Leveraging efficiency in automotive on-board chargers

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Agenda

1	Introduction	
2	Single-phase chargers	
3	Three-phase chargers	
4	Case study and conclusion	

Agenda

System requirements

Power class?

Efficiency?

Bi-directional charging?
Vehicle-to-load?
Vehicle-to-Vehicle?
Vehicle-to-Grid?

AC charging?
DC charging?

Size?

Costs?

Battery voltages
400 V or 800 V?

Isolation requirements?

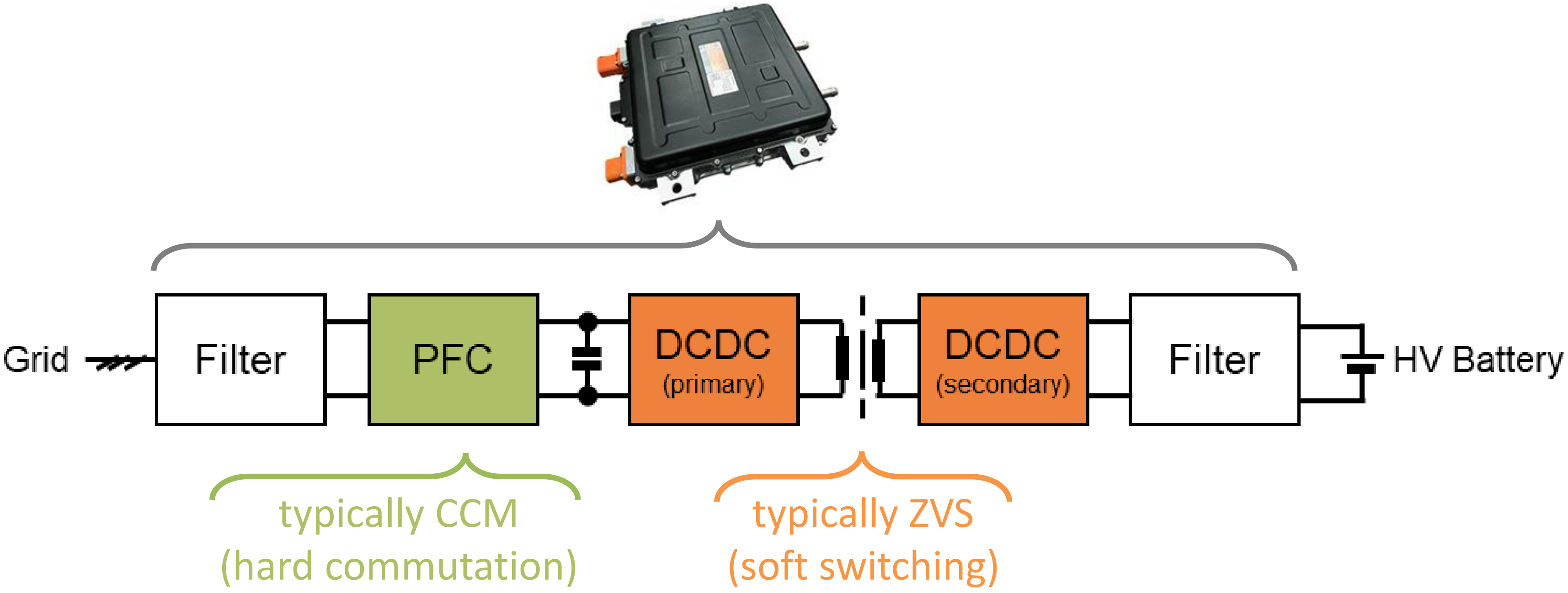
Reliability?

3 Phase AC?

1 Phase AC?

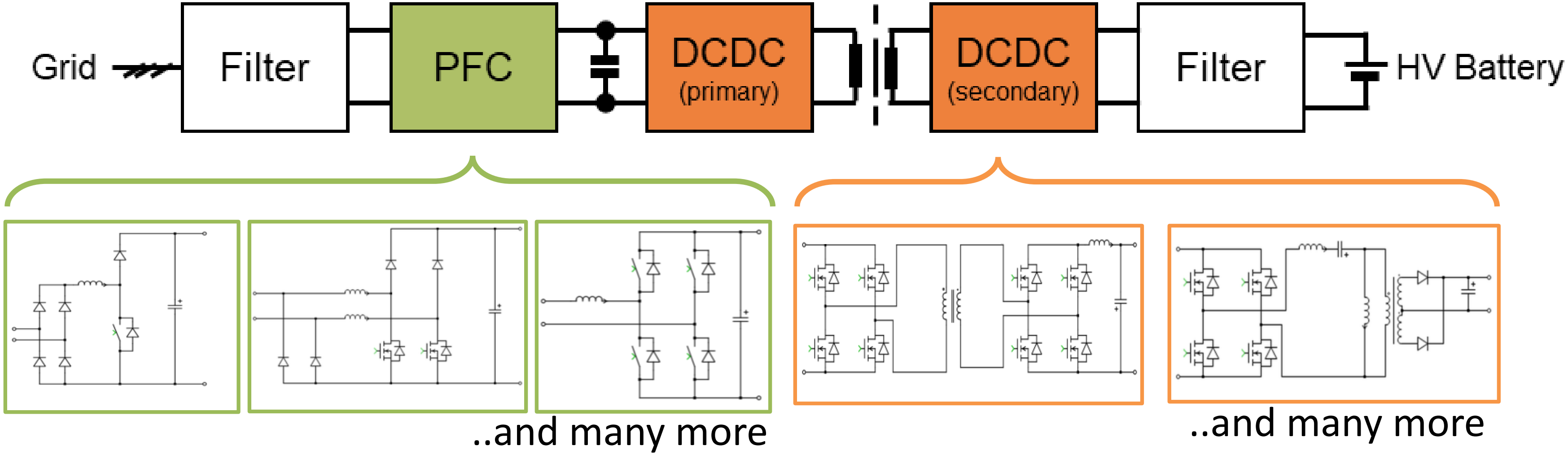
The system has to cover many different requirements

OBC block diagram



Typical OBCs are composed of a PFC block and an isolated DCDC block

Various topologies and semiconductor combinations possible



Final implementation depends on required functionality

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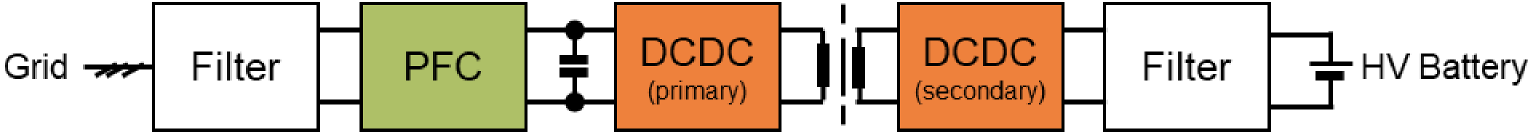
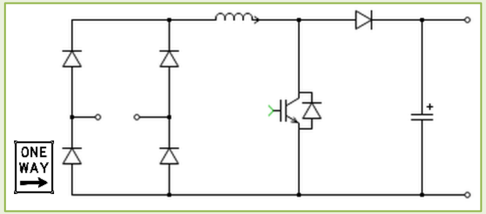
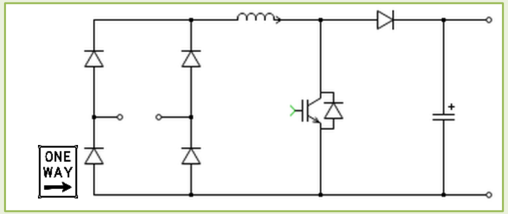
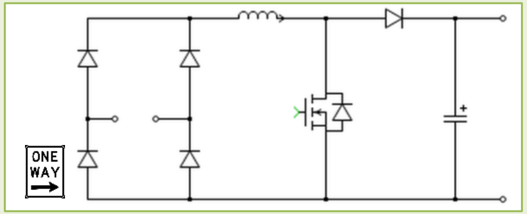
1ph

Classic-boost PFC



IGBT + PN D	IGBT + SiC D	CoolMOS™ + SiC D
97.9%	98.3%	98.4% *(3pin)* 98.5% *(4pin)*
1x PN diode 1x 650V IGBT with diode	1x 650 V SiC diode 1x 650 V IGBT with diode	1x 650 V SiC diode 1x 650 V CoolMOS™
		

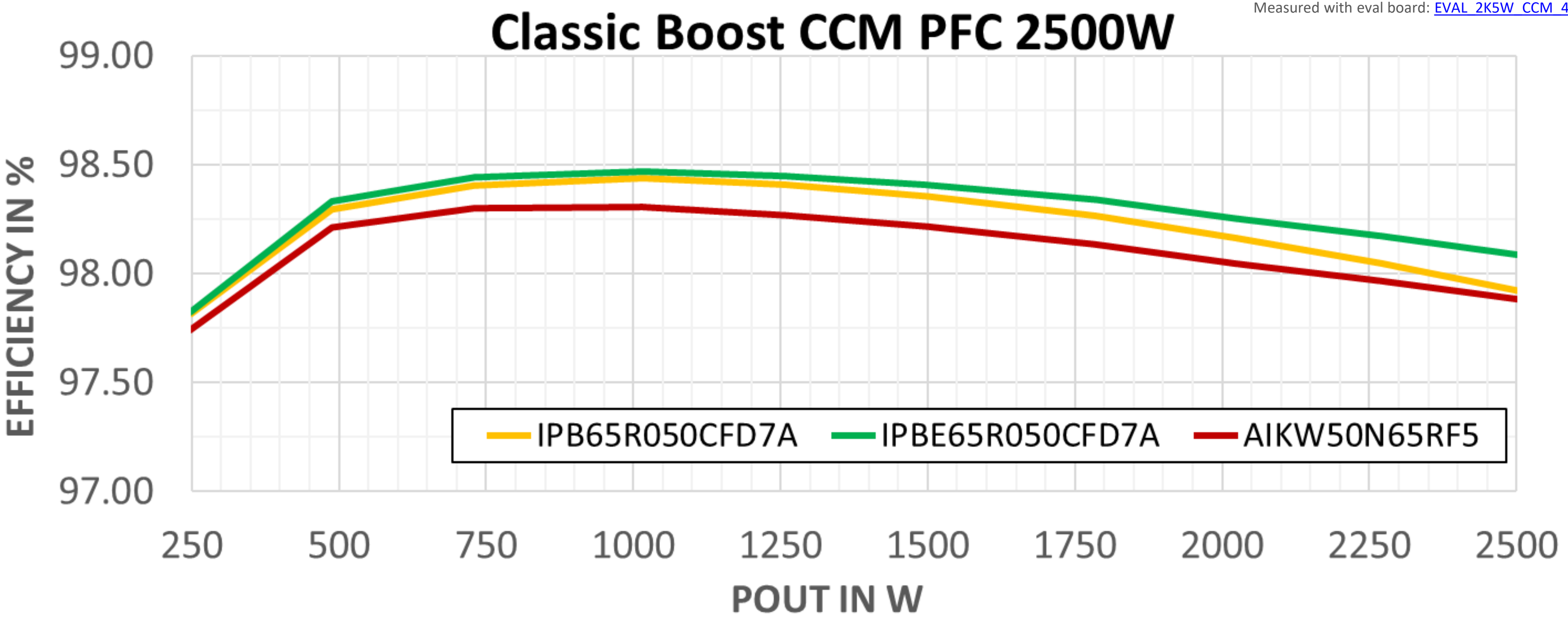
efficiency increase

measured on [EVAL_2.5KW_CCM_4PIN]

1ph

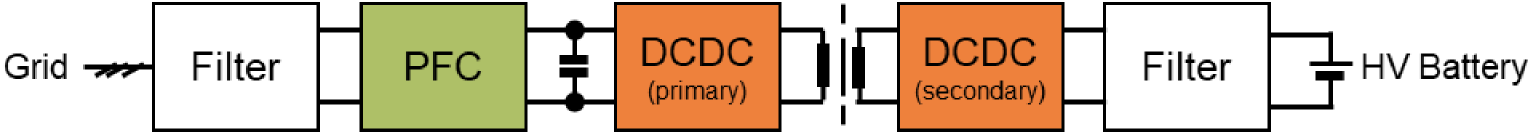
Efficiency measurement

Measured with eval board: [EVAL_2K5W_CCM_4P_V3]



1ph

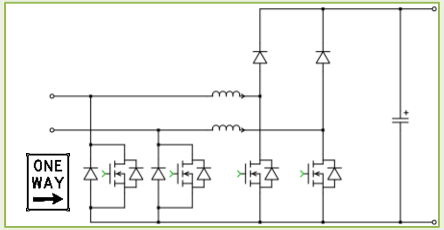
Dual-boost (bridgeless) PFC



650 V CoolMOS™ + SiC D

98.6%

2x 650 V SiC Diode
4x 650 V CoolMOS™
2x PN diodes



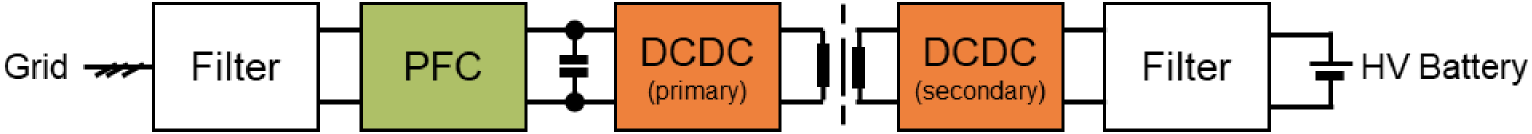
Very high efficiency

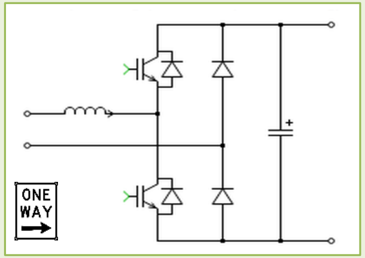
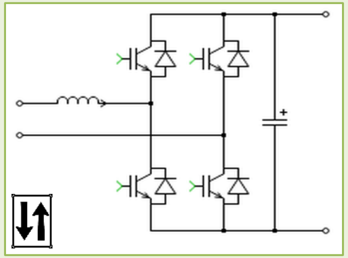
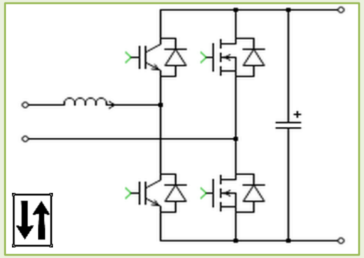
increased number of active switches

Measured on EVAL_3KW_DB_PFC_C7 with bypass transistors parallel to diodes

1ph

Totem Pole PFC



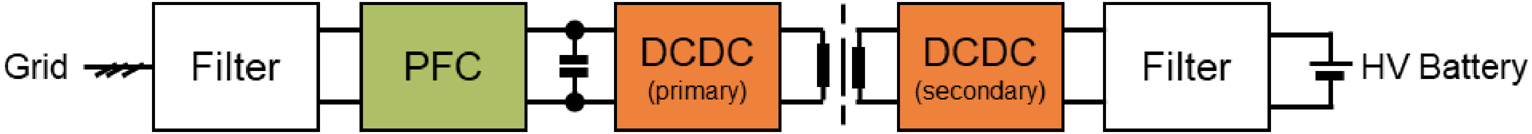
Half-bridge IGBT	Full-bridge IGBT	IGBT and CoolMOS™
98.7%	98.7%	98.8%
2x PN Diode 2x 650 V IGBT with diode	4x 650 V IGBT with diode	2x IGBT with diode 2x 650 V CoolMOS™ *)
		

*) as long as hard commutation on the body diode is avoided

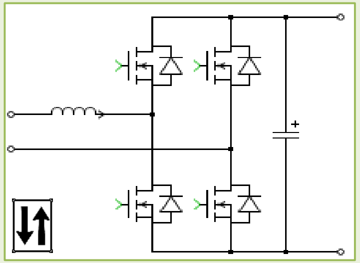
efficiency increase

1ph

TCM PFC (soft-switching)



650 V CoolMOS™ + SiC D
99.1%
> 4x 650 V CoolMOS™



Measured on TCM_PFC

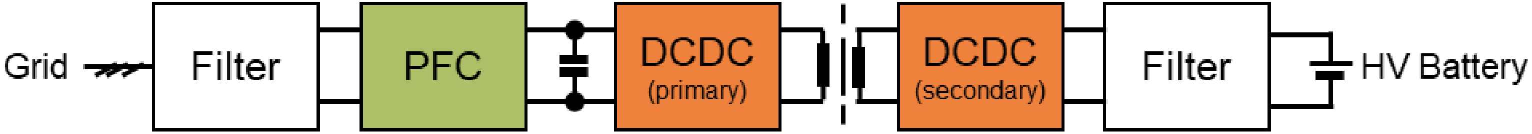
Highest performance with Silicon devices

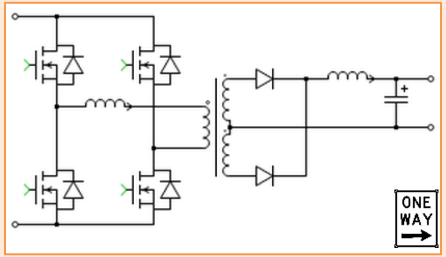
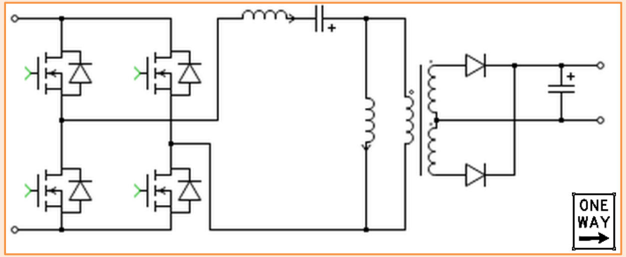
High control complexity

Interleaving required

1ph

DCDC (soft-switching)

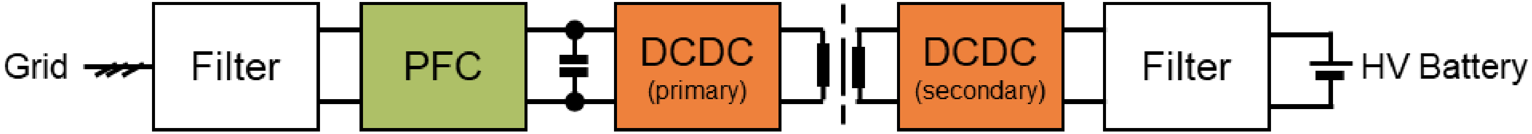


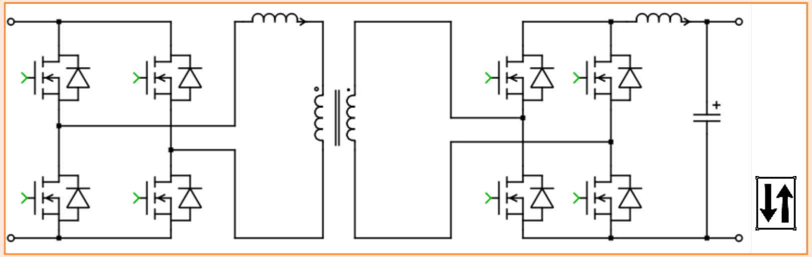
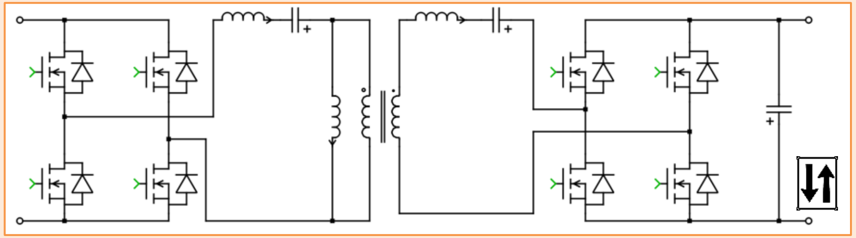
Phase-shifted full-bridge	Full-bridge LLC
98.1%	98.5%
4x 65 0V CoolMOS™ 2x PN diodes (with ctr-tap)	4x 650 V CoolMOS™ 2x PN diodes (with ctr-tap)
	

efficiency increase

1ph

DCDC (soft-switching)



Phase-shifted full-bridge	Full-bridge cLLC
98.1%	~98.3%
8x 650 V CoolMOS™	8x 650 V CoolMOS™
	

efficiency increase

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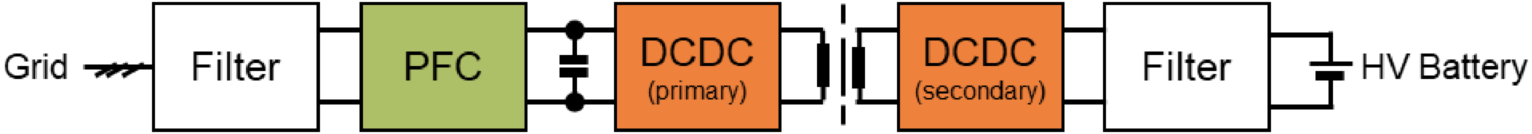
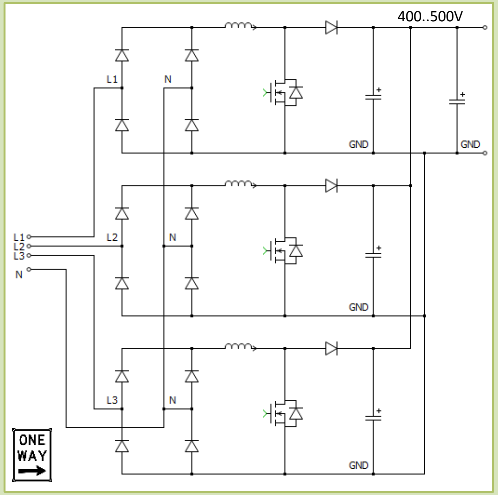
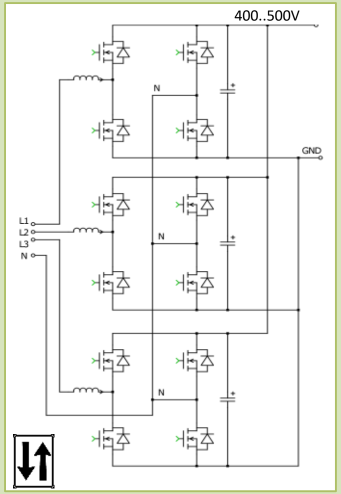
3ph

Stacked PFC

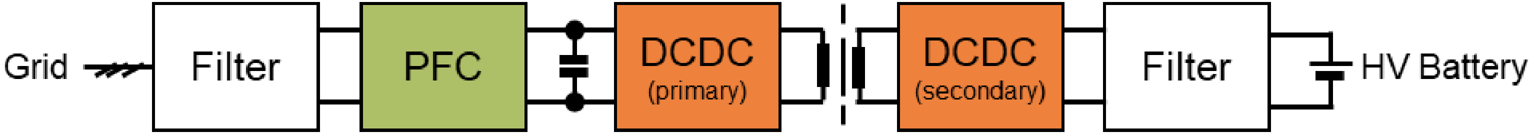


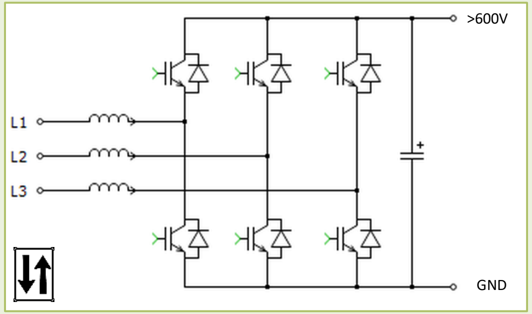
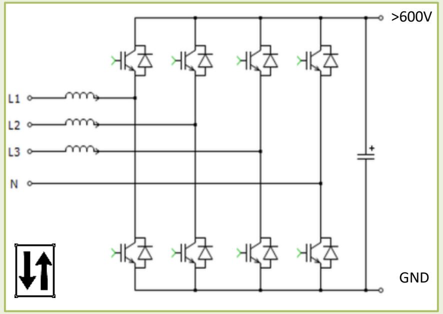
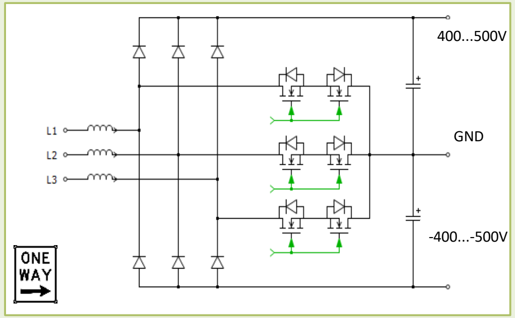
Stacked classic boost		IGBT + SiC D	
12x PN Diodes 3x 650 V SiC diode 3x 650V CoolMOS™ Alternatively: 3x 650 V IGBT		12x 650 V IGBT Alternatively: 6x 650 V IGBT 6x 650 V CoolMOS™	

efficiency increase

3ph

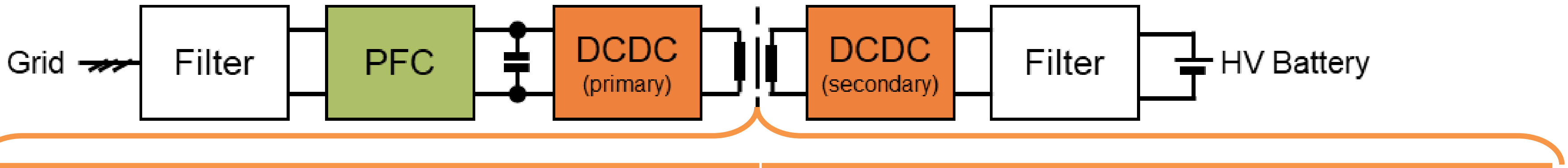
PFC with higher DC-link



3ph full-bridge PFC	3ph full-bridge PFC + N	Vienna Rectifier
6x 1200 V SiC MOSFET	8x 1200 V SiC MOSFET	6x 650 V IGBT or CoolMOS™ 6x 1200 V SiC Diode
		

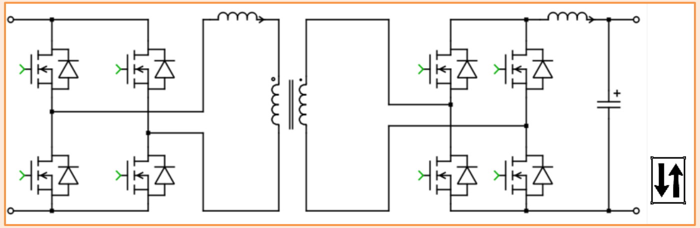
3ph

DCDC for 3ph OBCs

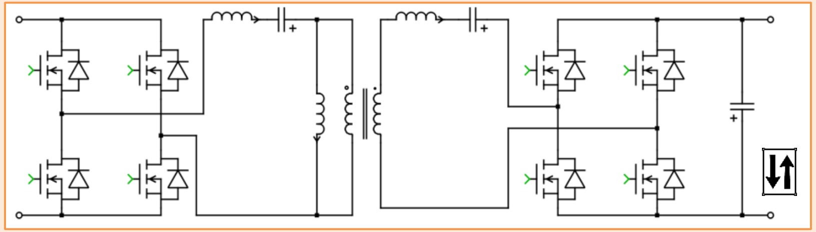


Single-stage

PSFB:



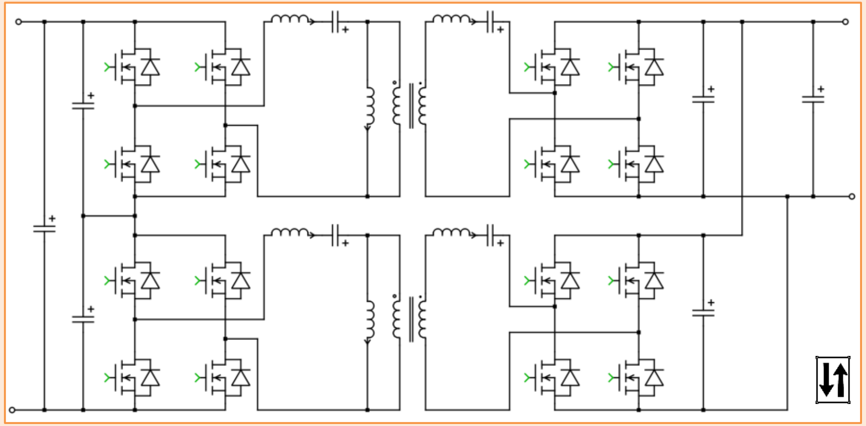
CLLC:



8x 1200 V SiC MOSFET

Stacked DCDC

Stacked CLLC with split DC-link:



16x 650 V CoolMOS™

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Case study: OBC efficiency today

EV	Charge standard	Charge power	Energy Efficiency		
			η_3	$\eta_{2,E}$	$\eta_{1,E}$
iOn	10 A @ 1 phase	2.3 kW	77 %	70 %	79 %
iOn	16 A @ 1 phase	3.7 kW	75 %	69 %	77 %
LEAF	10 A @ 1 phase	2.3 kW	74 %	85 %	
LEAF	16 A @ 1 phase	3.7 kW	70 %	90 %	
Zoe	10 A @ 1 phase	2.3 kW	49 %		
Zoe	16 A @ 3 phase	11 kW	64 %		
Zoe	32 A @ 3 phase	22 kW	65 %		
Zoe	63 A @ 3 phase	43 kW	63 %		

Highest efficiency in their experiment

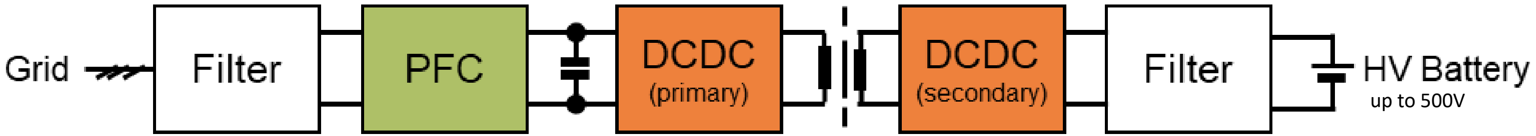
Source: Kieldsen, Andreas; Thingvad, Andreas; Martinenas, Sergejus; Sørensen, Thomas Meier, *Proceedings of EVS29 - International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium*, 2016.

$\rightarrow \eta_{OBC\_max} = 95\%$

efficiency from typical OBC spec of today

Today's OBCs require only moderate efficiency values

Which combinations do the job?

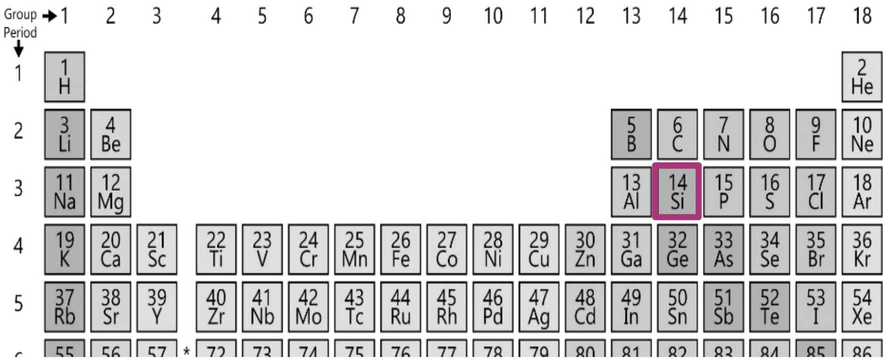


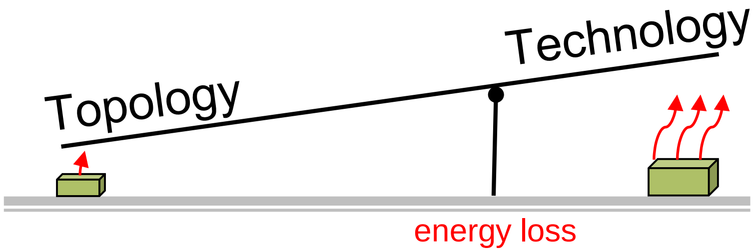
$\eta_{req} = 95\%$

Topology	Technology	η	Topology	Technology	η	η_{OBC}	ok?
Classic-boost	IGBT + SiC D	98.3%	PSFB	CoolMOS™	98.1%	96.4%	✓
Dual-boost	CoolMOS™ + SiC D	98.6%	LLC	CoolMOS™	98.5%	97.1%	✓
Totem-Pole	IGBT + CoolMOS™	98.8%	LLC	CoolMOS™	98.5%	97.3%	✓

Smart topology choices with Silicon power devices do a great job!

Conclusion





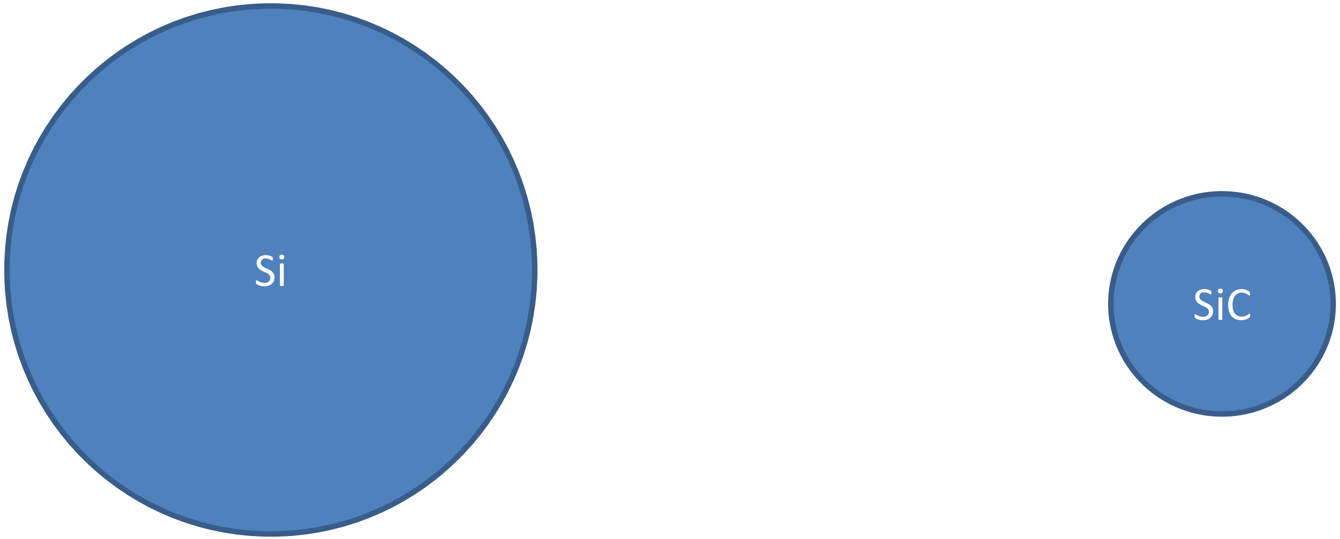
Today’s efficiency requirements are achievable with economic device choices

Stacking of single-phase topologies for 3phase systems allow usage of 650 V devices

Leverage efficiency by changing the topology (rather than just changing the power device technology)

Backup slides

Manufacturing



Lower manufacturing complexity
Lower costs for base material
20 years+ experience

Better Figure-of-Merits (for some parameters)
Higher manufacturing complexity
Higher costs for base material