ETH zürich

APEC 2017

Rap Session #1

Power Electronic Topologies – Do We Need More or Any Benefit to New Ones?

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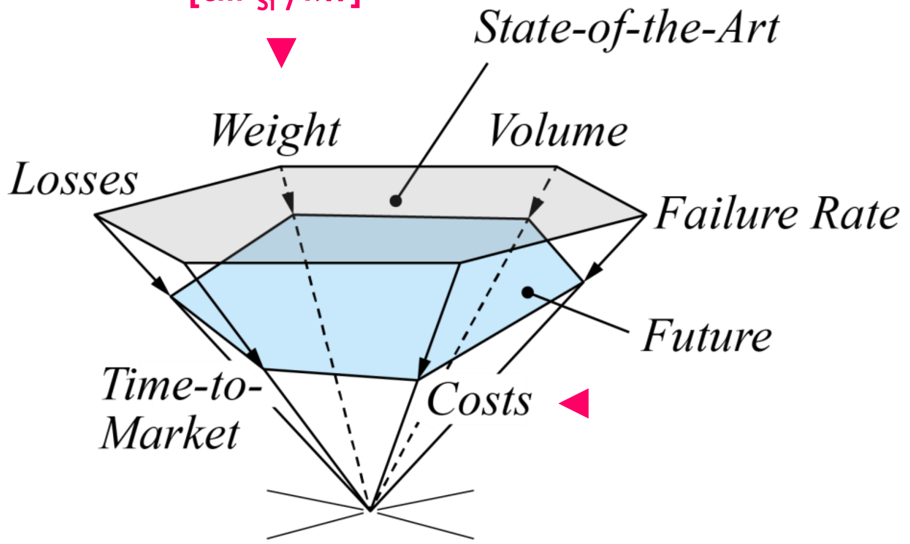
Why Are We Developing New Topologies? →

▶ *Market Pull* – Performance Improvement

Environmental Impact... [kg_{Fe} /kW]
[kg_{Cu} /kW]
[kg_{Al} /kW]
[cm^2_{Si} /kW]

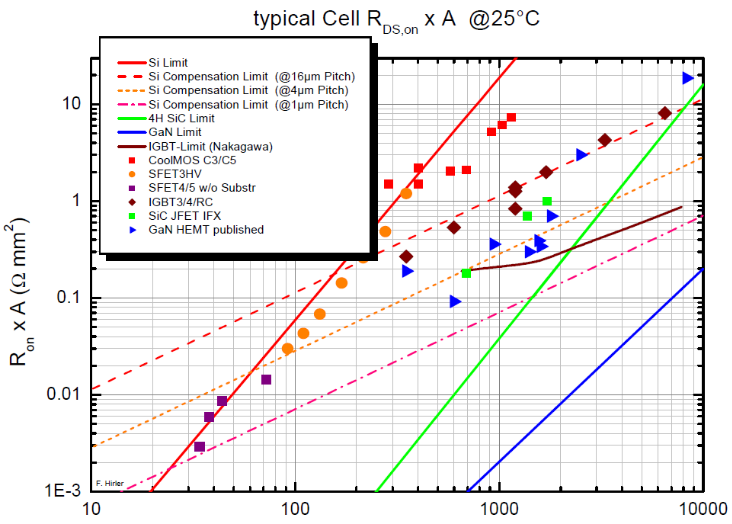


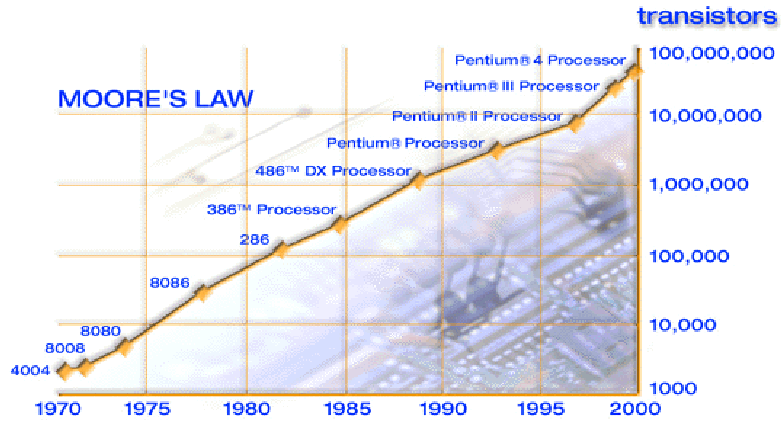
■ Performance Indices

- Power Density [kW/dm^3]
- Power per Unit Weight [kW/kg]
- Relative Costs [kW/$]
- Relative Losses [%]
- Failure Rate [h^{-1}]

▶ Technology Progress – *Technology Push*

- WBG Semiconductor Technology → Higher Efficiency, Lower Complexity
- Microelectronics → More Computing Power





→ + Advanced Packaging (!)

→ Moore's Law

▶ Keep the Publications Running (Academia ;-)) – I

→ **Benefits from Extremely Large Number of Possible Combinations !**

► Keep the Publications Running (Academia ;-)) – II

- **Very Large Number of Possible Topologies !**

IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 7, NO. 1, JANUARY 1992

– **Example**

Topologies for Three-Element Resonant Converters

Rudolf P. Severns

– **26 out of 48 Topologies are of Potential Interest**

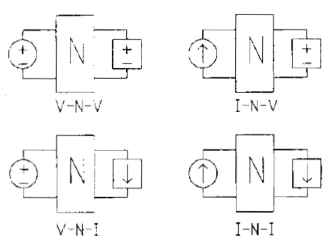


Fig. 13. Source-network-load combinations.

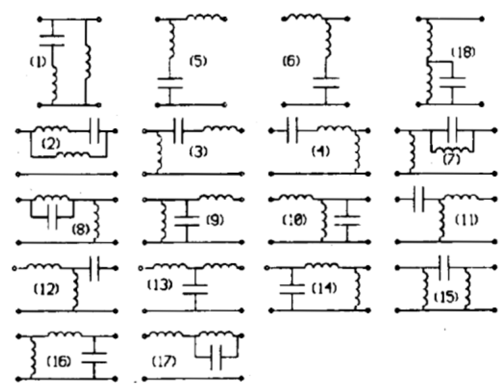


Fig. 17. Networks with $2L$ and $1C$.

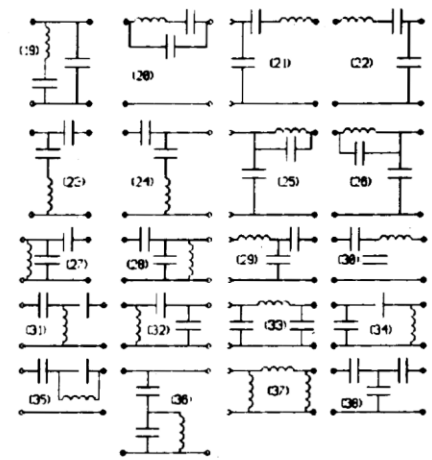


Fig. 18. Networks with $2C + 1L$, $3C$, and $3L$.

- **Keeps the Wheel Spinning, Even If the Hamster is Dead (!)**

Are New Topologies Really "New"?

History and Development of the Electronic Power Converter

E. F. W. ALEXANDERSON
FELLOW AIEE

E. L. PHILLIPI
NONMEMBER AIEE

THE TERM "electronic power converter" needs some definition. The object may be to convert power from direct current to alternating current for d-c power transmission, or to convert power from one frequency into another, or to serve as a commutator for operating an a-c motor at variable speed, or for transforming high-voltage direct current into low-voltage direct current. Other objectives may be mentioned. It is thus evidently not the objective but the means which characterizes the electronic power converter. Other names have been used tentatively but have not been accepted. The emphasis is on electronic means and the term is limited to conversion of power as distinguished from electric energy for purposes of communication. Thus the name is a definition.

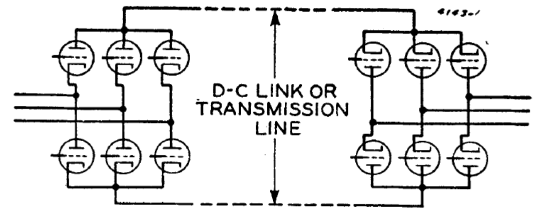


Figure 1. Electronic converter, dual-conversion type

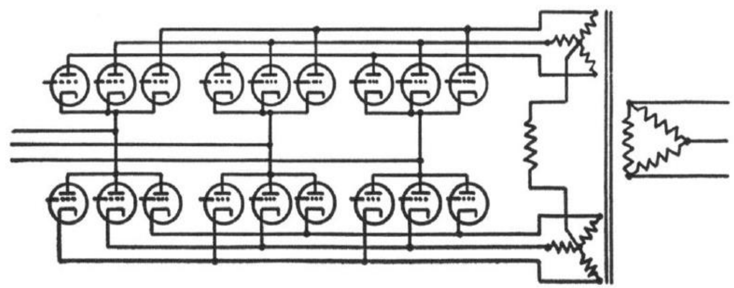
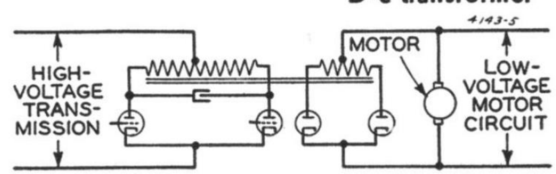


Figure 4 (left). Single - conversion-type frequency changer

Figure 5 (below). D-c transformer



Paper 44-143, recommended by the AIEE committee on electronics for presentation at the AIEE summer technical meeting, St. Louis, Mo., June 26–30, 1944. Manuscript submitted April 25, 1944; made available for printing May 18, 1944.

E. F. W. ALEXANDERSON and E. L. PHILLIPI are with the General Electric Company, Schenectady, N. Y.

1944 !

United States Patent [19] [11] **4,412,277**
Mitchell [45] **Oct. 25, 1983**

1983 !

[54] **AC-DC CONVERTER HAVING AN IMPROVED POWER FACTOR**

[75] Inventor: **Daniel M. Mitchell,** Cedar Rapids, Iowa

[73] Assignee: **Rockwell International Corporation,** El Segundo, Calif.

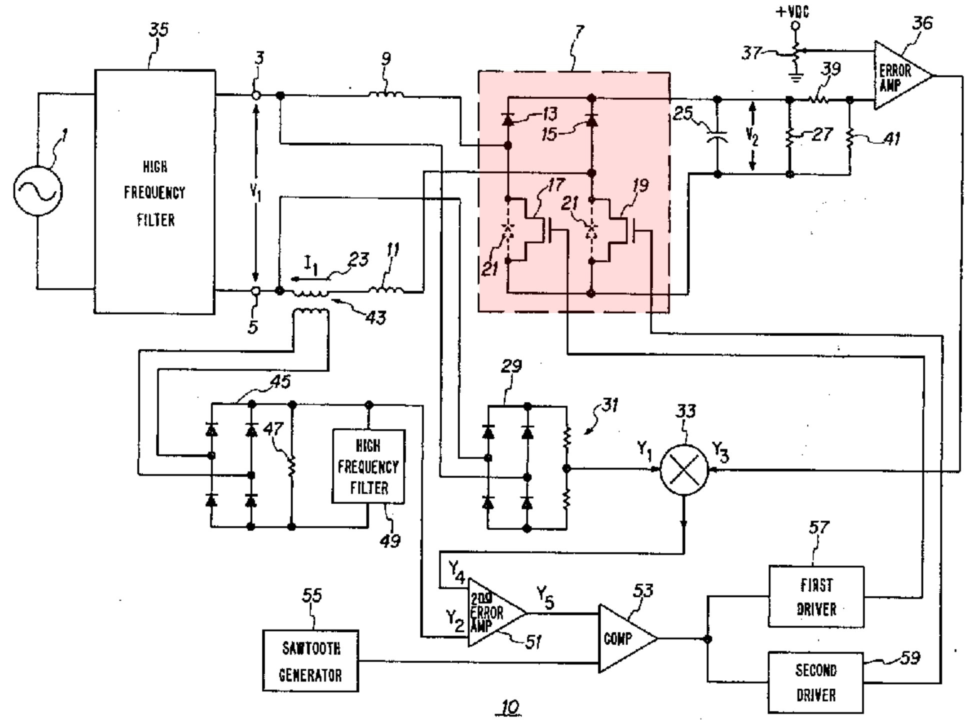
[21] Appl. No.: **414,757**

[22] Filed: **Sep. 3, 1982**

[57] **ABSTRACT**

An AC to DC converter utilizes a first power converter for converting an AC signal to a DC signal under the control of a control signal. The control signal is generated by a control circuit that includes a first analog generator that provides a first signal that is analogous to the voltage of the AC signal that is to be converted. A second analog generator generates a second signal that is analogous to the current of the AC signal that is to be converted and a third analog generator generates a third signal that is analogous to the voltage of the DC output signal. The third signal and the first signal are multiplied together to obtain a fourth signal. The control signal is generated from the fourth signal and the second signal and is used to control the power converter such that the waveform of the current of the AC signal is limited to a sinusoidal waveform of the same frequency and phase as the AC signal.

8 Claims, 2 Drawing Figures

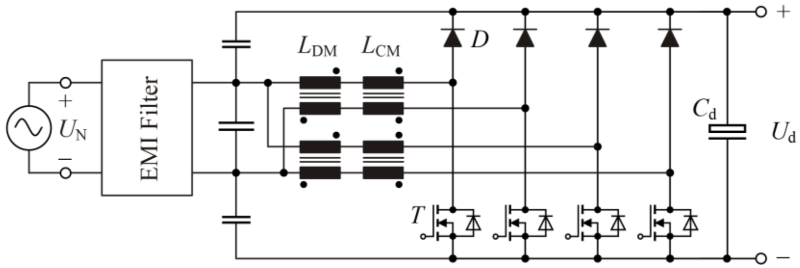


▶ 10 Years Ago ...

- **Example of Highly-Compact 1-Φ PFC Rectifier**
- **Double-Interleaved (2 x 1.65 kW Systems)**

P_0 = 3.3kW
U_N = 230V±10%
U_0 = 400V

f_P = 450kHz ± 50kHz



- *CoolMOS*
- *SiC Diodes*
- Hard Switching / CCM

★ ρ = 5.5 kW/dm³ @ η = 95.8%

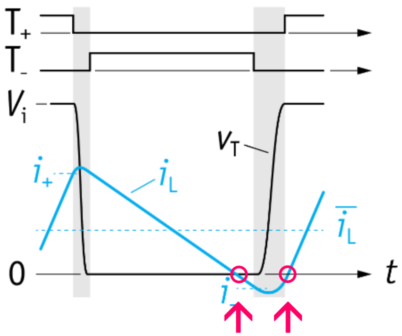
→ Based on Patent of 1983 (!)
→ High Power Density @ Low Efficiency

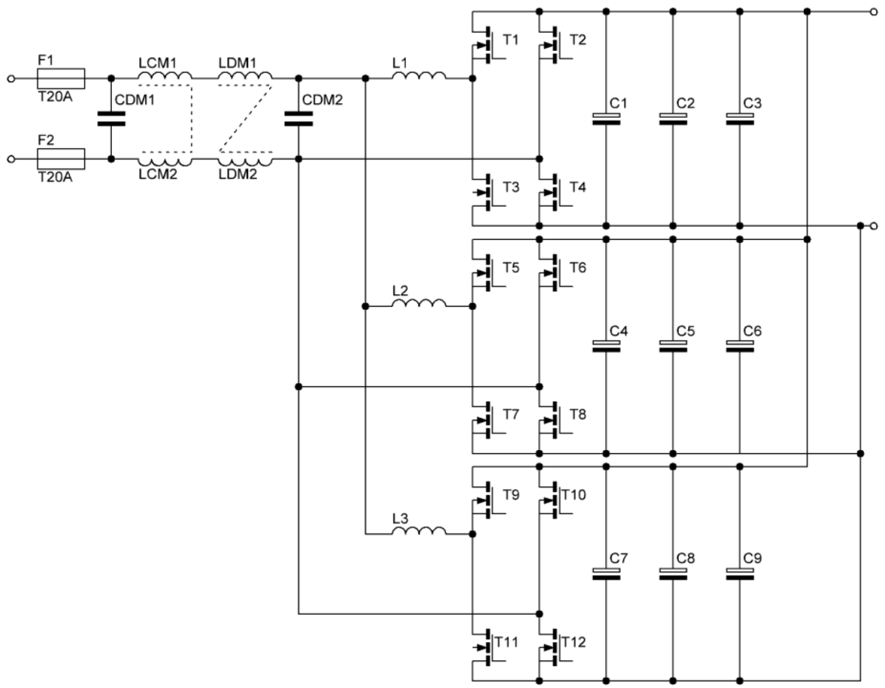
5 Years Ago ...

- **Example of Highly-Compact 1-Φ PFC Rectifier**
- **Two Interleaved 1.65 kW Systems**

P_0 = 3.3kW
U_N = 230V±10%
U_0 = 400V

f_P = 50kHz ± 20kHz





- *CoolMOS*
- *DSP / FPGA Control*
- Soft-Switching / TCM Operation
- Unfolder Bridge Leg

▶ 5 Years Ago ...

- **Example of Highly-Compact 1-Φ PFC Rectifier**
- **Two Interleaved 1.65 kW Systems**

P_0 = 3.3kW
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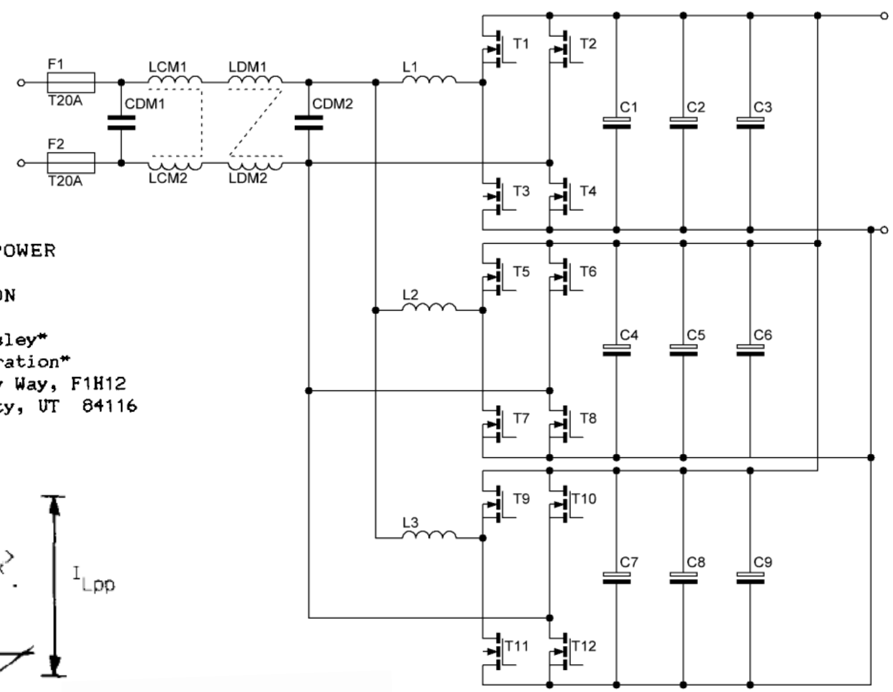

ZERO-VOLTAGE SWITCHING IN HIGH FREQUENCY POWER CONVERTERS USING PULSE WIDTH MODULATION

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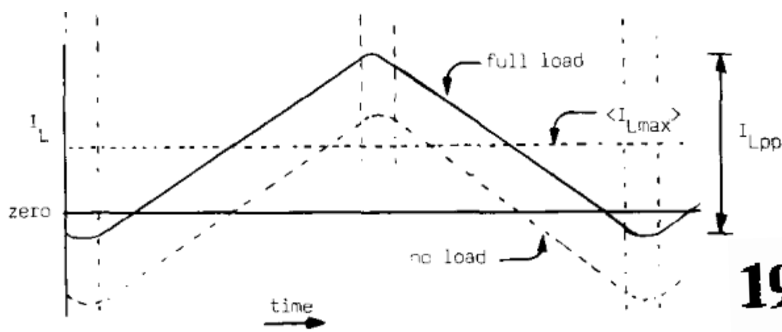


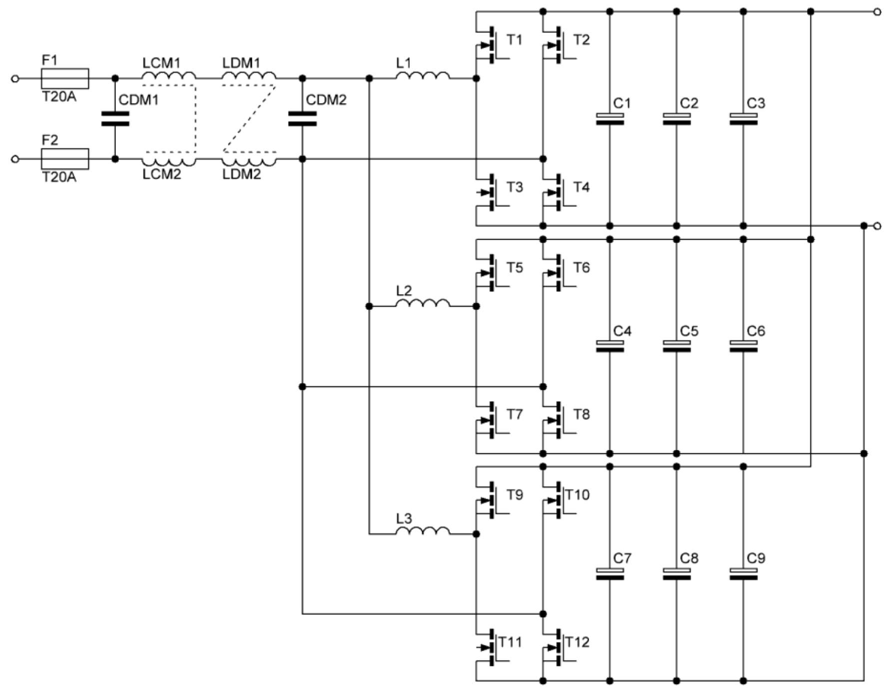
1988 IEEE

▶ 5 Years Ago ...

- Example of Highly-Compact 1-Φ PFC Rectifier
- Two Interleaved 1.65 kW Systems

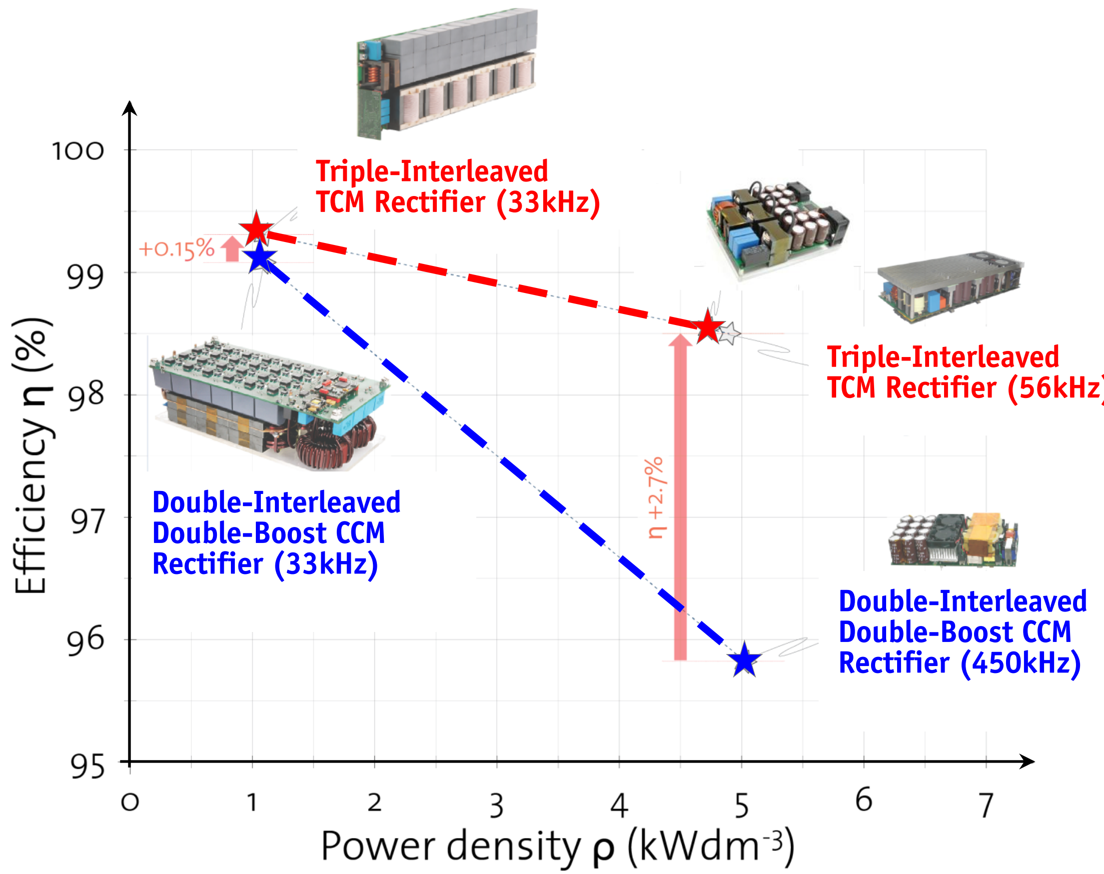
$P_O = 3.3\text{kW}$
$U_N = 230\text{V} \pm 10\%$
$U_O = 400\text{V}$

$f_P = 50\text{kHz} \pm 20\text{kHz}$



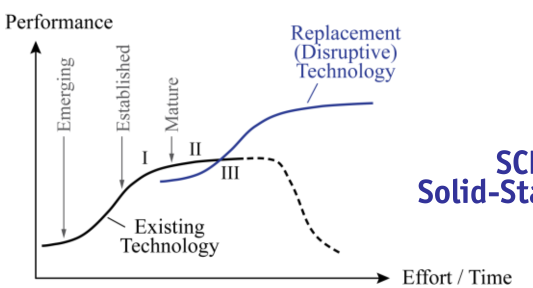
★ $\rho = 4.5\ \text{kW/dm}^3$ @ $\eta = 98.6\%$

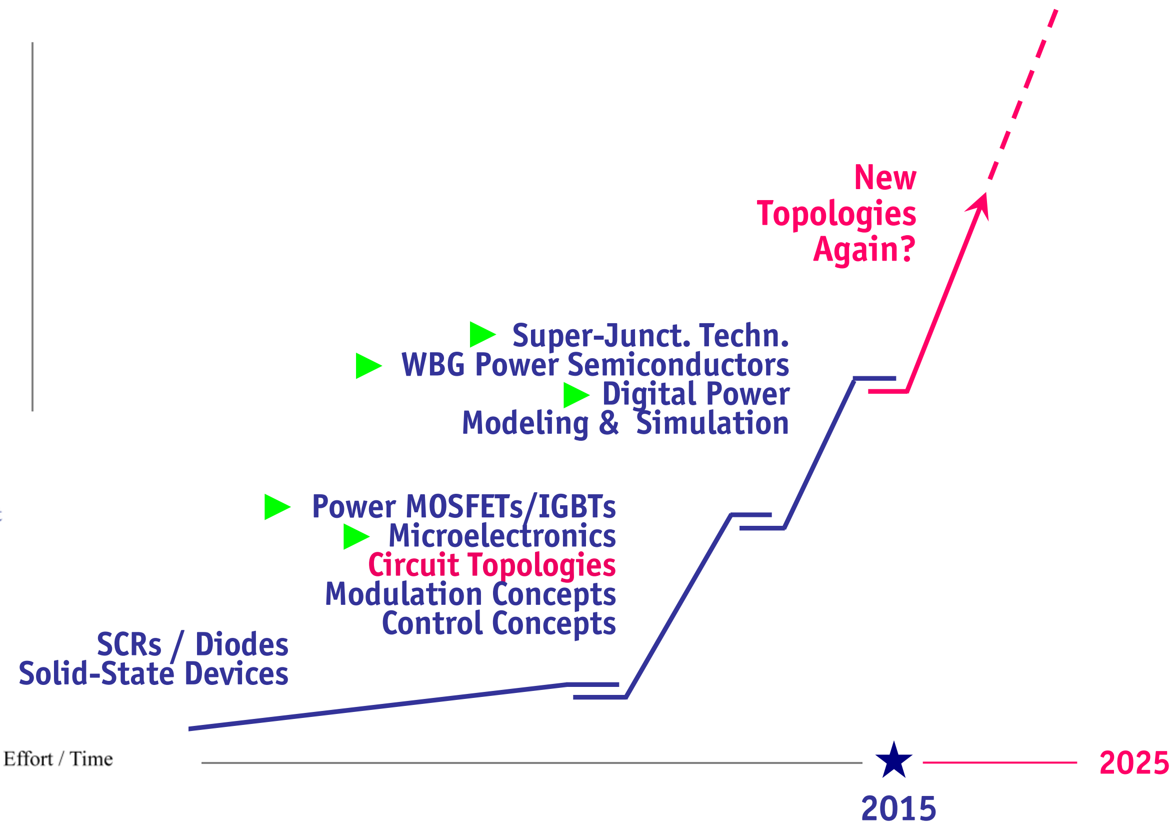
▶ Performance Improvement



- → „Old" Topologies
- → „Old" Control Schemes
- → „New" Semiconductors
- → „New" Digital Control

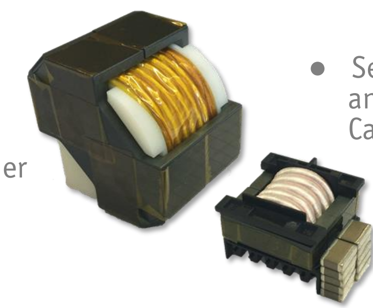
▶ Technology S-Curve

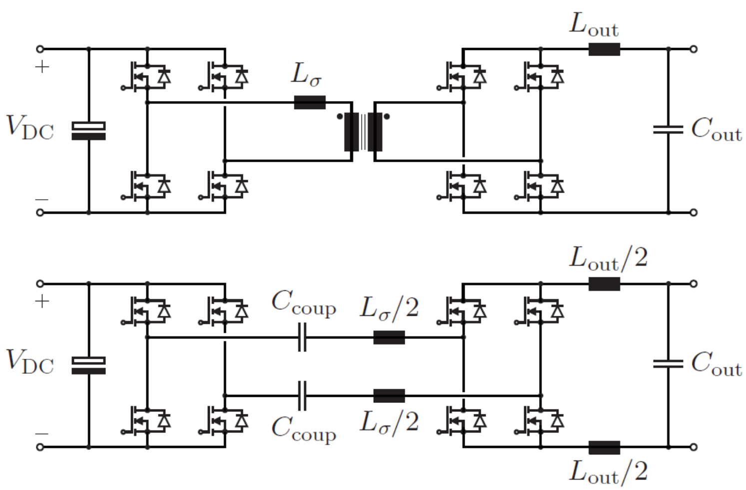


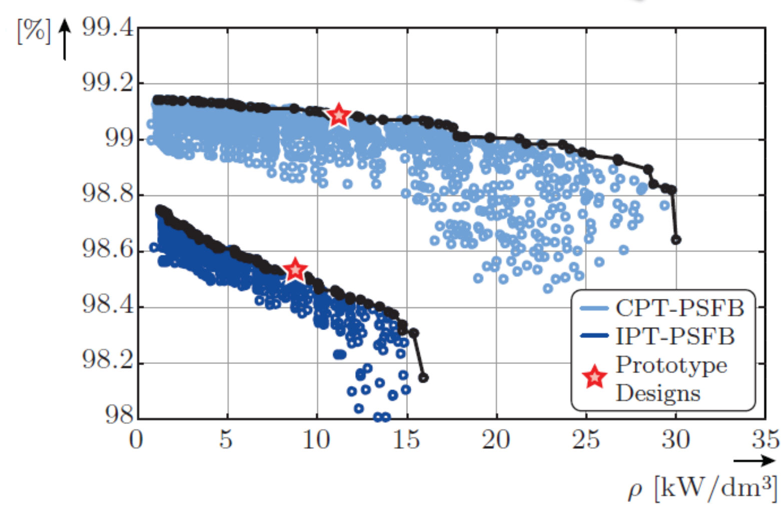


▶ What´s Next?

- Utilize GaN And High-Frequ. Magnetic Materials (Air Cores ?)
- Hybrid Structures – Switched Capacitor + Magnetics
- Active Storage Instead of (Passive) Capacitors
- Multi-Cell Topologies – Minimize Magnetics



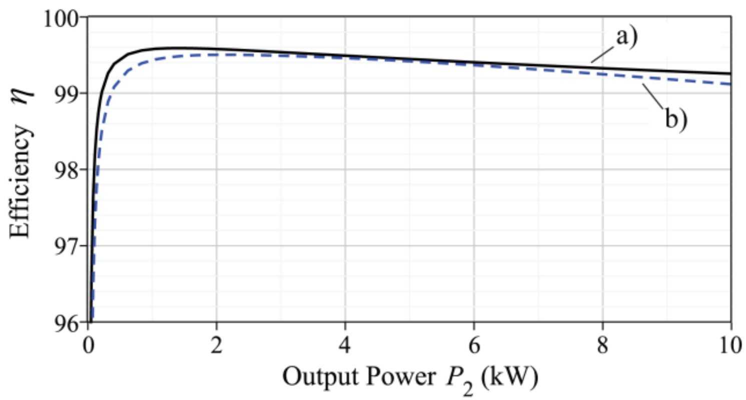


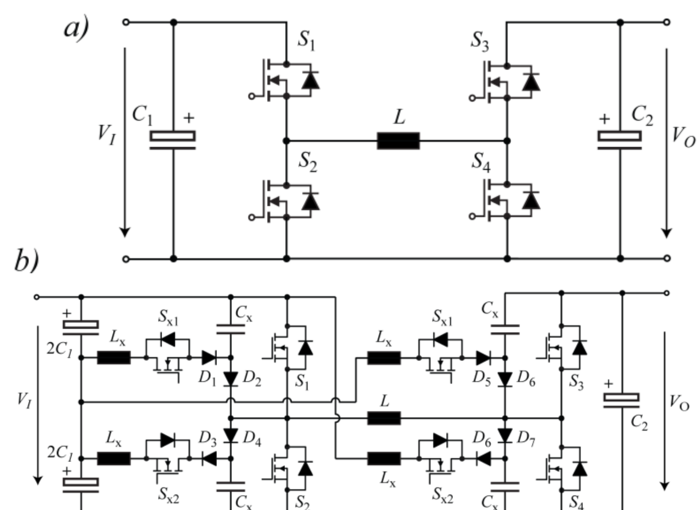


▶ Lessions Learned Concerning Topologies

- Think of Changing Operation Mode First (Not the Topology)
- Need to Forget "Textbook" View (Implicit Low Ripple Assumption)
- Always Go with the Most Basic Topology (No Aux. Circuits)

- Topologies are Changing to Best Utilize a Given Set of Technologies („Followers")
- Topologies are Getting More Complex Once Limits of a Technology Set are Reached
- Cont. Demand for Min. Complexity – Complexity Collapses with Next Technology Step





Future Trends / Side Conditions →

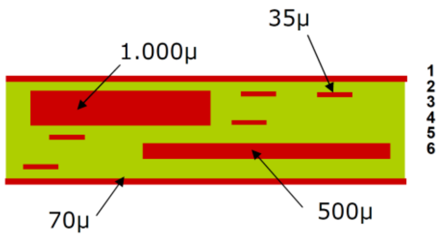
▶ Side Conditions

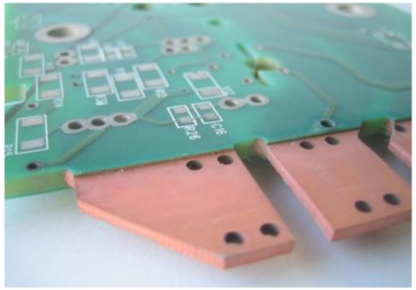
■ **Mature Technologies → Optimize for Manufacturing (PCB Oriented)**

* PCB Oriented – "Planar World" Allows Realizing Magnetics w. Reasonable Efforts
* More Complex Interconnections Possible
* Facilitates Topologies of Magnetic Structures (Magn. Integr.)

■ **Semiconductors & Control**

* Integration of Switch & Gate Drive → "Switching Cell"
* Switching Cells → Multi-Cell Converters Minim. Magnetics
* Active Gate Drives



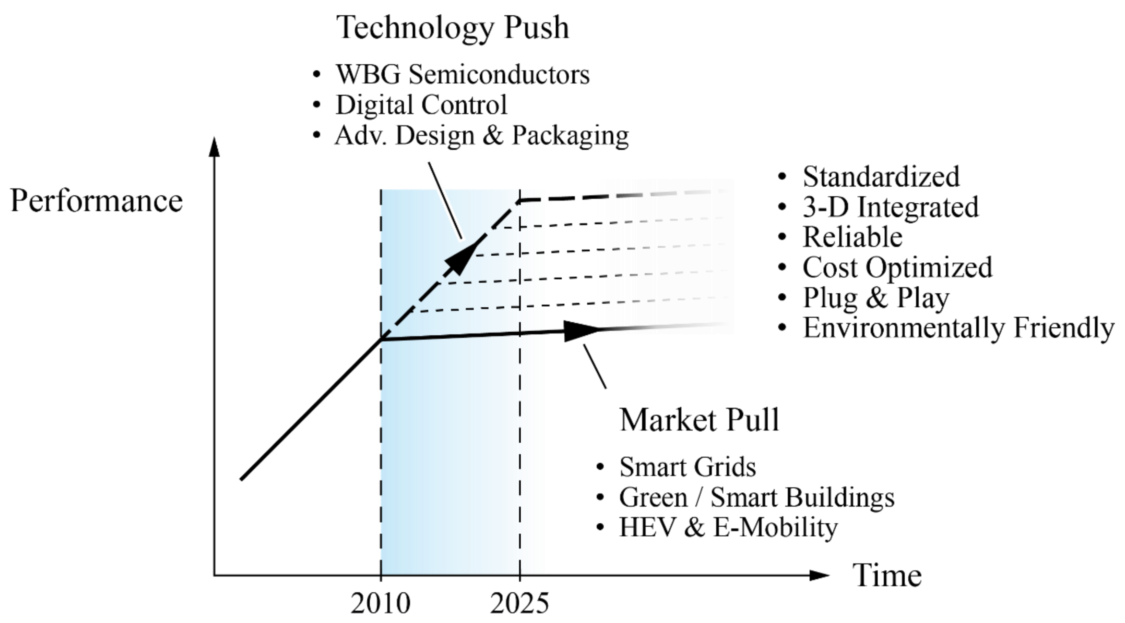


■ **Digitalization**

* Power Electronics 4.0
* Control, Monitoring, etc.

► Future Development

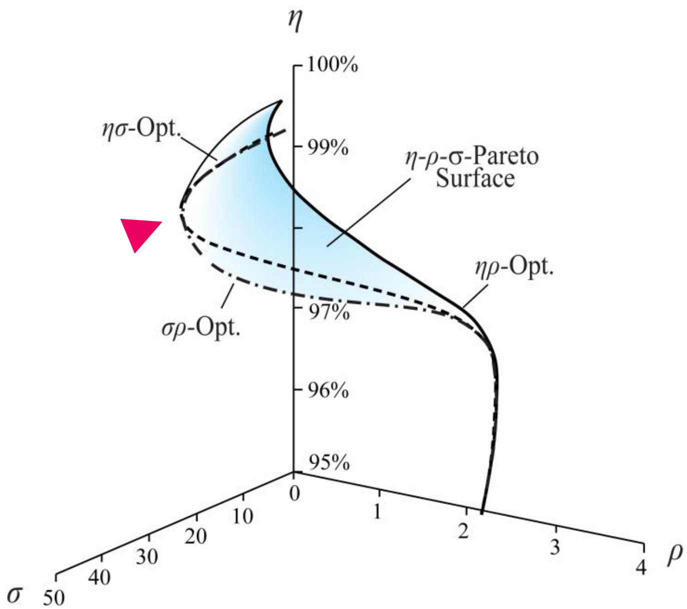
- Megatrends – Renewable Energy / Energy Saving / E-Mobility / "SMART" XXX
- Power Electronics will Massively Spread in Applications

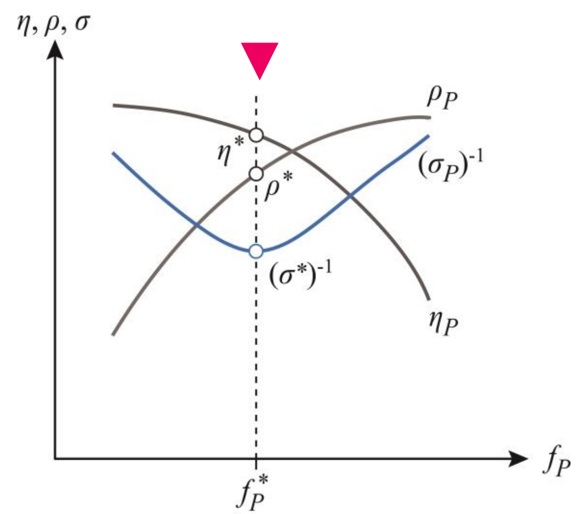


→ More Application Specific Solutions
→ Mature Technology – Cost Optimization @ Given Performance Level
→ Don´t Need "More Topologies" BUT Tools to Better Understand Performance of Known Topologies (!)

► Fair Comparison – Performance Evaluation Based on η-ρ-σ-Pareto Surface

- Definition of a Power Electronics *"Technology Node"* → (η^*,ρ^*,σ^*,f_P^*)
- Maximum σ [kW/$], Related Efficiency & Power Density





→ Specifying Only a Single Performance Index is of No Value (!)
→ Achievable Perform. Depends on Conv. Type / Specs (e.g. Volt. Range) / Side Cond. (e.g. Cooling)

■ End

Thank You !