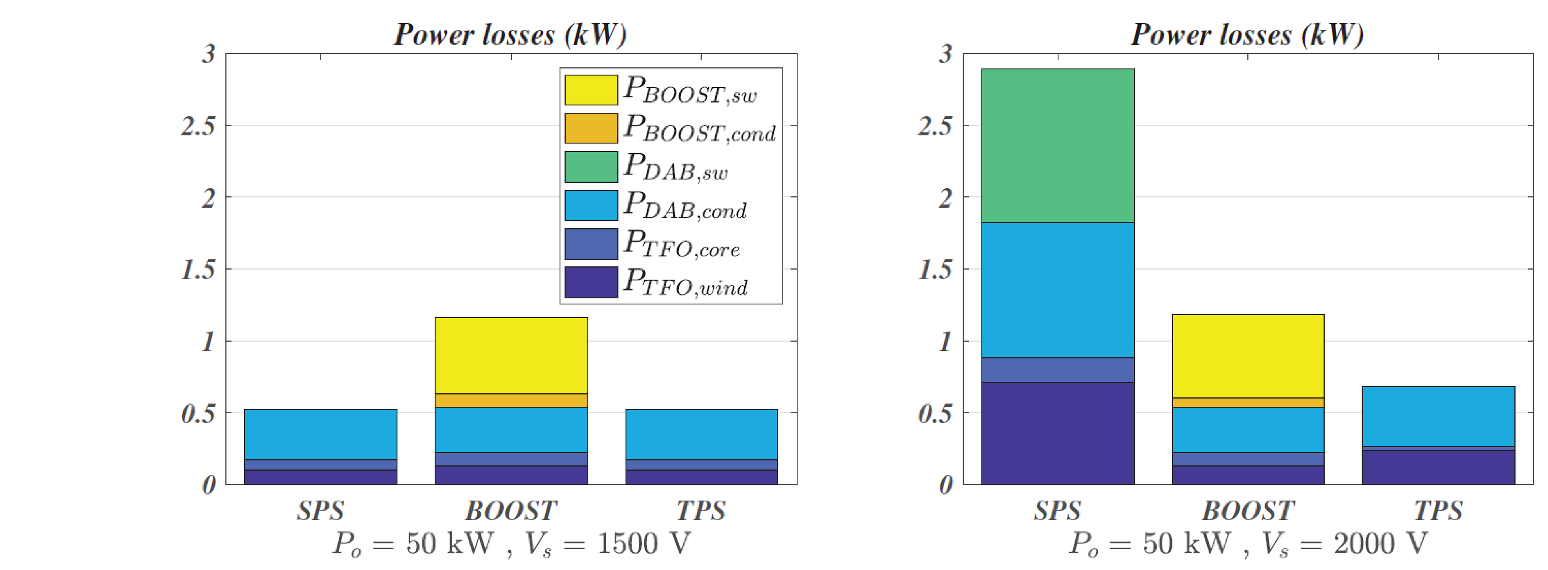
Solution :
- New converter design.
- Extended Modulation strategy (TPS).
- Simple and efficient Active Damping.

Steady-state

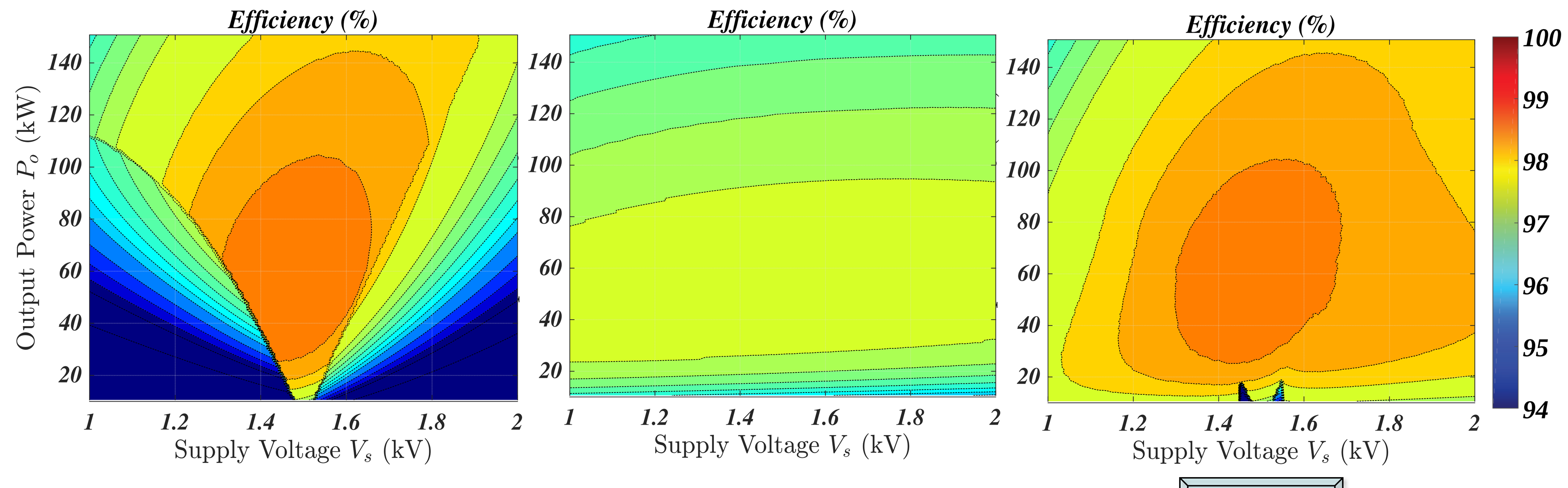
New converter design

	With boost converter	Without boost converter
Output Power Range P_o	10 ~ 150 kW	10 ~ 150 kW
Supply dc voltage V_s	1 ~ 2 kV	1 ~ 2 kV
DAB Input dc voltage V_d	2 kV	1 ~ 2 kV
DAB Output dc voltage V_o	750 V	750 V
Switching frequency	5 kHz	5 kHz
Transformer Turns Ratio n	3/8	1/2
Primary side max rms Current	91 A	167 A
Mass of the transformer	**70 kg**	**111 kg**
Output Capacitor max rms Current	**88 A**	**167 A**

Power loss model



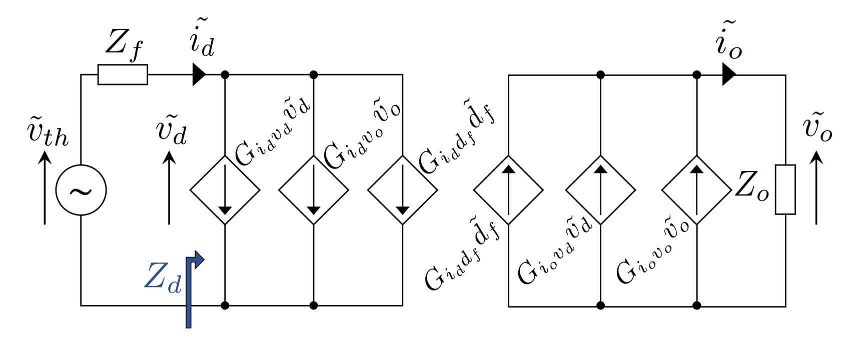
Power loss distribution.



Simulated efficiency heatmap for every operating point.

Transient

Small-signal modelling



Equivalent Small-Signal model.

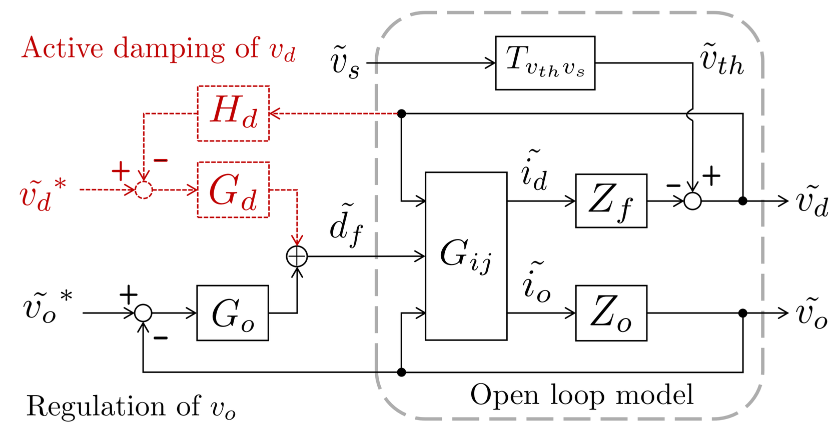
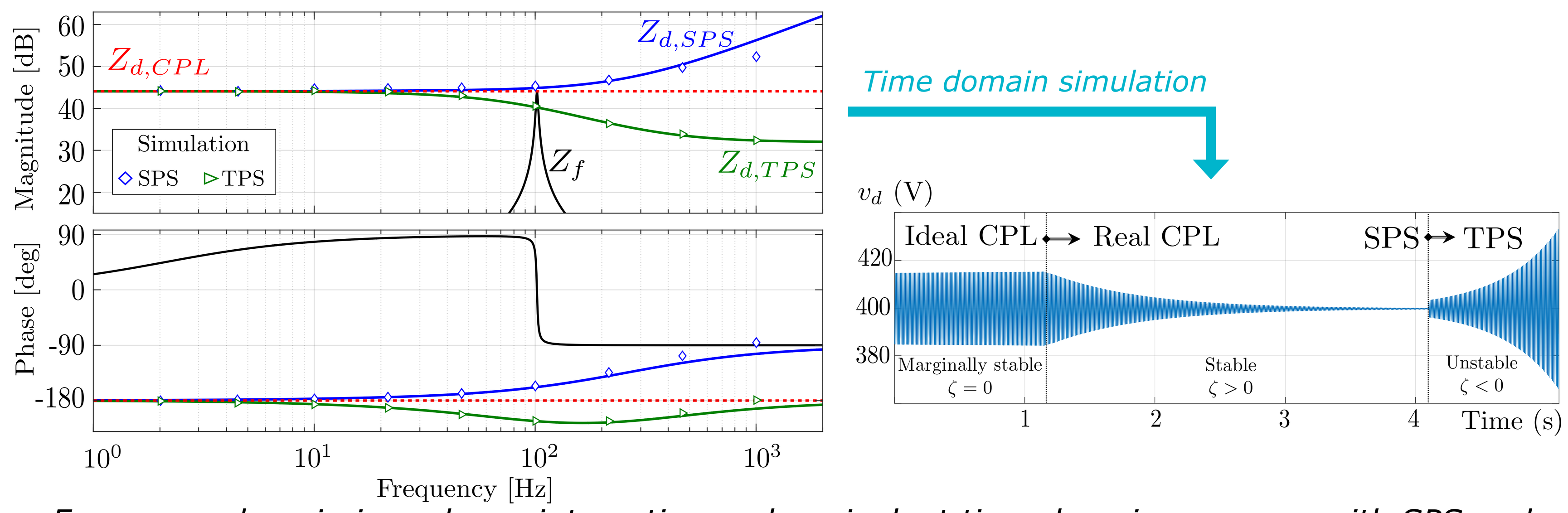


Diagram of the dual closed-loop control

Stability analysis

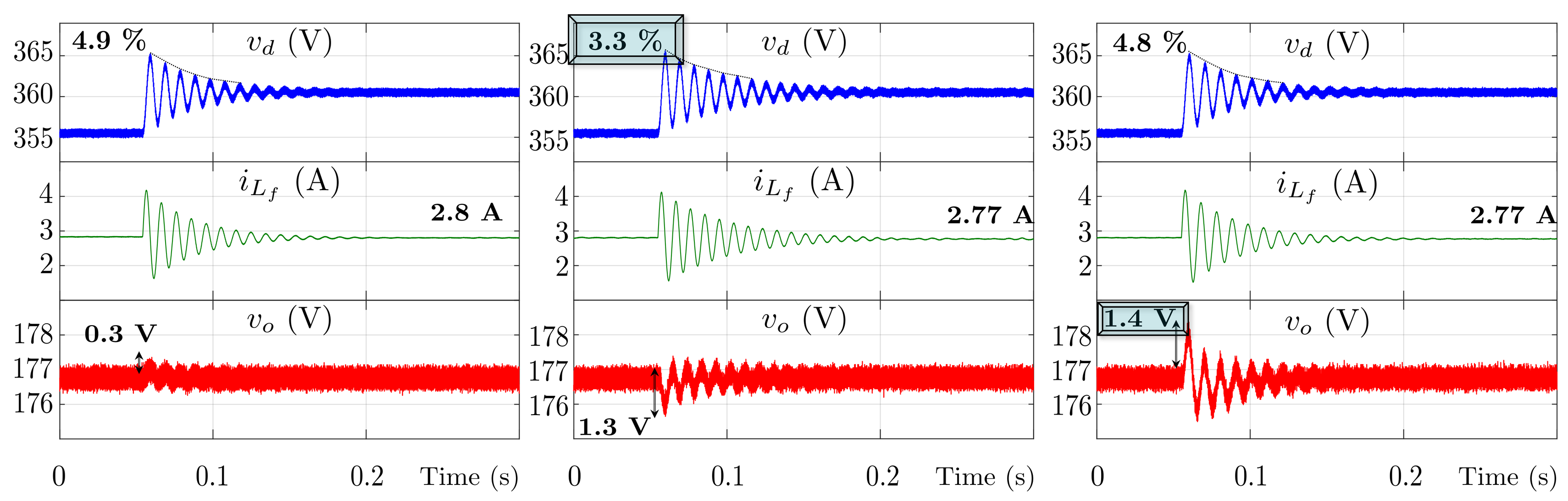
The TAB converter acts as a Constant Power Load (CPL) and destabilizes the input voltage of the LC filter. Instability occurs if $Z_f = -Z_d$.



Frequency domain impedance interaction and equivalent time domain response with SPS and TPS modulation.

Active damping

A feedback loop on v_d shapes the input impedance and increases the damping.



Experimental results : Supply voltage step response at 1 kW load when $v_s = 355 \rightarrow 360$ V

Conclusion

An accurate dynamical modelling of the converter is crucial as extended modulation strategies affect the stability. Controller design and informed modulator selection is thus allowed. A simple control structure can achieve active damping of the input voltage at the expense of the output voltage regulation. Finally, the power density of the multiport IBDC can be enhanced via TPS modulation as it limits losses over the entire operating range. Nevertheless, remaining passive components become bulkier.