A General Approach for Design Optimization of High-Performance Hybrid Switched-Capacitor Converters

Berkeley Power and Energy Center

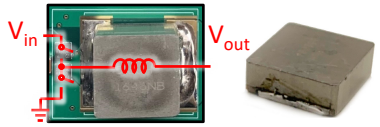
Motivation and Application

Hybrid switched-capacitor converters

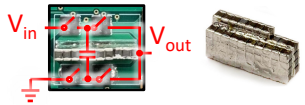
- More capacitive energy storage than inductive energy storage for size reduction
- Multiple low-voltage switches in place of a single high-voltage switch for efficiency improvement

Topology Comparison

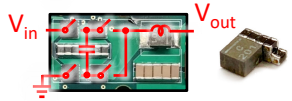
- Analytical method to compare relative size and performance of various topologies
- Include the impacts of capacitor voltage ripple and inductor current ripple on passive component volume and switch stress



Buck: 2059 mm³
97% peak eff.

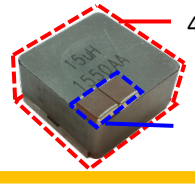


Pure SC: 272 mm³
99% peak eff.



Hybrid SC: 76 mm³
99% peak eff.

Performance comparison at 48V-to-24 V

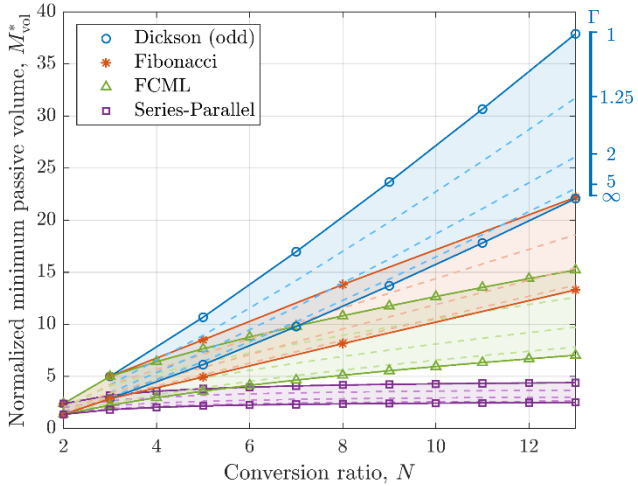


4 mJ of inductive energy storage

80 mJ of capacitive energy storage (after dc-derating)

Impacts of Switching Frequency and Conversion Ratio on Minimal Passive Volume [1]

- Series-Parallel has smaller passive volume → Higher power density
- Increasing $\Gamma = \frac{f_{sw}}{f_{res}}$ → smaller passive volume → Higher power density



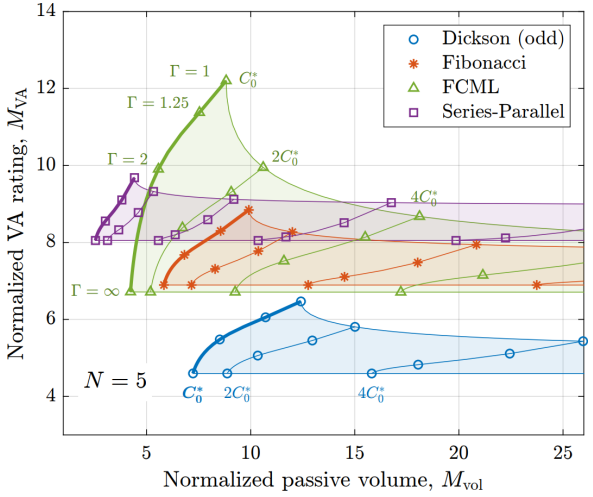
Passive Component Volume and Switch Stress Trade-Off

Increasing the switching frequency beyond resonance

- Trading ↑ switching loss for ↓ conduction loss

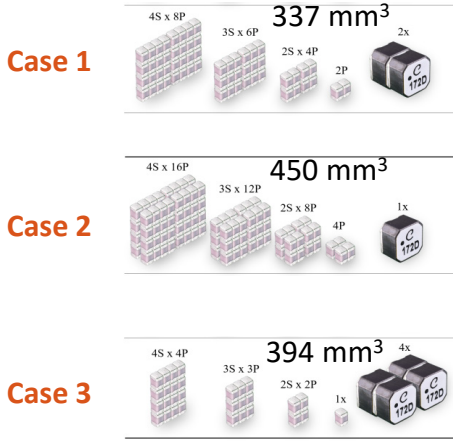
Increasing capacitance beyond minimal volume

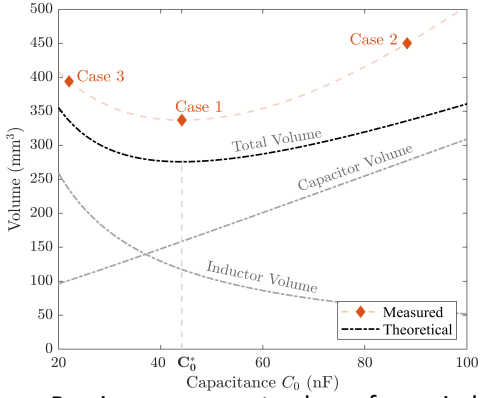
- Trading ↑ volume for ↓ VA rating (efficiency)



Validation of Analytical Model

$\rho_C = 8800\ \mathrm{J/m^3}$ $\rho_L = 123\ \mathrm{J/m^3}$





Passive component volume for varied capacitance to validate minimal volume method

References:
[1] N. M. Ellis, et. al., "A General Analysis of Resonant Switched Capacitor Converters Using Peak Energy Storage and Switch Stress Including Ripple," in *IEEE Transactions on Power Electronics, Early Access.*
[2] J. Azurza Anderson, G. Zulauf, J. W. Kolar and G. Deboy, "New Figure-of-Merit Combining Semiconductor and Multi-Level Converter Properties," OJPEL 2020.

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