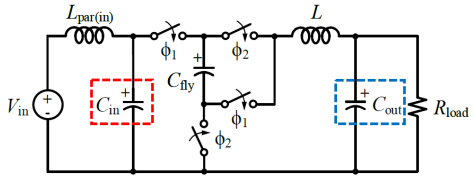
Modeling and Control of Pure and Resonant Switched-Capacitor Converters with Finite Terminal Capacitances

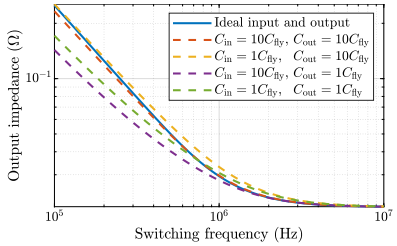
Berkeley Power and Energy Center

Background and Motivation

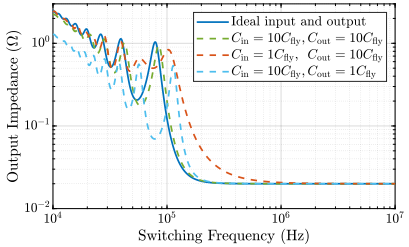
- Insufficient terminal capacitances can greatly affect converter efficiency
- Bulky terminal capacitors become the bottleneck of converter miniaturization



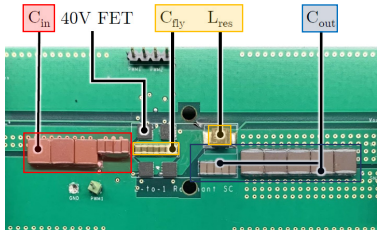
(a) Schematic



Output impedance of a 2-to-1 pure SC converter with different C_{in} and C_{out}



Output impedance of a 2-to-1 resonant SC converter with different C_{in} and C_{out}



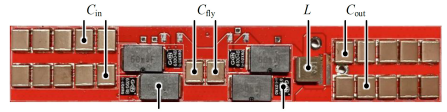
(b) Hardware prototype
2-to-1 resonant SC (ReSC) converter

Simulation and Experimental Verification

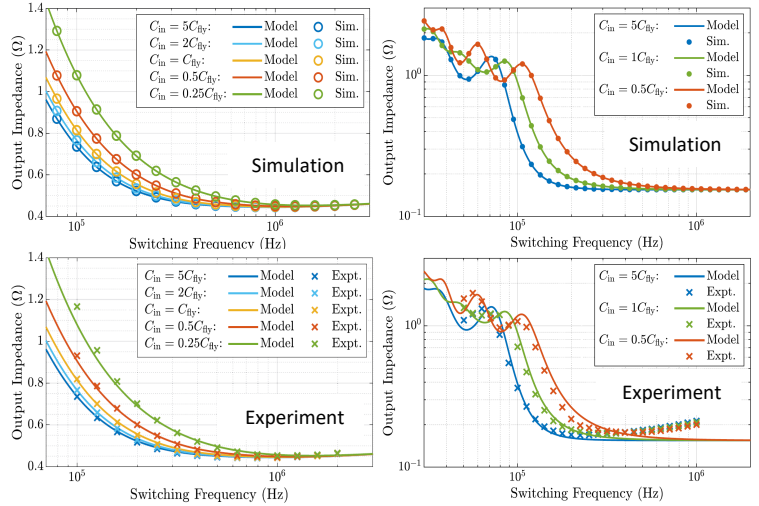
Key considerations

- Minimize switching loss
- Accurate parameter acquisition

High accuracy

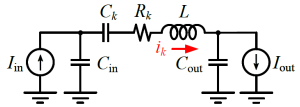


Hardware prototype

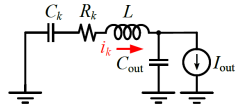


Modeling Derivation and Effect Analysis

Simplified circuit model and general output impedance model

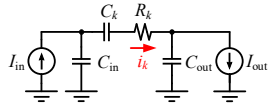


(a) Phase 1

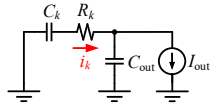


(b) Phase 2

Circuit model of a ReSC converter with C_{in} and C_{out}



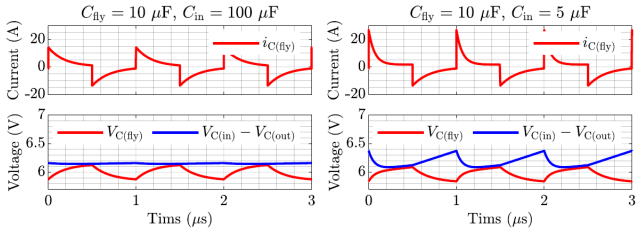
(a) Phase 1



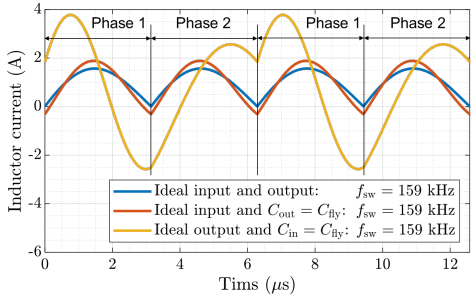
(b) Phase 2

Circuit model of a pure SC converter with C_{in} and C_{out}

Effect of terminal capacitances



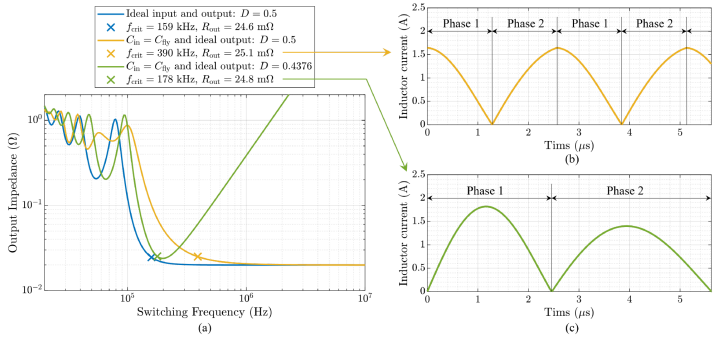
Inductor current waveform of a 2-to-1 pure SC converter with different terminal capacitances



Inductor current waveform of a 2-to-1 ReSC converter with different terminal capacitances

Multi-Resonant Compensation Control (MRCC)

- Challenge: zero current switching (ZCS) is not achievable with 0.5 duty ratio with small C_{in}
- Solution: ensure ZCS operation with the optimal duty ratio and switching frequency
- Result: 5x terminal capacitance reduction without harming efficiency



(a) Comparison of output impedance. (b) Inductor current waveform of the conventional control. (c) Inductor current waveform of MRCC.

References:

[1] Y. Zhu *et al.*, "Modeling and Analysis of Resonant Switched-Capacitor Converters with Finite Terminal Capacitances," COMPEL 2021.

[2] Y. Zhu *et al.*, "Multi-Resonant Compensation Control for Terminal Capacitance Reduction in Resonant Switched-Capacitor Converters," COMPEL 2021.

[3] Y. Zhu *et al.*, "Modeling and Analysis of Switched-Capacitor Converters with Finite Terminal Capacitances," APEC 2021.

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