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Multilevel Boost Converters, their Applications, Comparisons and Practical Design Aspects

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TEXAS INSTRUMENTS

Outline

1. Power Systems with Boost DC-DC Converters
2. Low Cost, High Efficiency and Density driving Technologies
3. Three-level Boost Topologies:
   a) Flying Capacitor
   b) Diode Clamped
4. Multi-level Topologies
5. Experimental Results
6. Conclusion and Acknowledgments

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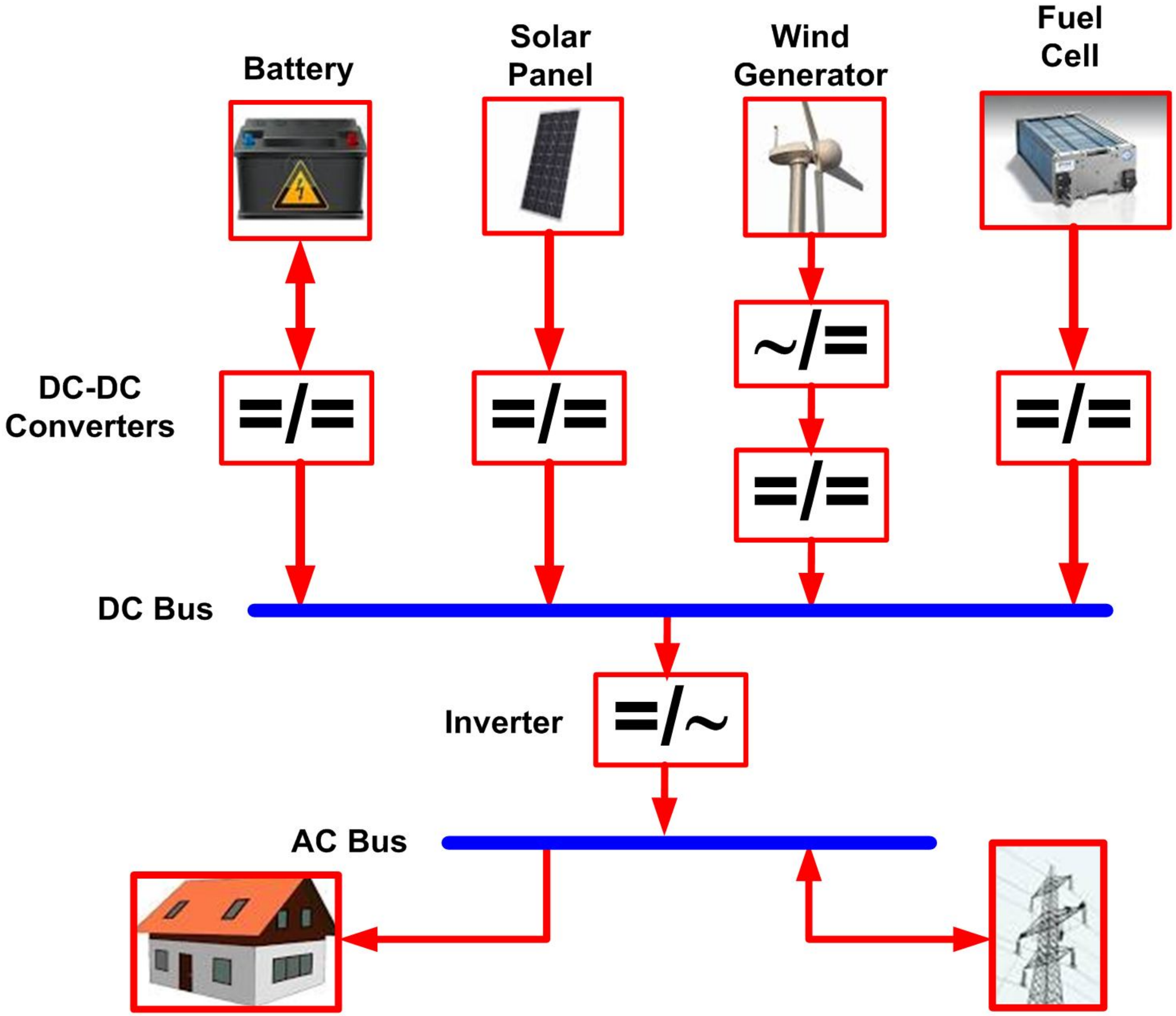
Power Generation and Distribution System with Intermediate DC Bus



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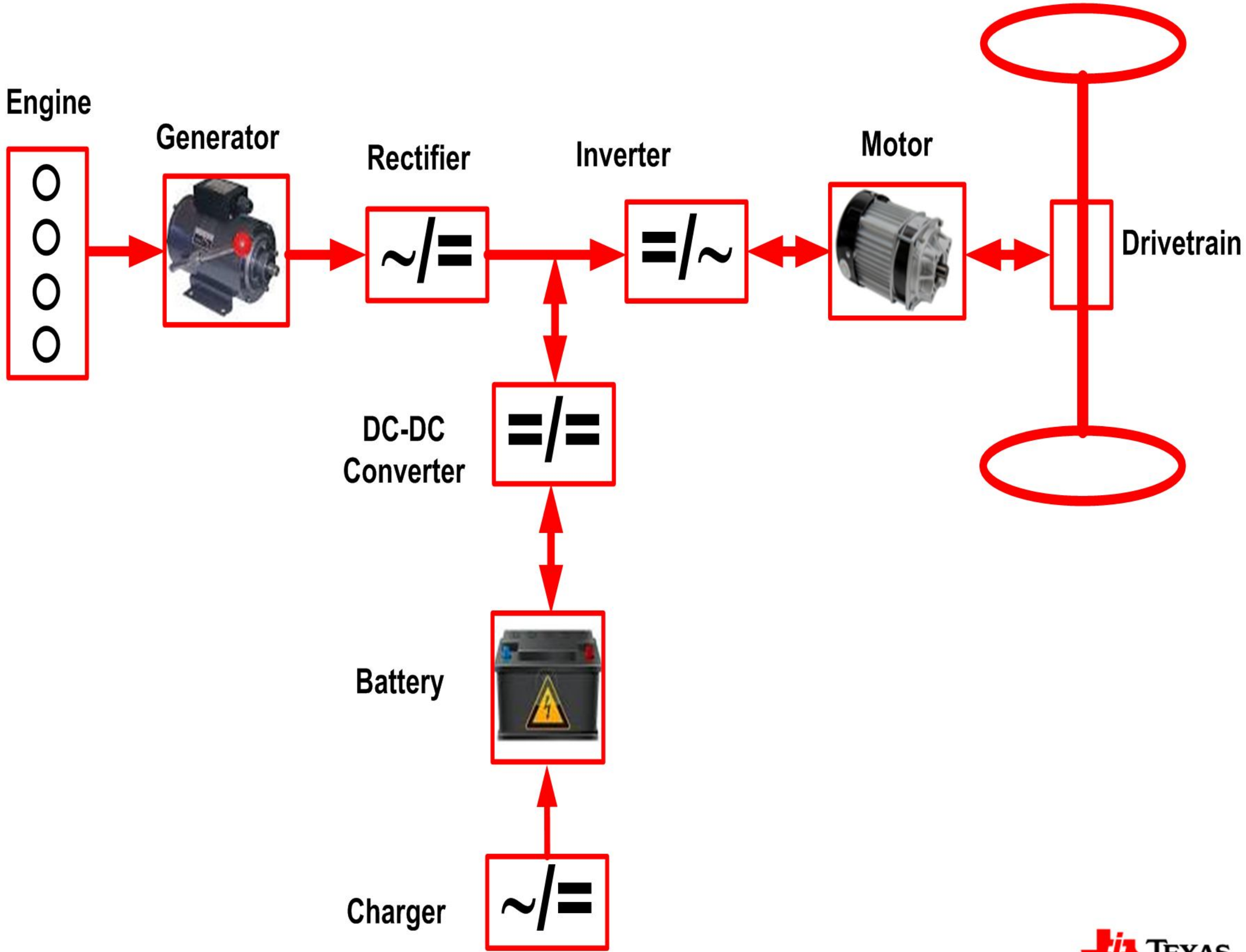
Power Conversion and Flow in HEV Powertrain



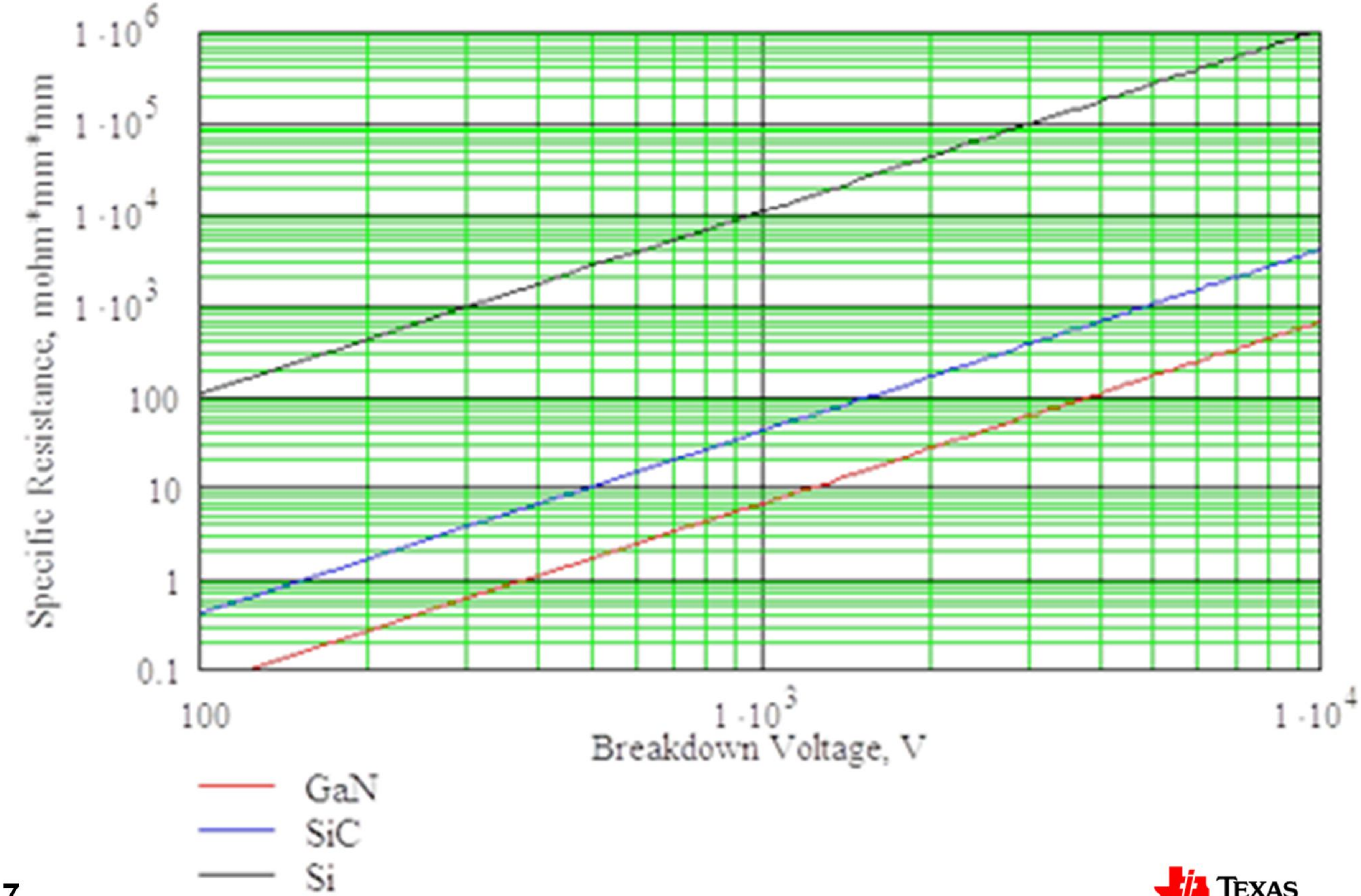
Key Vectors for Low Cost, High Efficiency and Density Solution

- **Optimal Power System**
- **Topology**
- **Components and Materials**
  - **New SiC and GaN Power Devices**
  - **Isolated Driver Technique**
  - **New Passives: Capacitors and Magnetics**

Key Parameters of Semiconductor Materials

Material	Si	GaAs	InP	GaN	4H-SiC
Bandgap, eV	1.1	1.43	1.35	3.4	3.26
Breakdown Field, V/µm	30	40	50	300	200-<300
Electron Mobility, cm^2/Vs	1500	8500	5400	1500	700
Saturated Electron velocity, 10^7 cm/s	1	<1.0	1	1.3	2
Peak Electron velocity, 10^7 cm/s	1	2.1	2.3	2.5	2
Thermal Conductivity, W/cmK	1.3	0.55	0.68	>1.5	<3.8
Lattice Constant (a), A	5.43	5.65	5.87	3.19	3.07
Dielectric Constant, ε_r	11.7	12.9	12.5	9	9.7

Specific Rdson vs Vbreak of Si, GaN and SiC



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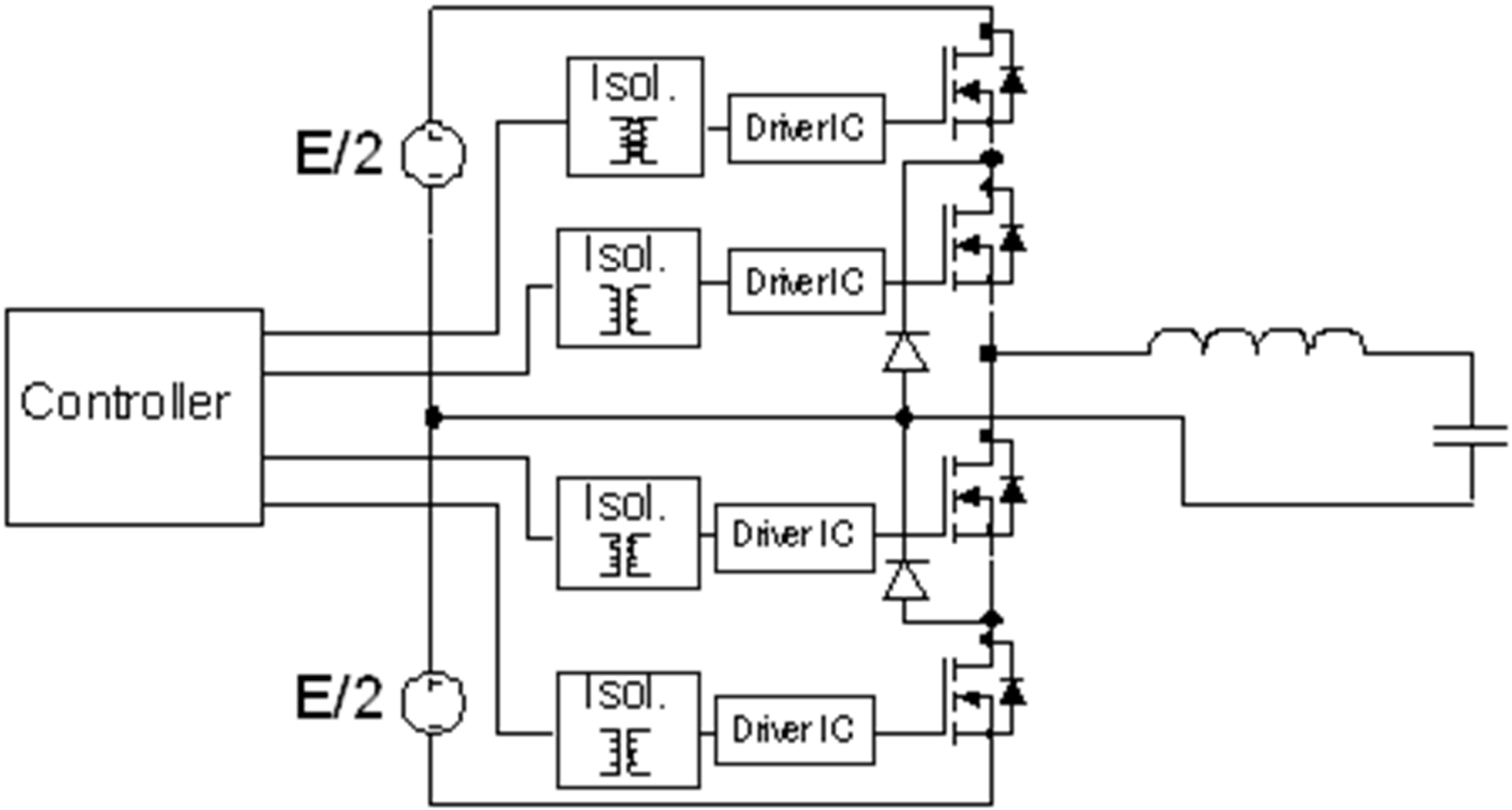
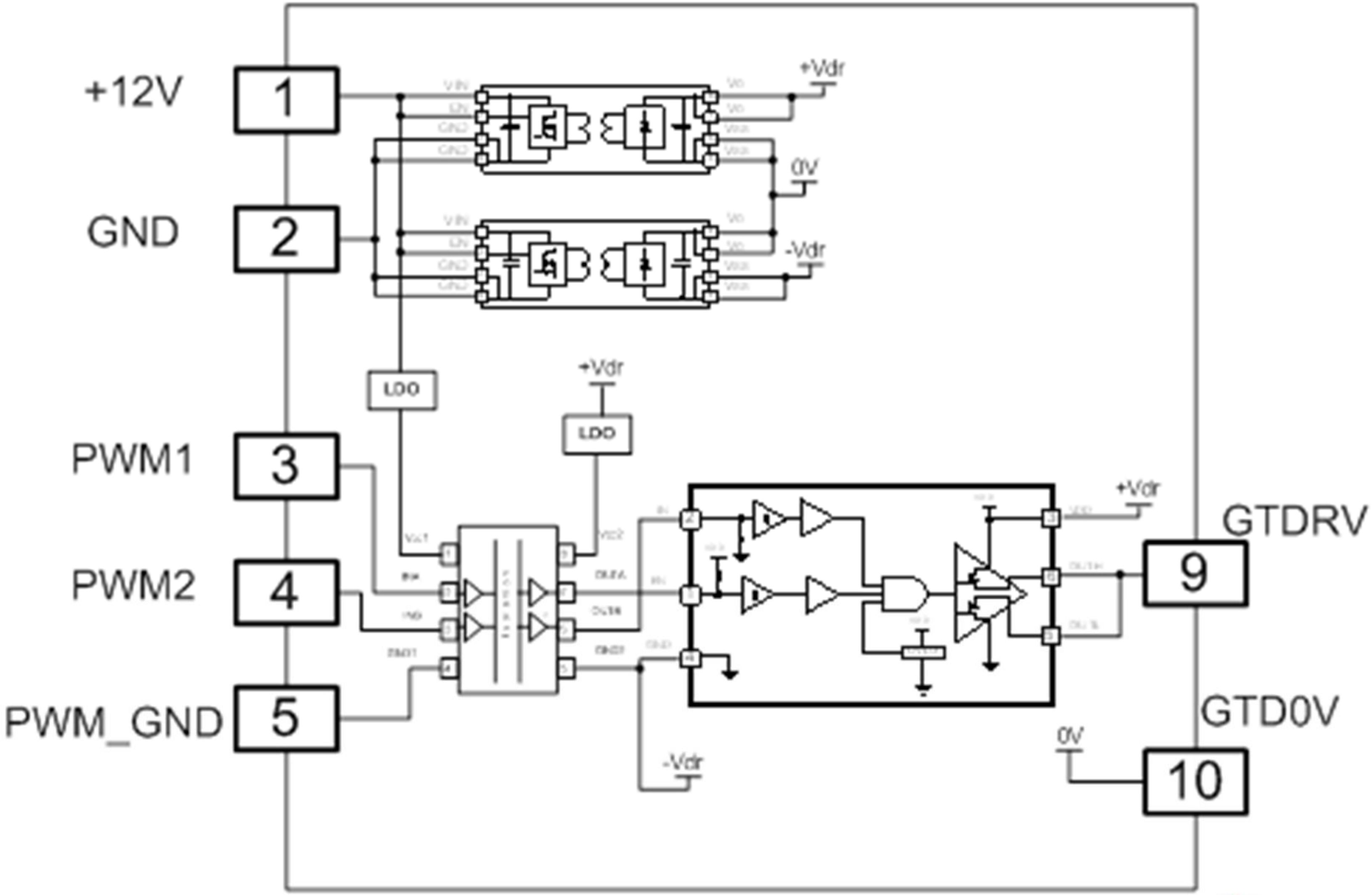
Key Parameters of Commercial SiC Transistors

Vendor	Part	Vds, V	Id, A	Vg, V	Rdson, mΩ	Qg, nc	FM, mΩ•nc	Die size, mm x mm	Spec. Ron. mΩ•mm^2
Cree	CPM2-1200-0080B	1200	20	+25/-10	80	49	3920	3.36x 3.1	833
Cree	CPM2-1200-0025B	1200	50	25/-10	25	179	4475	6.44x4.0 4	650
Rohm	SCT2080KE	1200	35	+22/-6	80	106	8480	TO-247	n/a
GeneSic	GA50JT12-247 (bipolar)	1200	50	3.3V, 2A	28	n/a	n/a	TO-247	n/a
MicroSemi	APTMC120AM55CT1 AG	1200	55	+25/-10	49	98	4802	Module	n/a
ST Micro	SCT30N120	1200	45	+25/-10	80	105	8400	HiP247	n/a

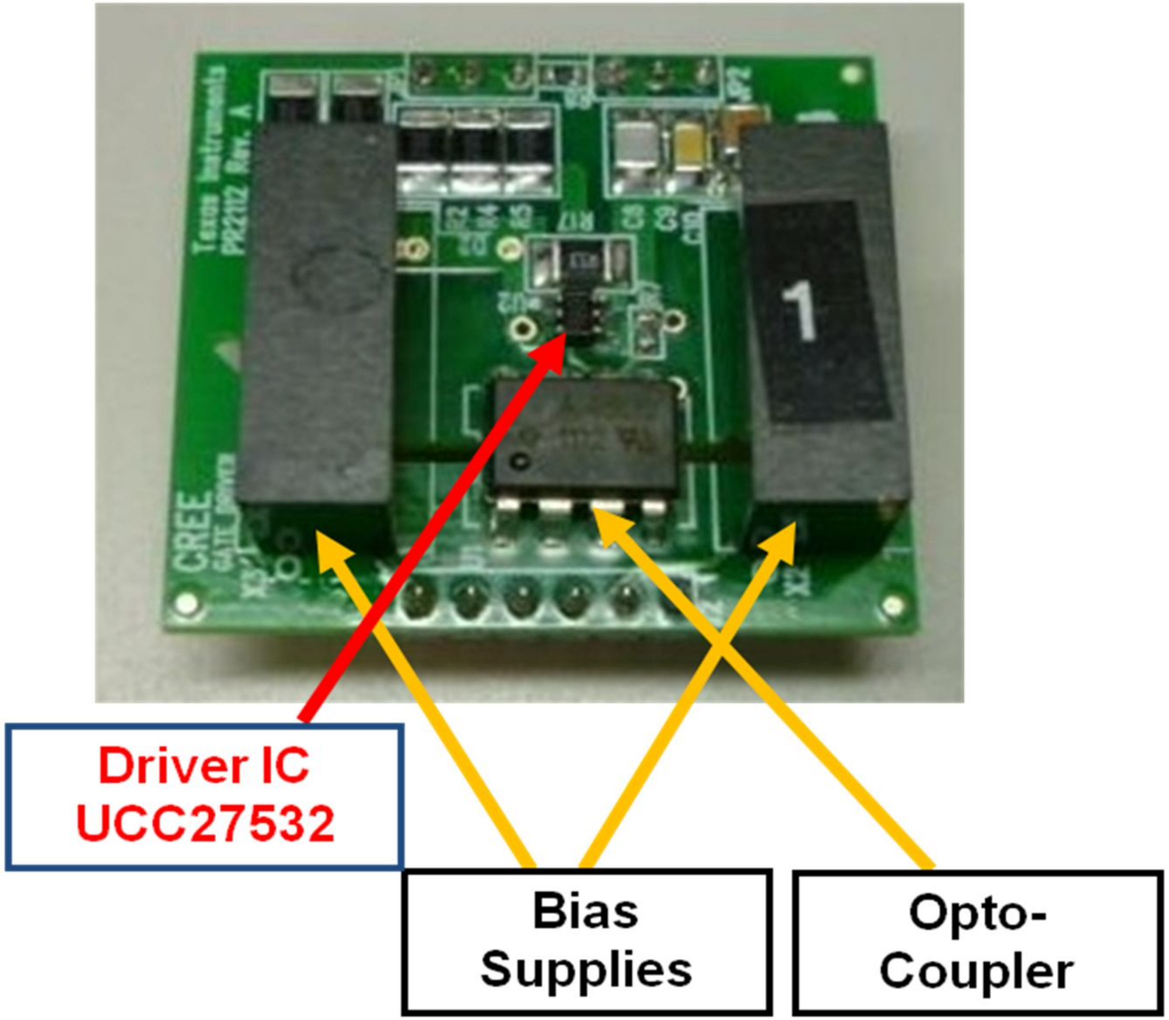
Signal and Bias Isolation Need for Multilevel Topologies



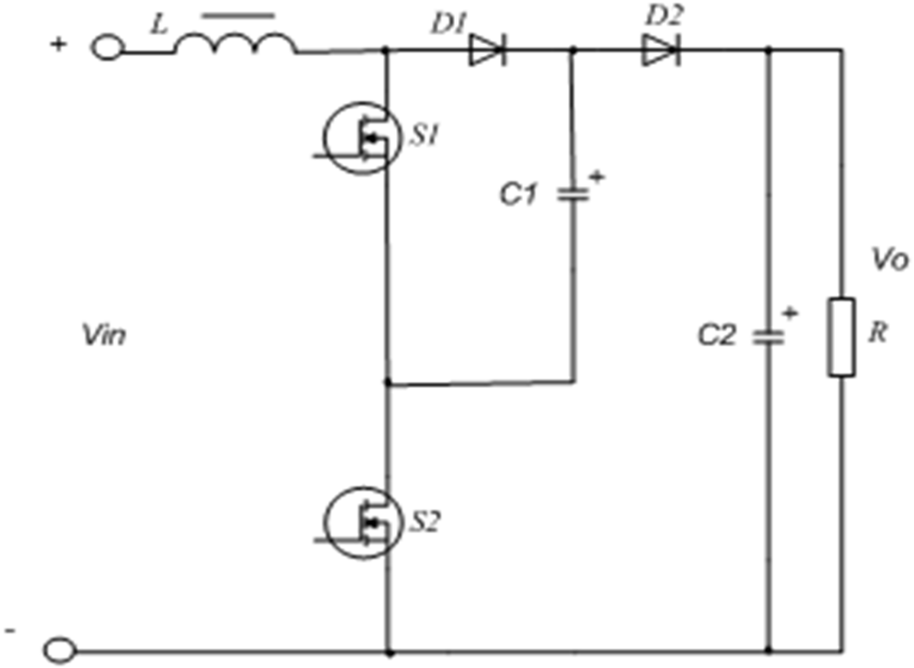
Electrical Diagram of Signal and Bias Isolation Driver Board

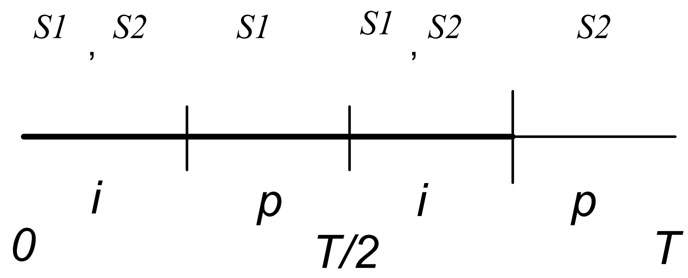


Isolated Driver Board View

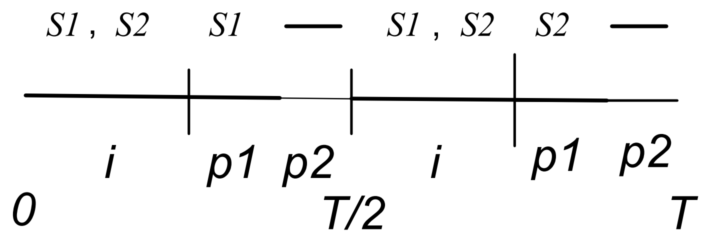


Three-level Flying Capacitor Boost Converter





a



b

TFR for Non-overlapping control

$$V_o = \frac{2V_{in}}{2-D}$$

TFR for Overlapping control

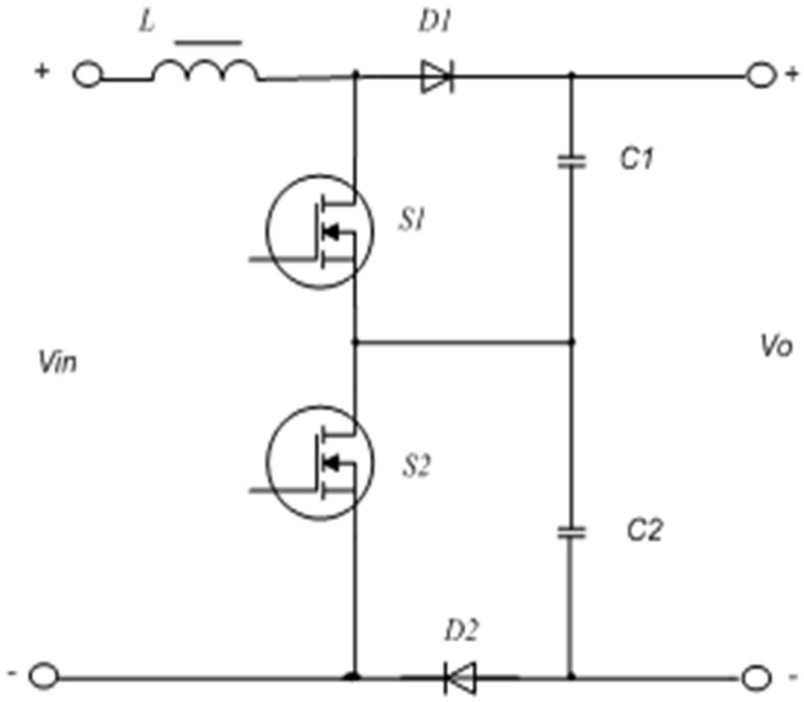
Version a)

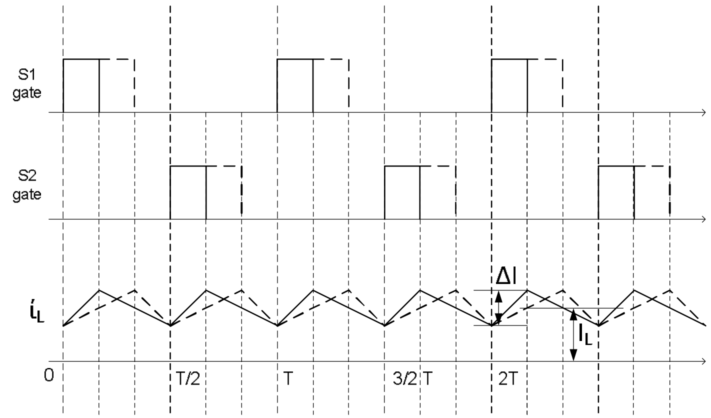
$$V_o = \frac{2V_{in}}{1-D}$$

Version b), 0 ≤ k ≤ 1

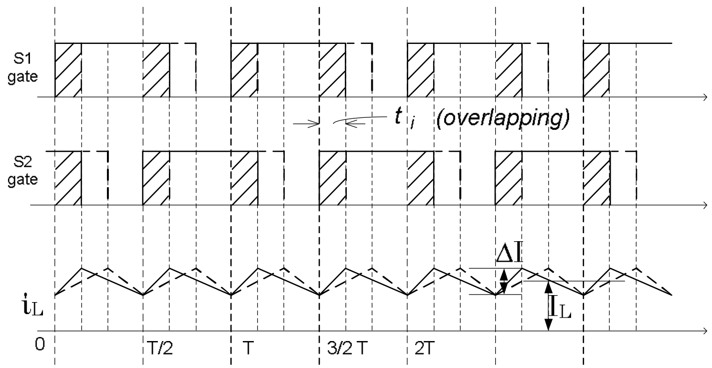
$$V_o = \frac{2V_{in}}{(1-D)(2-k)}$$

Three-level Boost Converter





a) Non-overlapping control



b) Overlapping control

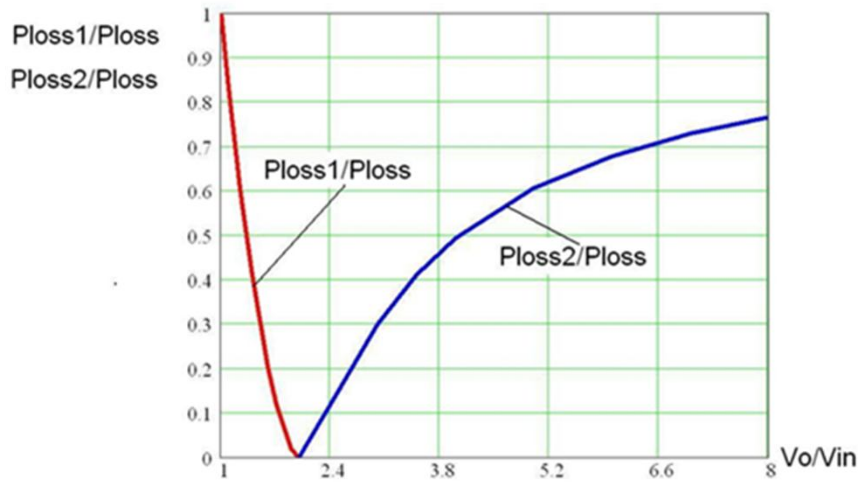
$$V_o = 2V_c = 2V_{in} / (2 - D)$$ **TFR for control a)**

$$V_o = 2V_c = 2V_{in} / (1 - D)$$ **TFR for control b)**

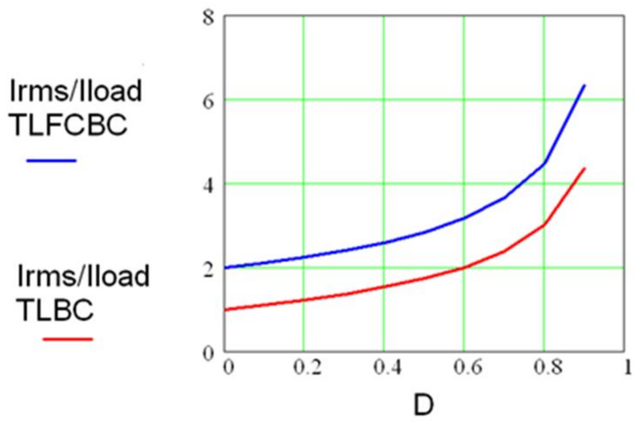
Comparison of TLFCBC vs TLBC

Circuit	Mode	Capacitor	I_{rms} / I_{load}
TLBC	Without overlapping	C1 (C2)	$\sqrt{D/(2-D)}$
	With overlapping		$\sqrt{(1+D)/(1-D)}$
TLFCBC	Without overlapping	C1	$2\sqrt{D}/(2-D)$
	With overlapping		$2/\sqrt{1-D}$
	Without overlapping	C2	$\sqrt{D/(2-D)}$
	With overlapping		$\sqrt{(1+D)/(1-D)}$

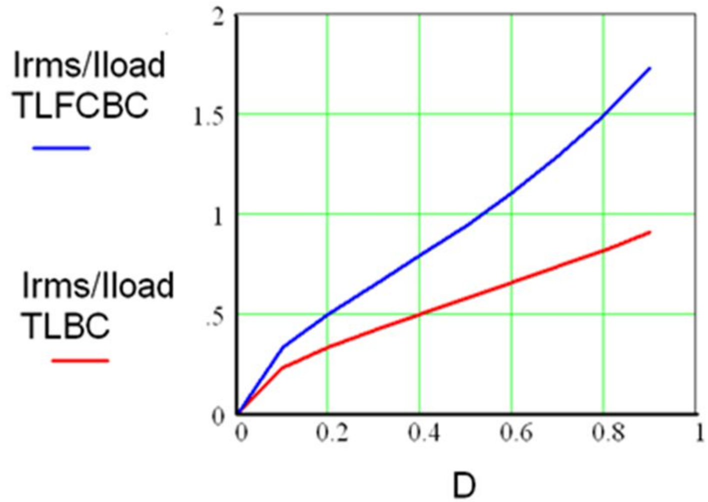
Core loss: BC vs TLBC



Capacitor RMS current: overlapping



Capacitor RMS current: non-overlapping



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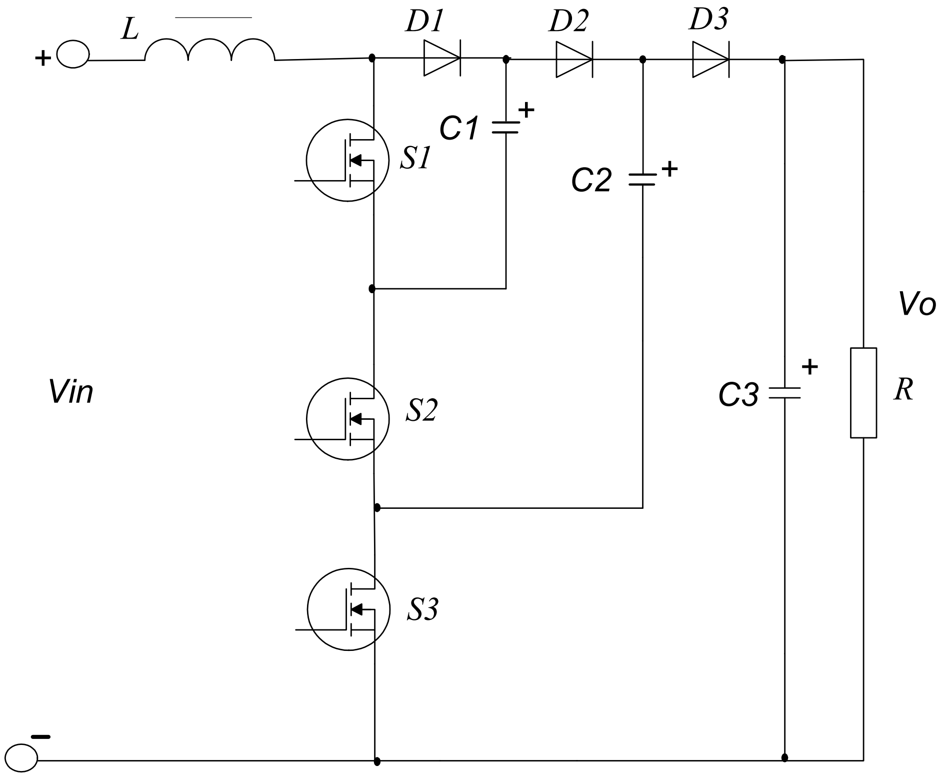
Four-level Flying Capacitor Boost Converter



$$D = t_i / (T / N)$$

- Definition of D

TFR for Non-overlapping control

$$V_o = 3V_{in} / (3 - 2D)$$

TFR for Overlapping control

$$V_o = 3V_{in} / (1 - D)$$

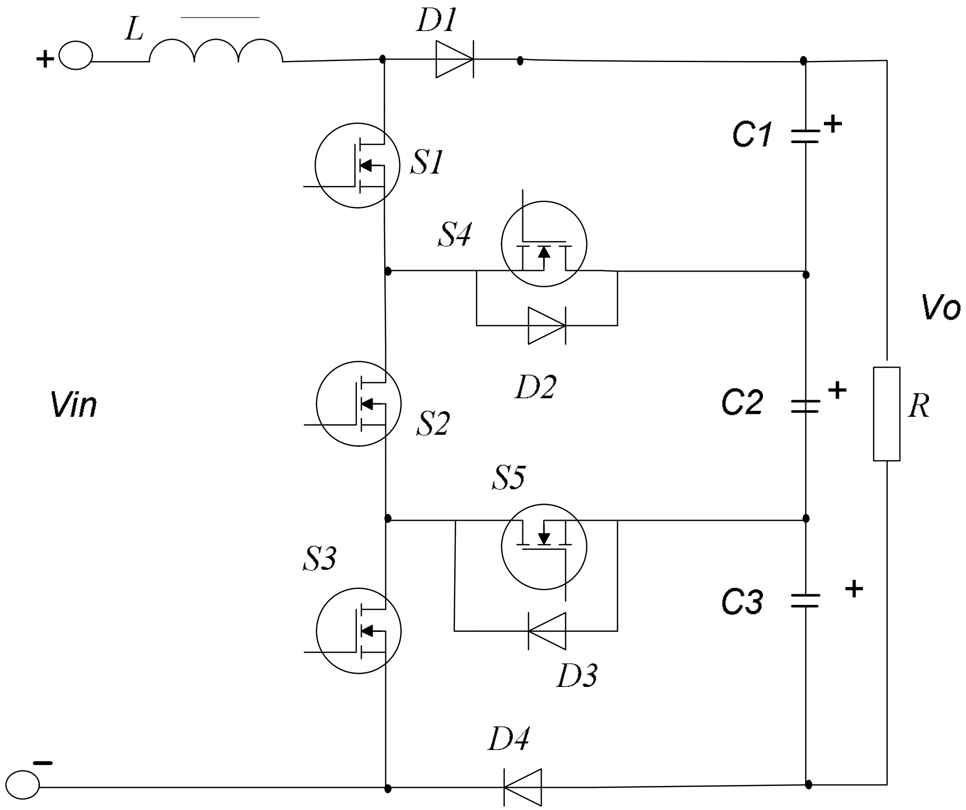
TFR for N-level converter with non-overlapping control

$$V_o = NV_{in} / (N - (N-1)D)$$

TFR for N-level converter with overlapping control

$$V_o = NV_{in} / (1 - D)$$

The same TFRs valid for Four-level Boost Converter



$$D = t_i / (T / N)$$ **- Definition of D**

TFR for Non-overlapping control

$$V_o = 3V_{in} / (3 - 2D)$$

TFR for Overlapping control

$$V_o = 3V_{in} / (1 - D)$$

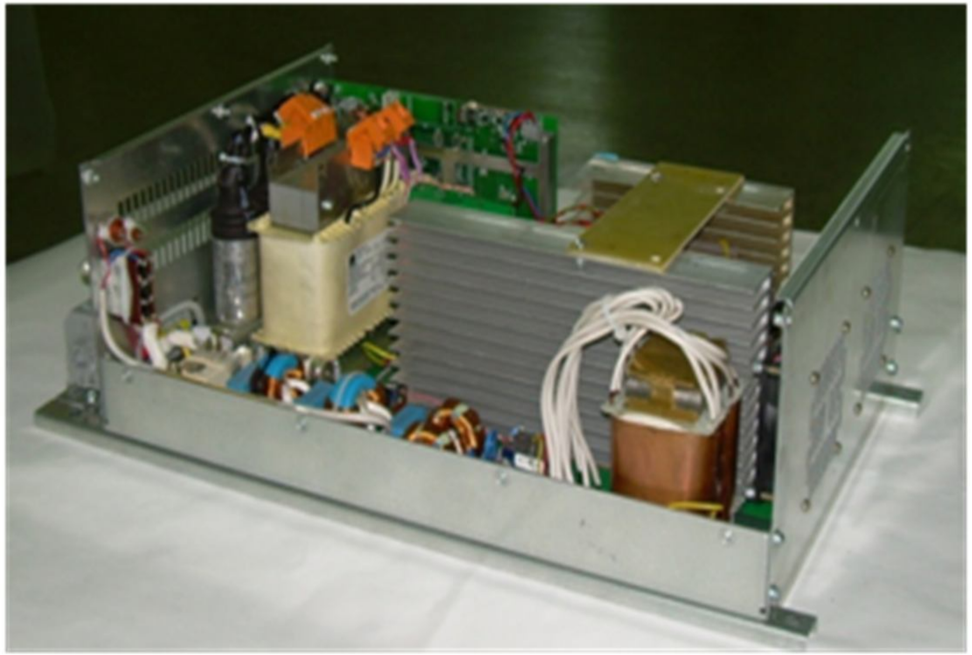
TFR for N-level converter with non-overlapping control

$$V_o = NV_{in} / (N - (N-1)D)$$

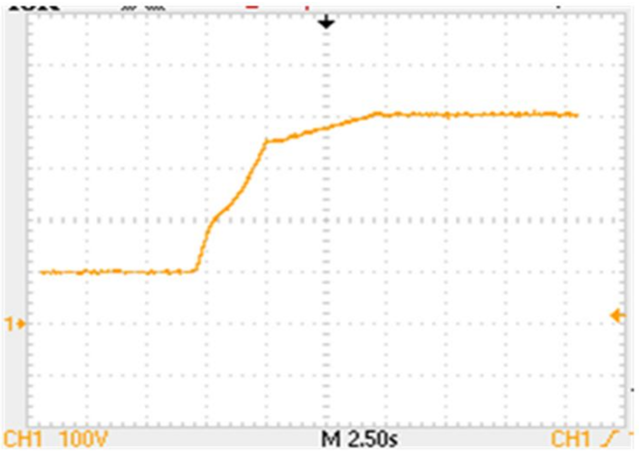
TFR for N-level converter with overlapping control

$$V_o = NV_{in} / (1 - D)$$

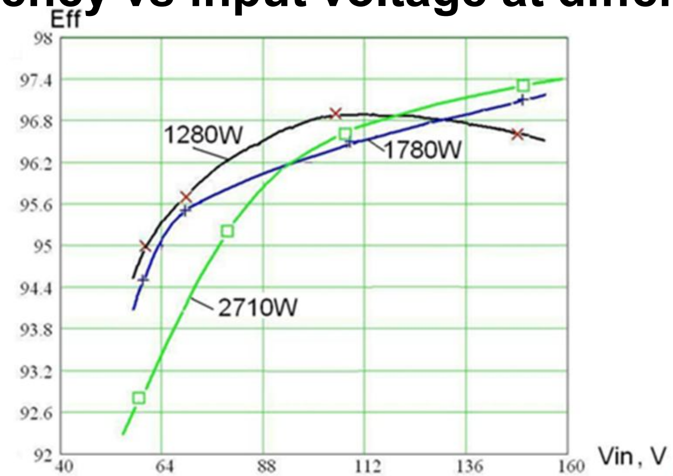
Prototype: Input 50V to 150V, Output 400V, 3kW



Start up waveform



Efficiency vs input voltage at different Pout



Conclusion and Acknowledgements

This topic is an attempt to outline key directions, solutions and implementations in Power using **multilevel boost converter and its supporting technologies.**

Obviously this talk is based on work and collective efforts of our colleagues at JSC "Electro C" and Texas Instruments to whom we extend our special thanks!