Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

10 kW/dm³ DC/DC Converter for Green Data Centers

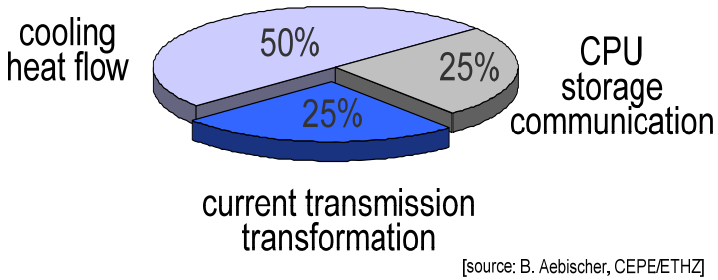
U. Badstuebner and J. Biela

Power Electronic Systems Laboratory
ETH Zurich, Switzerland

www.pes.ee.ethz.ch

En route to a Green Data Center

- Information Technology (IT) consumes 10% of the total power consumption (Switzerland)



[source: B. Aebischer, CEPE/ETHZ]

- 3-year-costs of powering and cooling is 1½ times the costs of purchasing

[source: www.uptimeinstitute.org]

Green Data Center

1. reducing cooling requirements
2. increasing facilities system efficiency
3. reducing power consumption with innovative technologies

"In so far as energy efficiency is concerned, we need an enormous increase, and we have to slow down our excess consumption."

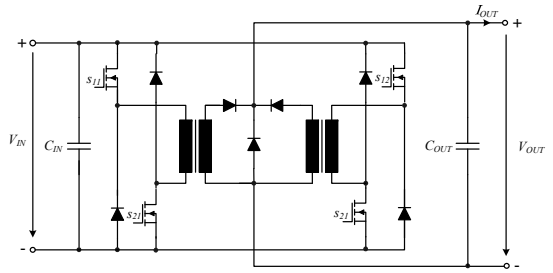
W. Steinmann, chief, Federal Agency of Energy

Demands on the power supply

1) together with a 10 kW/dm³ rectifier: 5.0 kW/dm³
state of the art (AC/DC @10kW): 1.2 kW/dm³

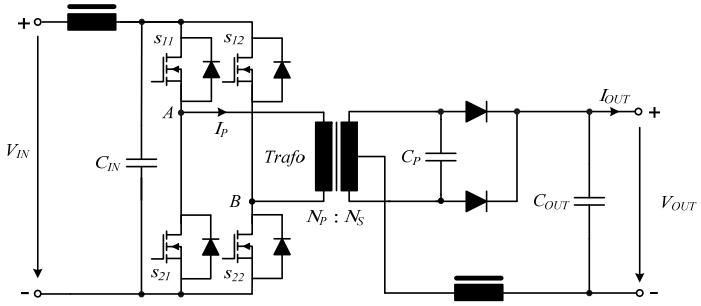
Goal: An ultra compact, high efficiency DC/DC converter for a **green** data center.

Topologies for 400V/48V DC/DC Converter

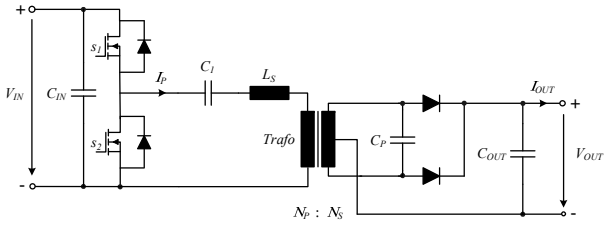


double interleaved, double ended forward converter

- galvanic isolation recommended
- for high power / high efficiency applications full-bridge topologies are needed
- high compactness requires high switching frequency
- soft-switching type topology helpful



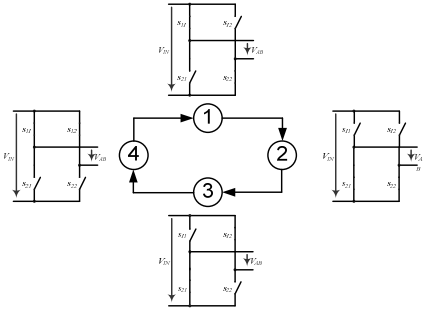
hard switched full bridge topology

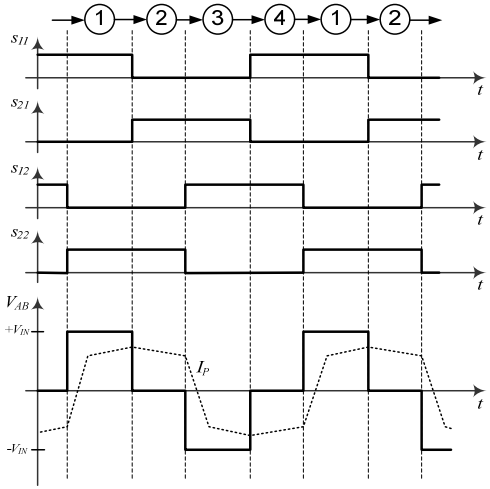


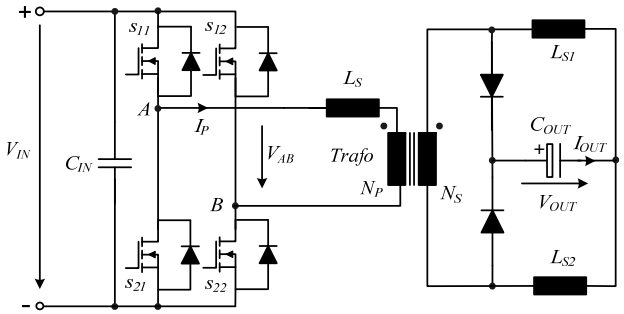
zero voltage switched asymmetrical half-bridge pulse width-modulation converter

Full-Bridge Converters with soft-switching techniques are recommend for high efficiency, ultra-compact, high density power supply.

Full-Bridge Phase-Shift PWM Converter



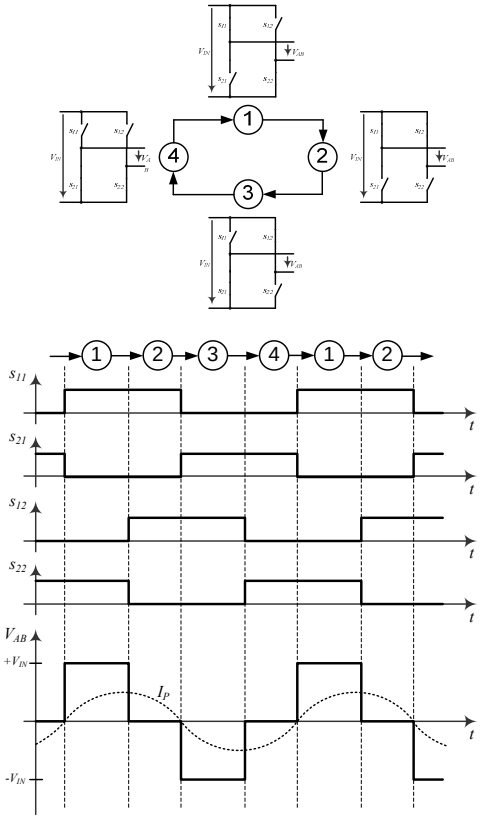


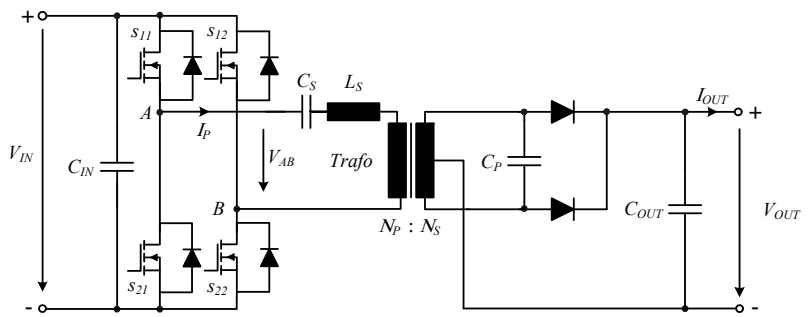


- higher frequency due to zero voltage switching possible
- reduction of passive elements size
- parasitics of active and passive elements used as resonant snubbers
- high power applications possible
- high efficiency over a large load range

Phase-shifted full bridge is applicable.

Series-Parallel Resonant DC/DC Converter





- soft switching technique: zero voltage and zero current switching possible
- combines advantages of series- and parallel resonant converter
- operates over a large load range
- high partial load efficiency
- approximately sinusoidal primary current I_p

Series-parallel resonant full bridge is applicable.

Comparison: Phase-Shift vs. Resonant

Conventional Criteria for Topology Comparison

- Number of Semiconductors
- Voltage Stress
- Current Stress
- Switching Conditions (Hard / ZVS / ZCS)
- Number of Passive Components
- Stress for Passive Components
- Published Efficiency Values
- Complexity of Control
- Evident EMI Performance

Obvious Criteria and Published Data

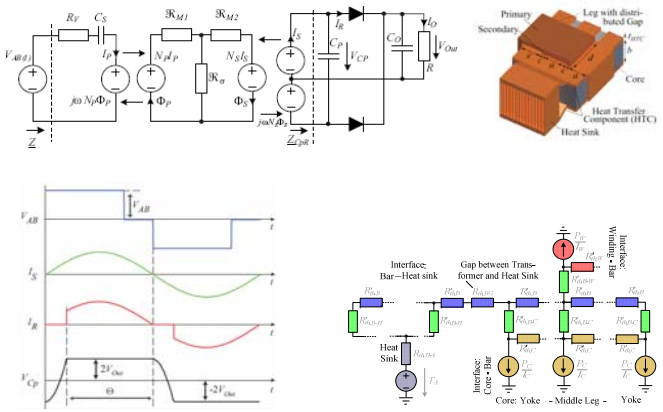
➔ "Similar" Performance for Different Topologies

Detailed analysis and optimization procedures are required for the comparison.

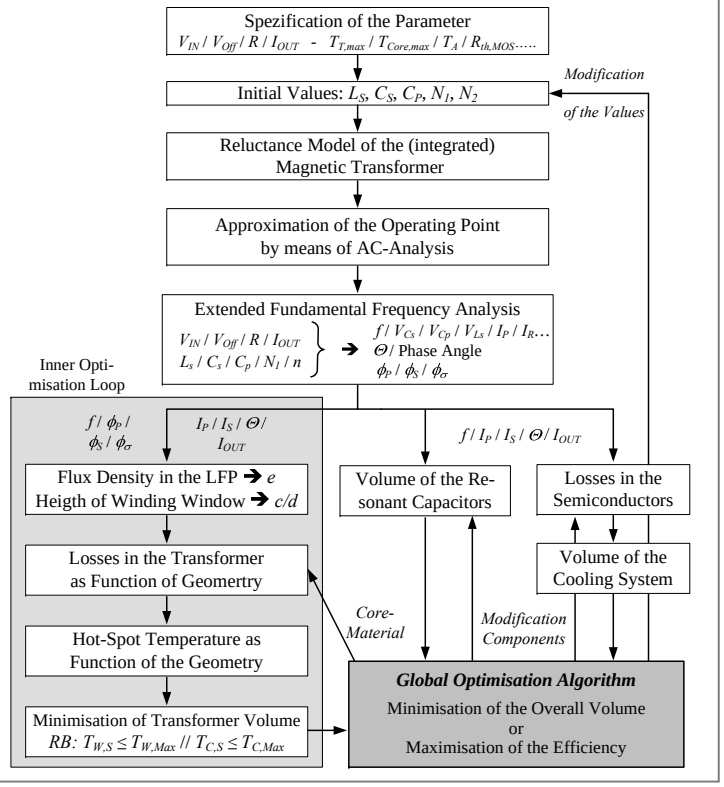
Optimization (Series-Parallel Resonant Converter)

models

- Analytical Converter Model
- Resonant Tank Capacitor
- Semiconductor Losses
- Transformer Model

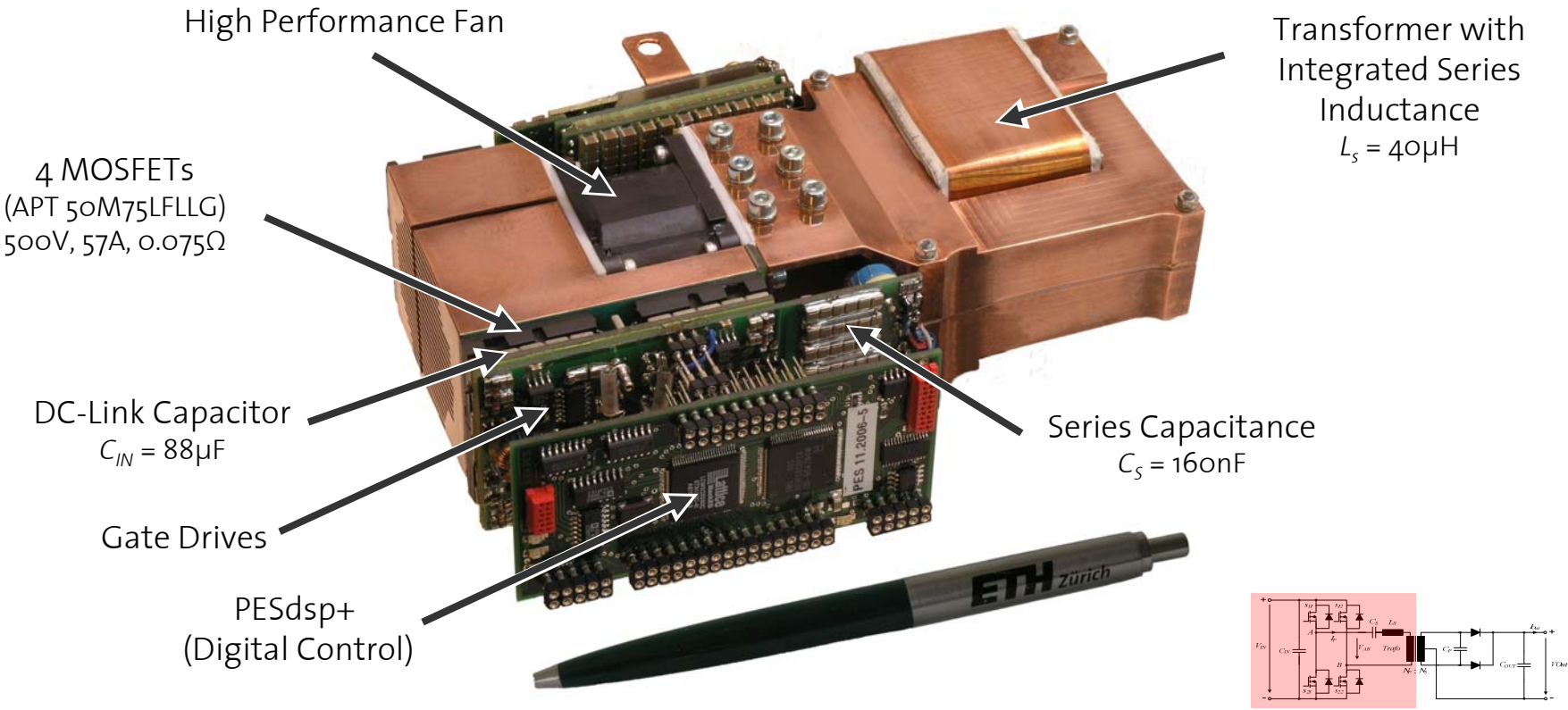


Optimization procedure



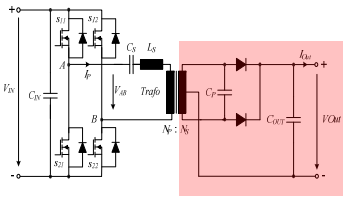
Optimized design parameters for series-parallel resonant converter found.
System volume: **0.49 dm³**, efficiency: **96.1%**, power density: **10.2 kW/dm³**.

Prototype (Front view with H-Bridge)



Ultra-compact, 5kW, 1U, 10kW/dm³ series-parallel resonant DC/DC converter
based on optimized parameters constructed.

Prototype (Back view with Rectifier)



Output Capacitance
C_{out} = 500µF

Transformer Heat Sink

Output
Connectors

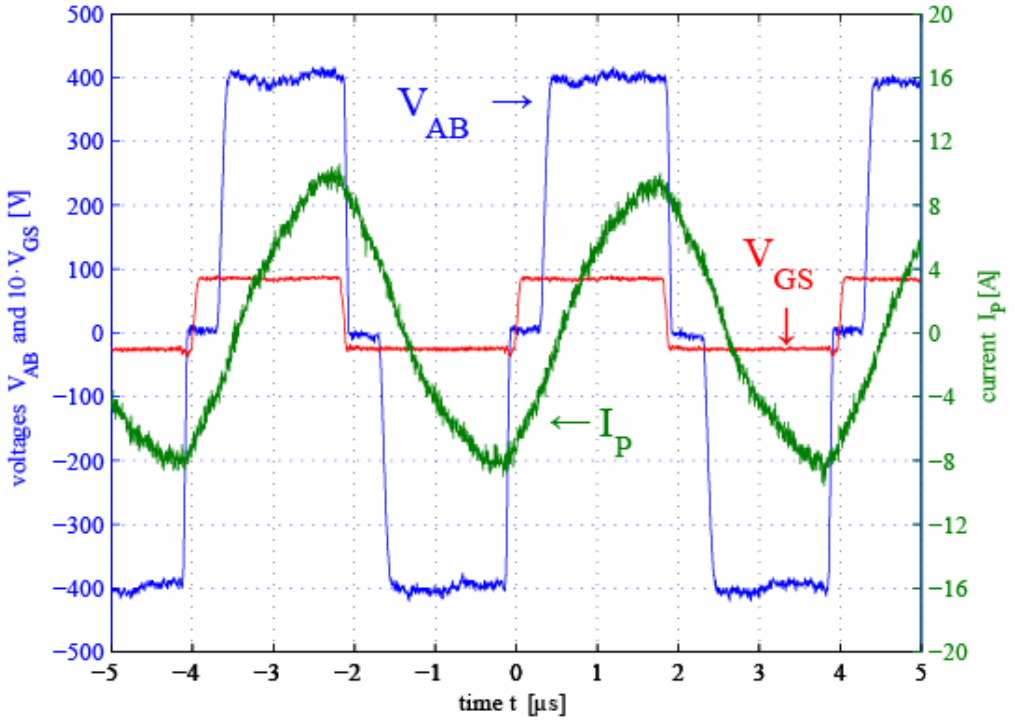
Output Voltage/Current
Measurement Board

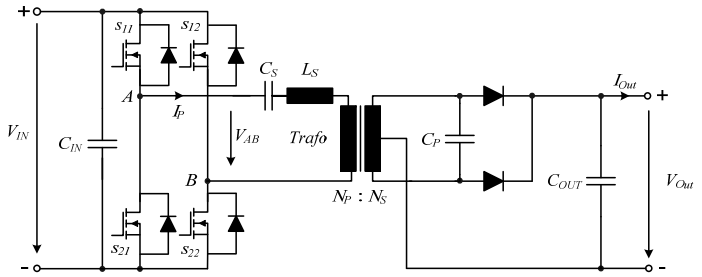
Parallel Capacitance
C_P = 120nF

Rectifier Diodes
(Schottky - APT 100S20B)
200V, 120A

Electrically Insulated
Heat Sink for Rectifier
Diodes

Measurement results





Intermediate circuit (input)

- voltage V_{IN} 400 V
- current I_{IN} 3.4 A

Output

- voltage V_{OUT} 44.3 V
- current I_{OUT} 28.2 A
- power P_{OUT} 1.25 kW

First measurements with the constructed prototype have been performed.

Summary and next steps

Goal: **An ultra compact, high efficiency DC/DC converter for a green data center.**

- Optimization procedure developed for a series-parallel resonant Converter ✓
- Construction using the optimized parameters ✓
- First measurements performed ✓

- Prototype Series-Parallel Resonant Converter
  - thermal behavior at higher power levels
  - validation of the simulation/calculation
- Optimization procedure for phase shift
- Construction of a phase-shift converter
- Comparison: phase-shift vs. resonant converter


Thank you!
[source: www.ibm.com]