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High Efficiency, Compact On-Board Chargers for Industrial Electric Vehicles

Wayne Salata

Power Discrete Group – Technical Marketing

Agenda

1 Introduction: Industrial On-Board Chargers

2 Typical Architecture

3 Topologies & ST Evaluation Boards

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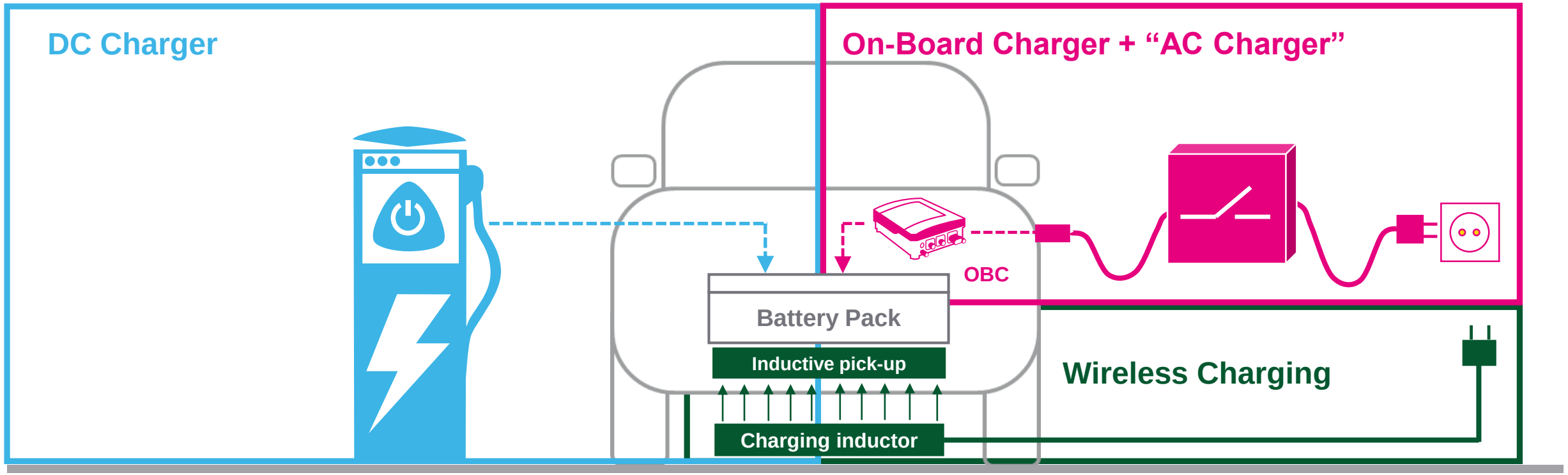
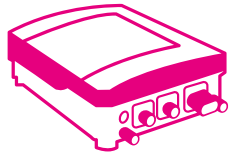
How to charge an electrical vehicle?



On Board Charger



Advantages:
+ Battery Compatible
+ Ease of use

Challenges:
* Cooling concept
* Mechanical Robustness
* Grid Configuration
* Reduced volume and weight

SiC!

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EVs: Many more applications beyond cars

Industrial Vehicles

Transition to greener platforms everywhere:

- Locally **CO2 neutral**;
- **Less noise** from EVs than combustion engines.

Shift from lead-acid to lithium-ion batteries:

- Larger storage capacity → **Longer Autonomy**
- Higher voltages → **Shorter charging time.**

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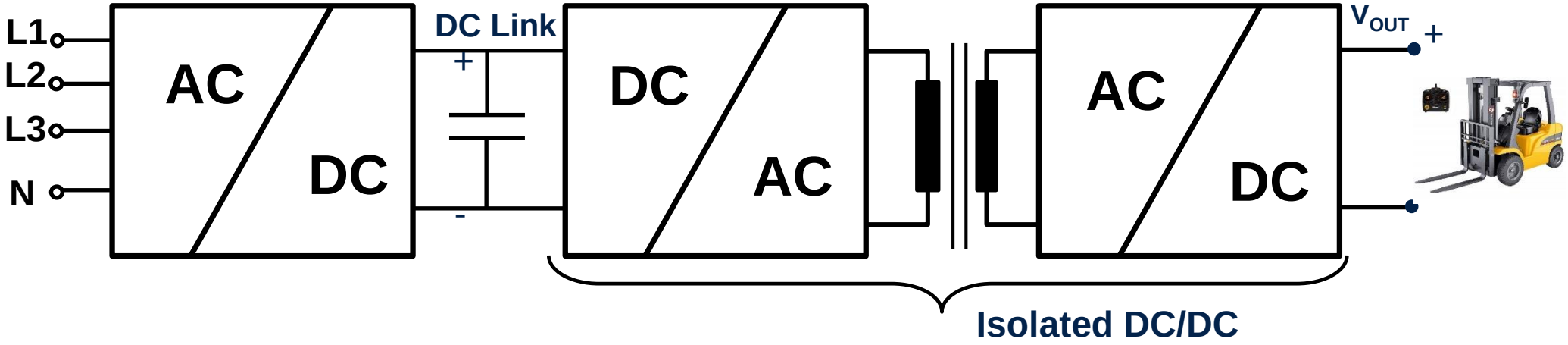
Industrial On-Board Charger

System Concept

3-ph Outlet



Parameter	Value
Input voltage	L_x-L_y → 400 V_{AC} L_x-N → 230 V_{AC}
DC Link Voltage	400..1000 V
Nominal Power	11..22 kW
Output Voltage	200..500 V_{DC} for 400 V_{DC} Batteries 500..900 V_{DC} for 800 V_{DC} Batteries

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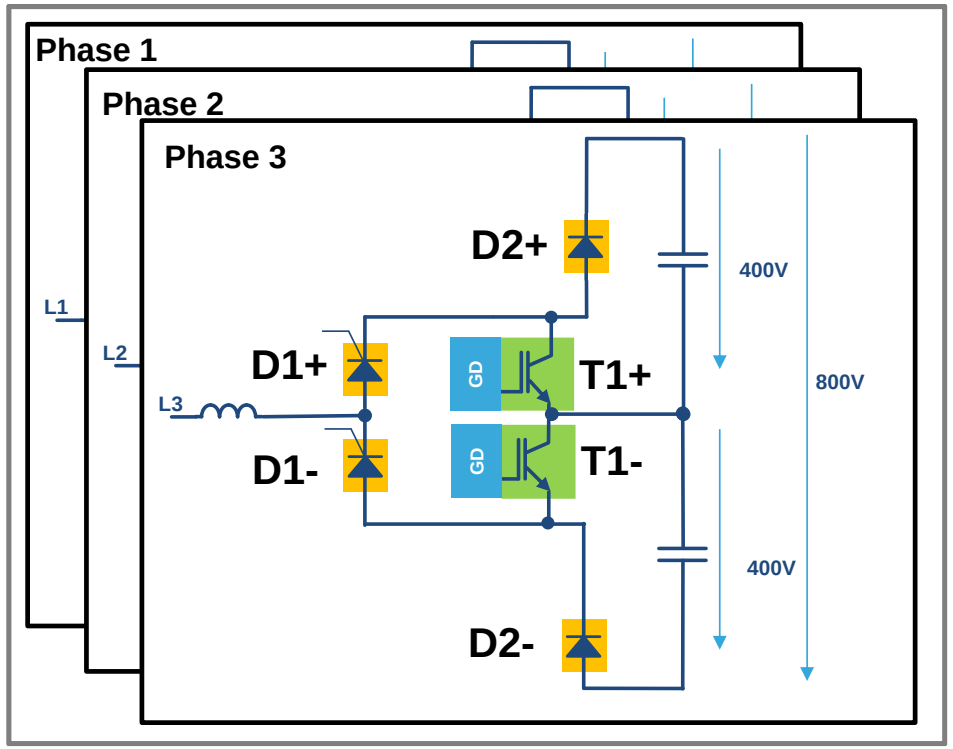
AC/DC concepts

3-Level 3-Phase

Example: Modified Vienna Type 1



+ 650V Si Switches.

- 6 devices / phase.

3x Independent 1-phase

Example: 3x PFC Booster

+ 4 devices / phase
+ Flexible grid configuration

- May need of 1200V SiC switches*
* In order to accomplish battery voltage requirements.

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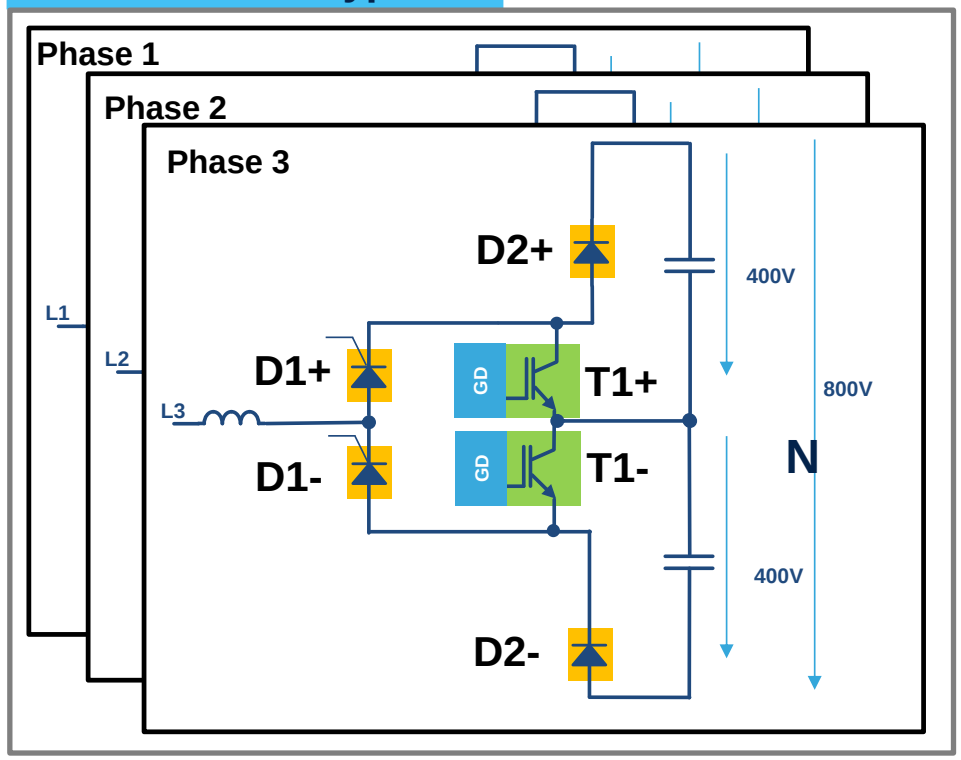
Modified Vienna Rectifier topology comparison

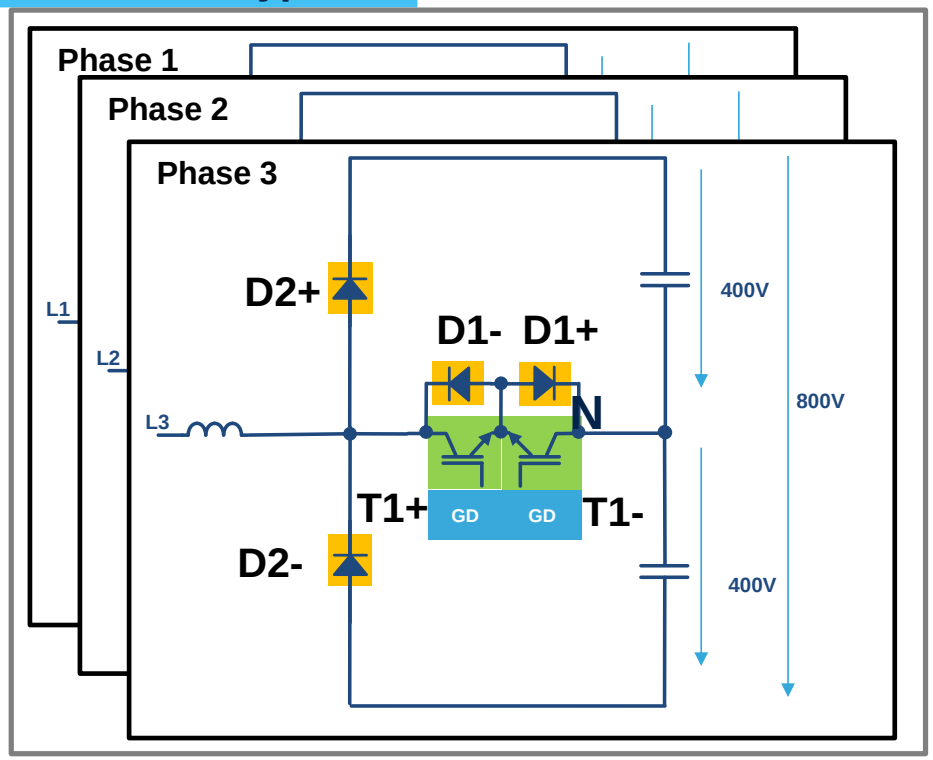
Mod. Vienna Type 1



+ All 650V rated devices
→ lower cost

- 2 devices in the main current path (D1&D2)
→ lower efficiency

Mod. Vienna Type 2



+ 1 devices in the main current path (D2)
→ Higher efficiency

- Need 1200V diodes (D2), typically SiC.
→ Higher cost

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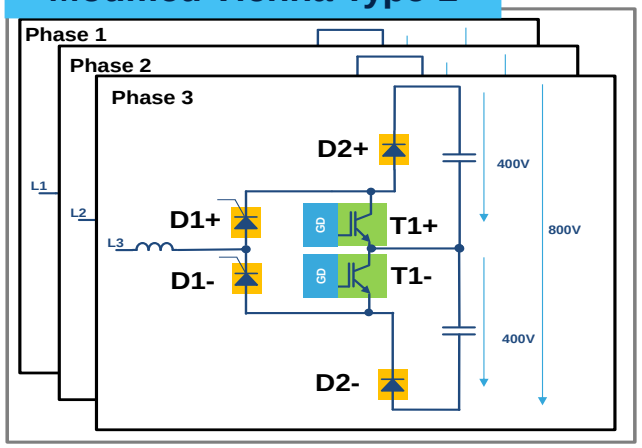
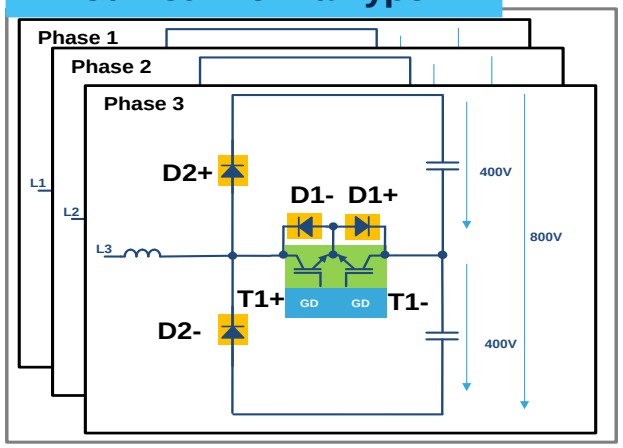
Modified Vienna Rectifier: device proposal

Modified Vienna Type 1



	Required Semiconductor	ST Solution
D1	Rectifier SCR	STBRxx12W TNxx50H-12WY
T1	650V IGBT 650V SJ POWER MOSFET 650V SiC POWER MOSFET	STGWAxxH65DFB2 STWxxN65M5 SCTWxxN65G2V
D2	600V FRD 650V SiC Diodes	STTHxxRQ06 STPSCxx065C
GD	Isolated driver	STGAP2S
	Control	STM32 (Digital) STNRGPF0x (Mixed mode)

Modified Vienna Type 2



	Required Semiconductor	ST Solution
T1/D1	650V IGBT 650V SJ POWER MOSFET 650V SiC POWER MOSFET	STGWAxxH65DFB2 STWxxN65M5 SCTWxxN65G2V
D2	1200V SiC Diode	STPSC40H12C
GD	Isolated driver	STGAP2S
	Control	STM32 (Digital) STNRGPF0x (Mixed mode)

xx→ Current class
x → Family name

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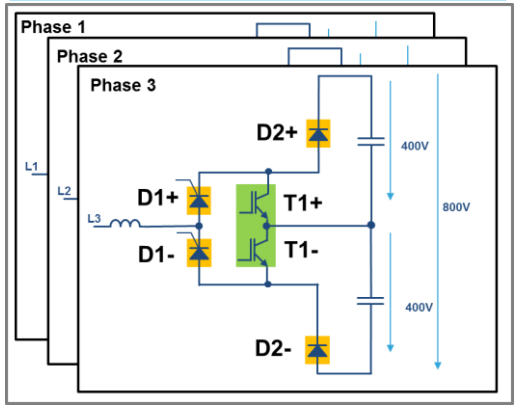
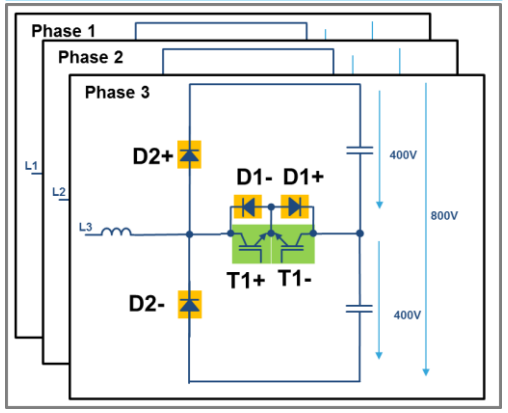
Topology efficiency comparison @ P_{out}=20 kW

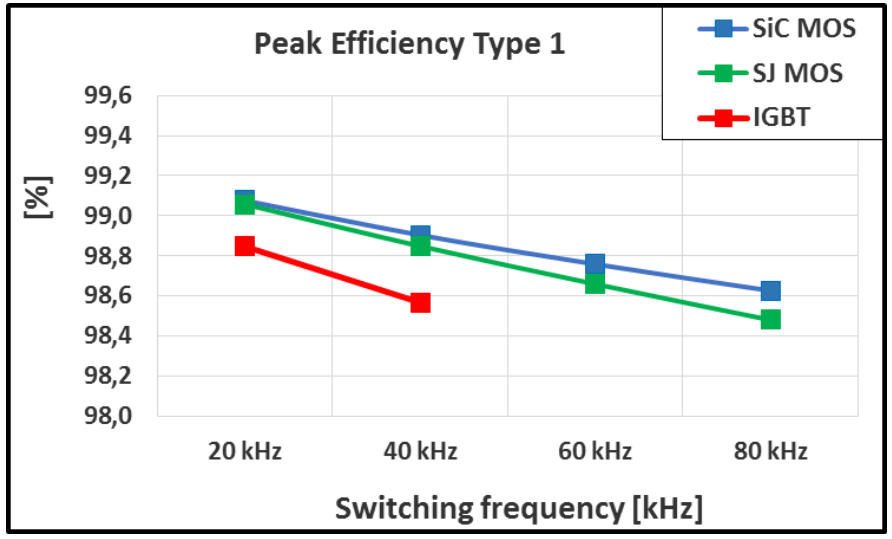
Vienna rectifier Type 1

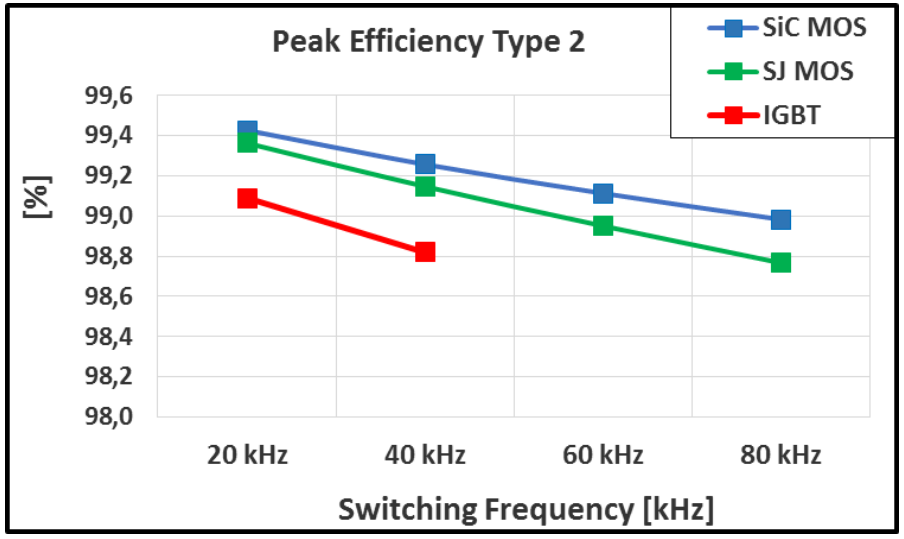


Vienna rectifier Type 2



	Mod. Vienna Type 1	Mod. Vienna Type 2
D1	STBR6012W	---------
T1	STGW40H65DFB-4 STW88N65M5-4 SCTW90N65G2V-4	
D2	STPSC40065C	STPSC40H12C





Simulated efficiency @ T_j = 125°C, considering only semiconductor losses.

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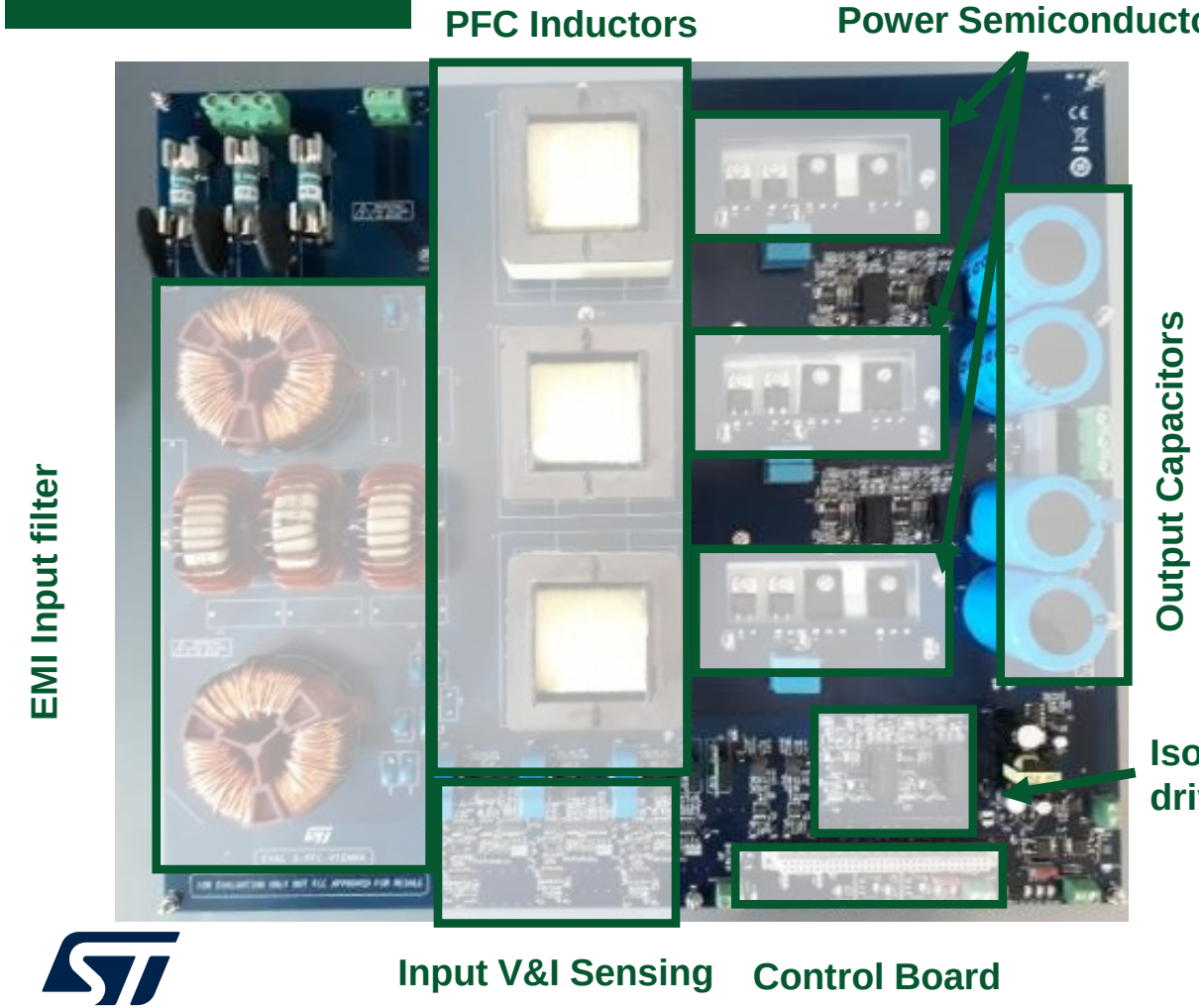
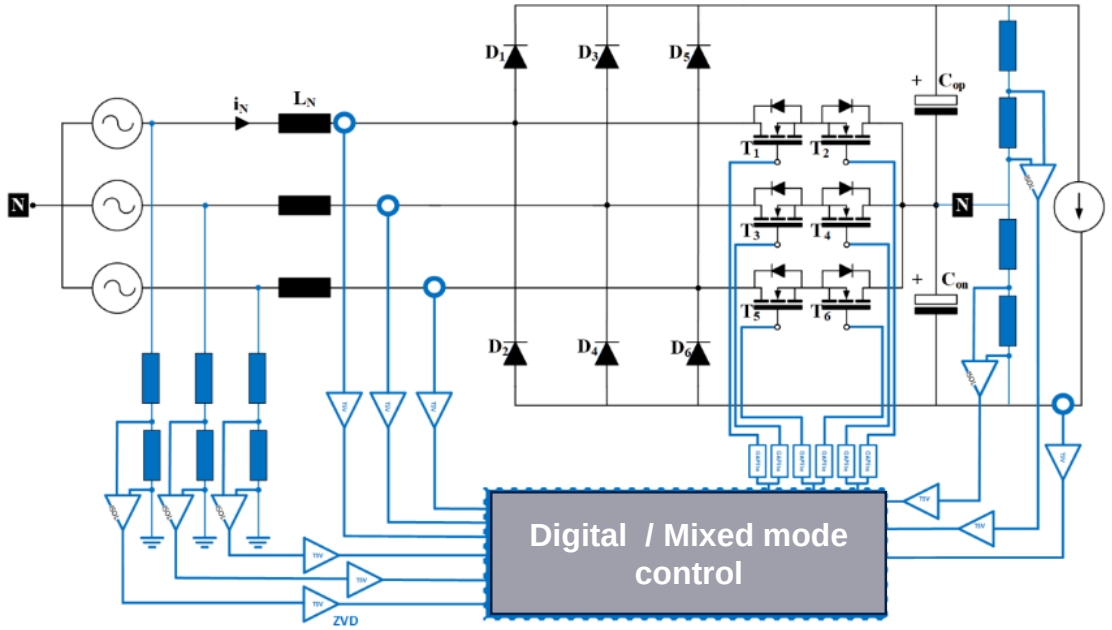
Evaluation Board 1: Modified Vienna Type 2

Documentation Available!



15 kW 3-ph PFC Converter



ST Solutions:

- SCTW35N65G2V (SiC MOSFET);
- STPSC20H12 (SiC Diode);
- STNRGPF0x (mixed mode controller, in development);
- STM32G474 (microcontroller);
- STGAP2S (Gate Driver).

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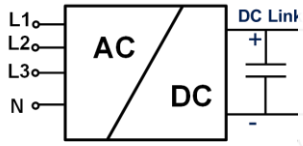


AC/DC concepts

3-Level 3-Phase

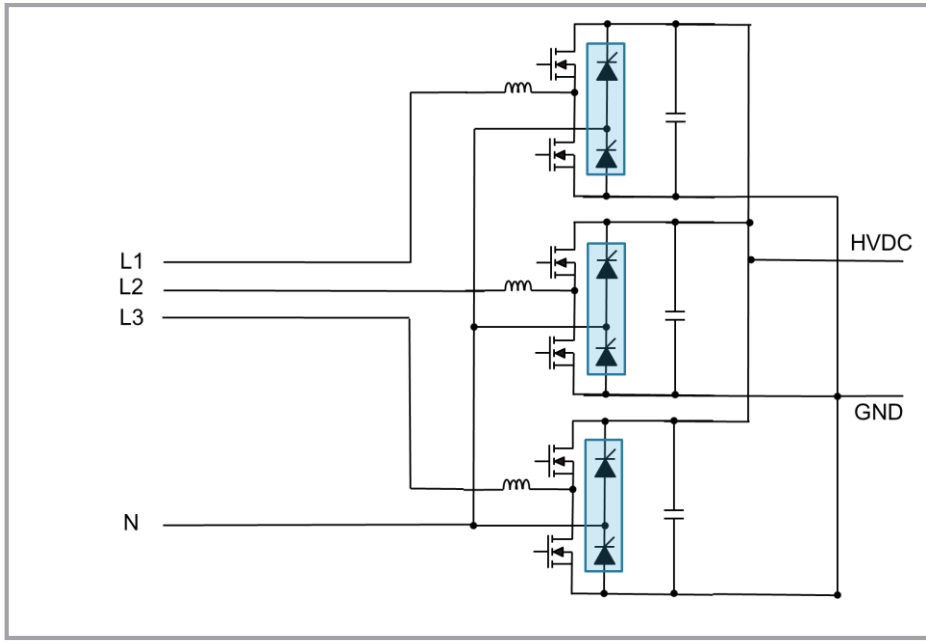
Example: Modified Vienna Type 1

+ 650V Si Switches.

- 6 devices / phase.

3x Independent 1-phase

Example: 3x PFC Booster



+ 4 devices / phase

+ Flexible grid configuration

- May need of 1200V SiC switches*

* In order to accomplish battery voltage requirements.

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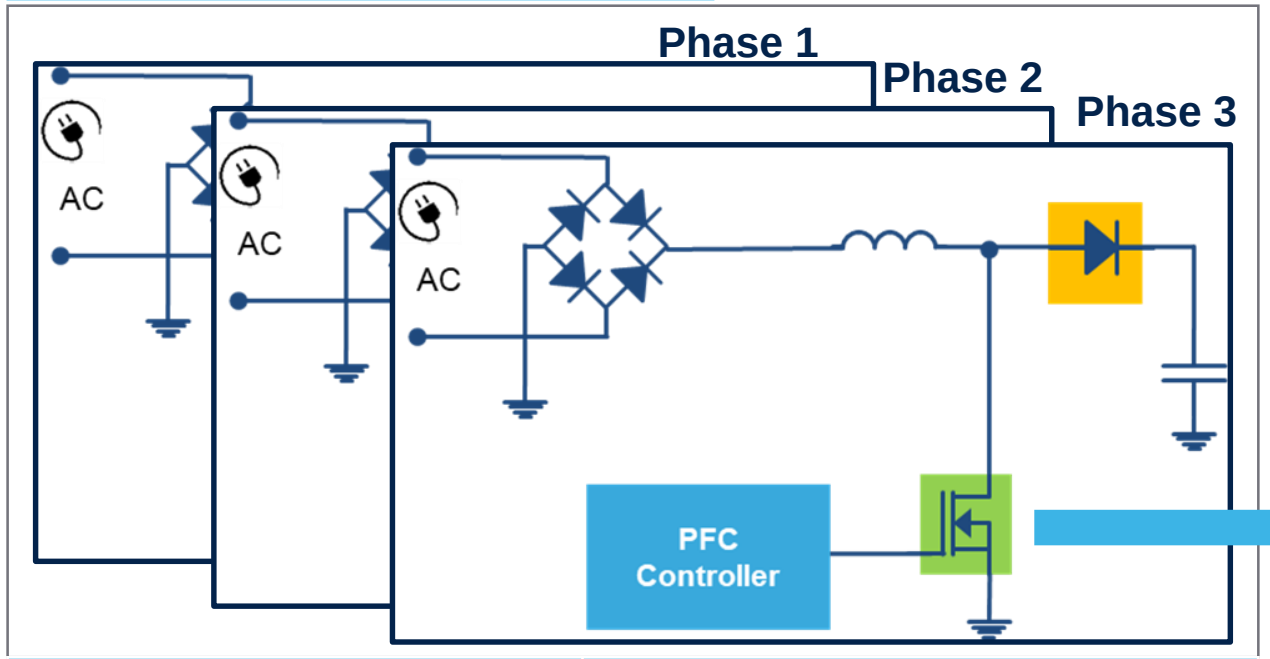
3x 1-Phase Topologies: Standard PFC

Booster PFC



1200V SiC MOSFET
Due to high DC link voltage.

Required Semiconductor	ST Solution
Rectifier SCR	STBRxx12W TNxx50H-12WY
1200V SiC POWER MOSFET	SCTxxN120
1200V SiC Diodes	STPSCxxH12C
Isolated driver	STGAP2S
Control	STM32 (Digital) STNRGPF0x (Mixed mode)

xx→ Current class
x → Family name

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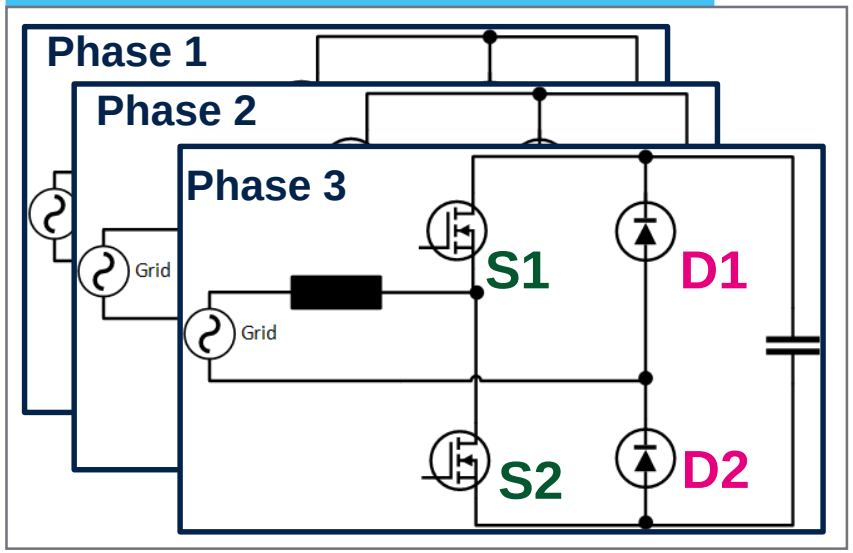
Bridge-less topologies: Totem Pole PFC

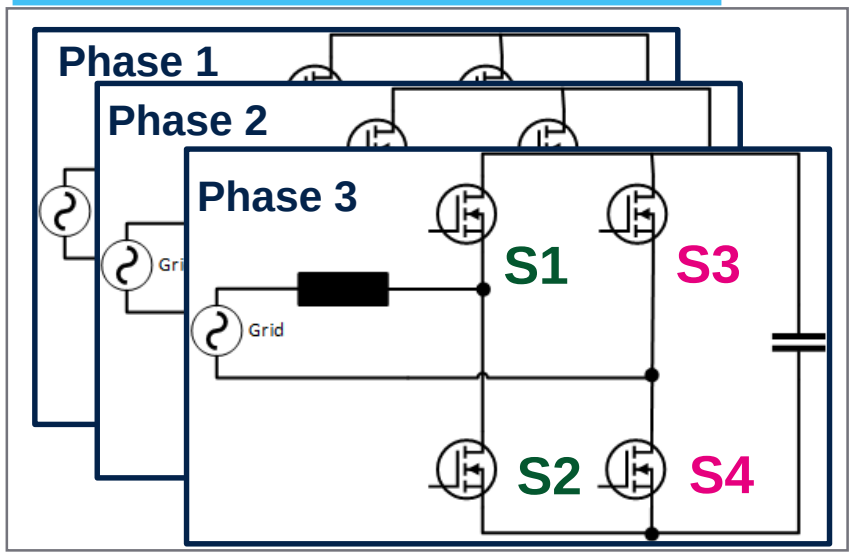
SiC MOSFET mandatory due high DC Voltage and body diode robustness.

Var. 1 – Cost – Diode Leg



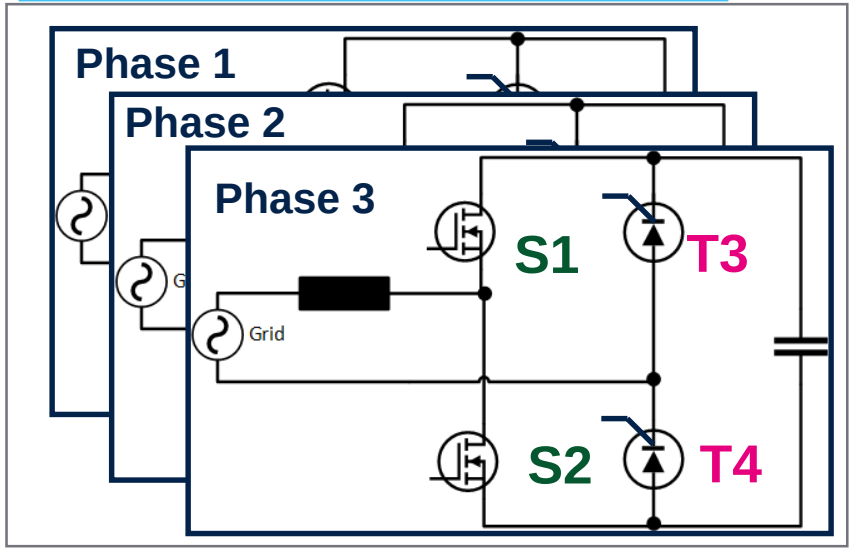
Device	Technology	ST Proposal
S1/S2	1200V SiC MOS	SCTxxN120
D1/D2	1200V Rectifier	STBRxx12W
	Driver	STGAP2S/D
	Control	STM32

Var. 2 – Performance – SiC MOS Leg



Device	Technology	ST Proposal
S1/S2	1200V SiC MOS	SCTWxxN120
S3/S4	1200V SiC MOS	SCTxxN120
	Driver	STGAP2S/D
	Control	STM32

Var. 3 – Relay-less – SCR Leg



Device	Technology	ST Proposal
S1/S2	1200V SiC MOS	SCTxxN120
T3/T4	1200V SCR	TNxx50-12PI
	Driver	STGAP2S/D
	Control	STM32

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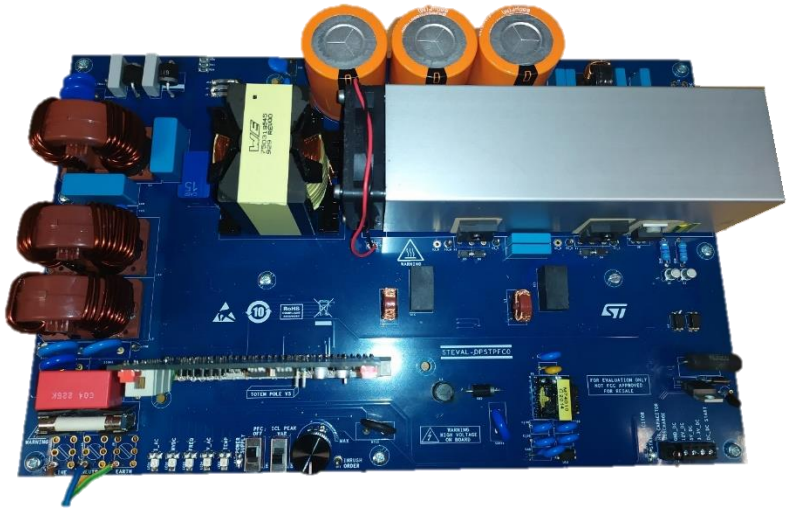
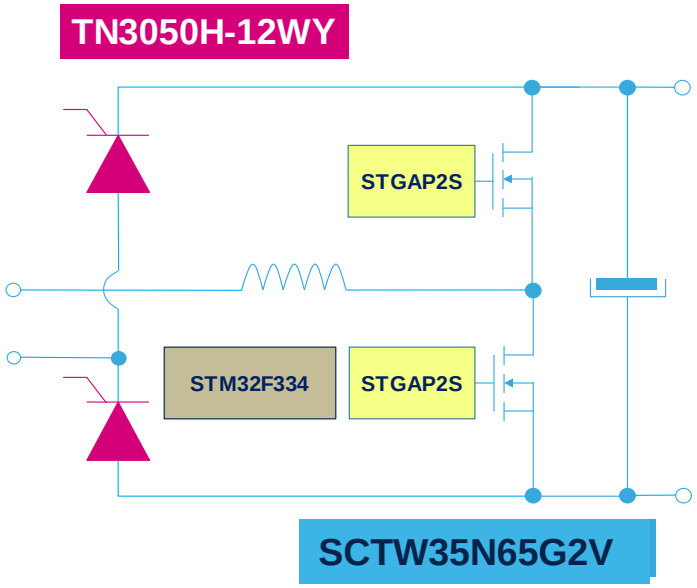
Evaluation Board 2: 3.6 kW Totem Pole PFC

Available Q2/20





Key Products

- **TN3050H-12WY → SCR in the Bridge**
- **SCTW35N65G2V → 650V SiC MOSFET**
- **STGAP2S → Isolated Gate Driver**
- **STM32 → 32-bit Microcontroller)**
- **VIPER26LD → HV Converter Controller**

Main Features

- Input AC voltage: 85VAC up to 264VAC
- DC output voltage: 400VDC
- Switching frequency: 72 kHz
- Maximum input current: 16 A RMS (POUT = 3.6KW)
- Efficiency: > 97,5%
- THD < 10 %
- Remove two bulky relays and an NTC resistor thanks to SCRs progressive start-up

- Compliant to :
  - **EN 55015 and IEC 61000-4-11 and IEC 61000-3-3**
  - **IEC 61000-4-5 surge: 4kV**
  - **IEC 61000-4-4 EFTY burst : criteria A @ 4kV min**
- Design for operation with DC/DC converter
- Peak inrush current tuning

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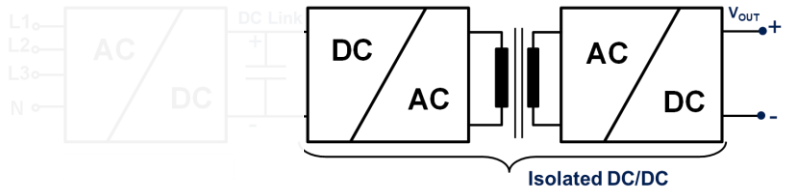
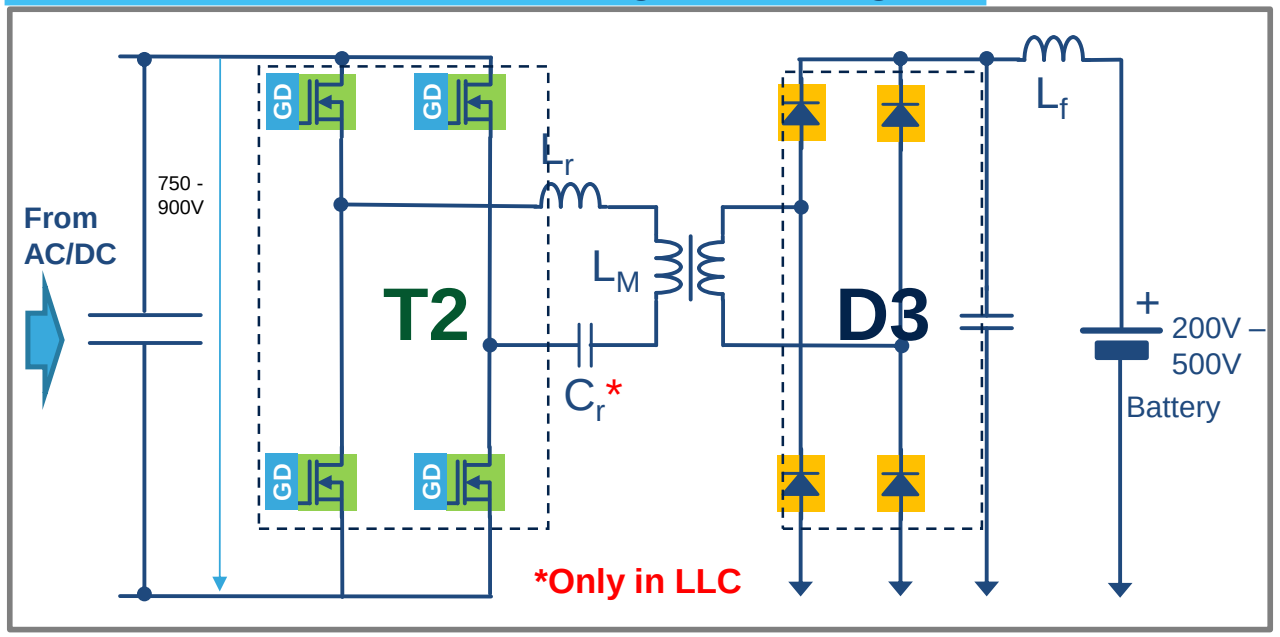


DC/DC stage topologies: Resonant LLC / ZVS or DAB

1200V SiC MOSFET due to robust diode, low $R_{ds,on.}$

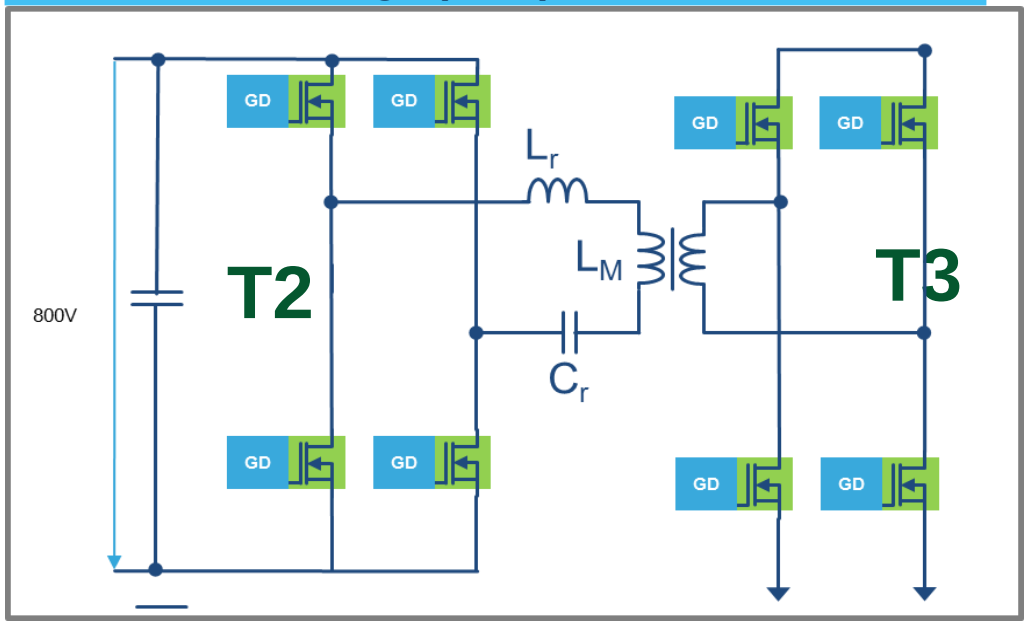
Resonant LLC / Zero Voltage Switching



Device	Technology	ST Solution
T2	1200V SiC POWER MOSFET	SCTxxN120
D3	600V FRD 1200V SiC Diodes	STTHxxRQ06 (LLC) STPSCxxH12C (ZVS)
GD	Isolated Driver	STGAP2S/D
Control	Microcontroller	STM32 (Digital)

Bi-directionality when needed.

Dual Active Bridge (DAB) / Bi-directional LLC



Device	Technology	ST Solution
T2	1200V SiC POWER MOSFET	SCTxxN120
T3	650V SiC POWER MOSFET 1200V SiC POWER MOSFET	SCTxxN65G2V [400V Batt.] SCTxxN120 [800V Batt.]
GD	Isolated Driver	STGAP2S/D
Control	Microcontroller	STM32 (Digital)

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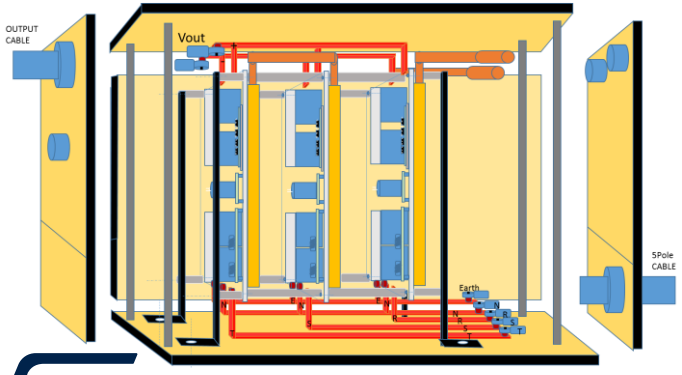
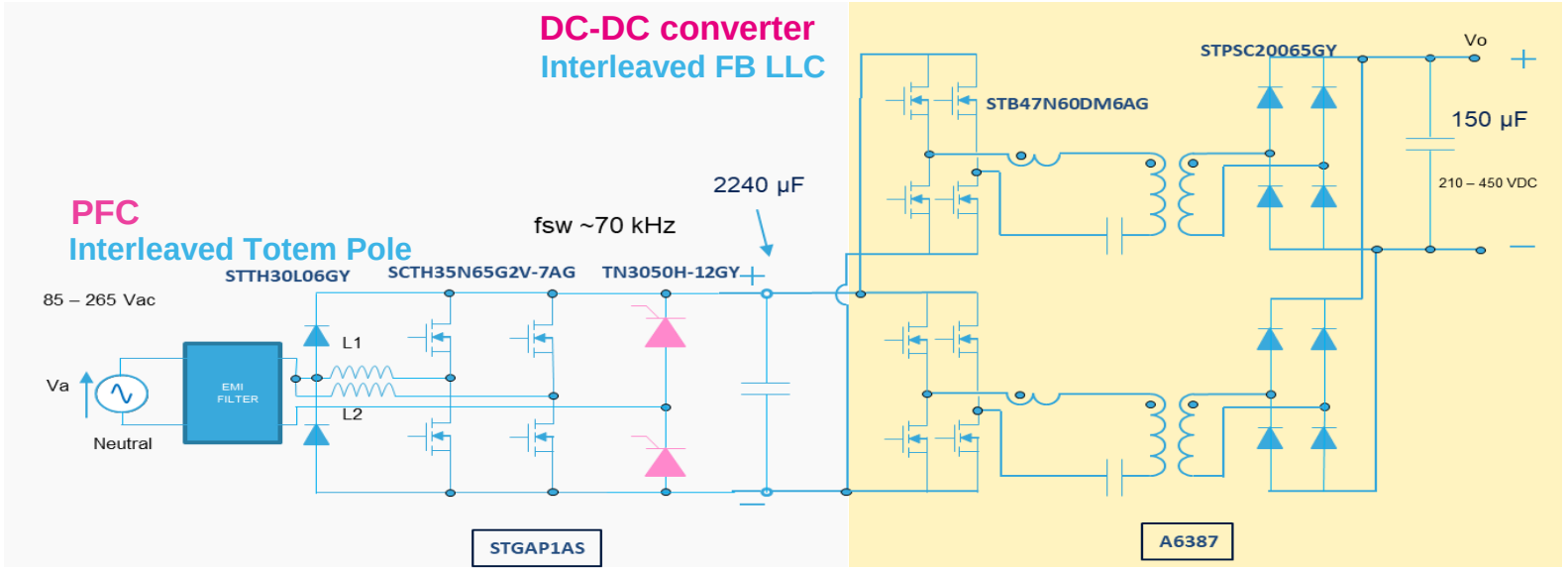
Evaluation Board 3
3x 7 kW On-Board Charger

Available Q2/20

Single solution 7 kW

21 kW solution, stacked modules with bus bars





Semiconductor	Automotive version	Industrial Version
Rectifier	STTH30L06GY	STTH30L06C
650V SiC POWER MOSFET	SCTH35N65G2V-7AG	SCTH35N65G2V-7
Thyristors	TN3050H-12GY	TN3050H-12GY
Isolated driver	STGAP1AS	STGAP2S
650V SJ MOSFET	STB47N60DM6AG	SCTH35N65G2V-7
650V SIC Diode	STPSC20065GY	STPSC20065
Microcontroller	SPC58NN84E7 (x 2)	STM32G474

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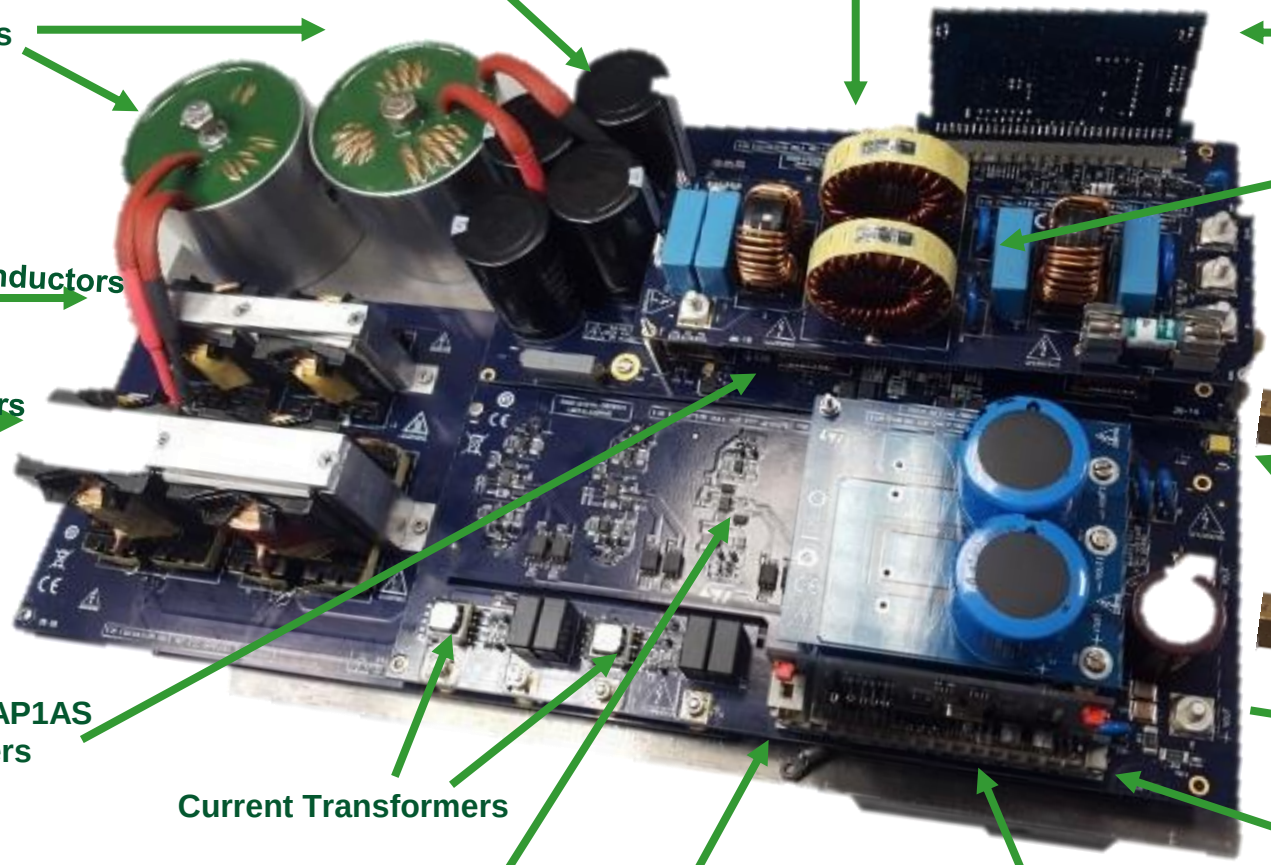
OBC First Platform Overview

Single Module 7 kW



IMS substrate PFC

Control Board
STEVAL-DPSC58C1 Bernina

Bulk Capacitors

PFC Inductors

Input Filter

DC-DC resonant inductors

AC Input
Voltage

DC-DC Transformers

Water Inlet

External 12V supply
Voltage

Water outlet

Output
Voltage

STGAP1AS
Drivers

Current Transformers

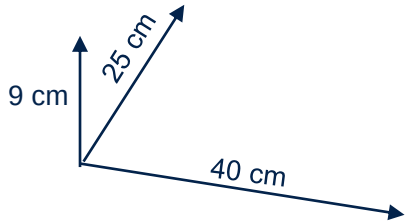
IMS substrate LLC

Drivers A6387 board

Control Board
STEVAL-DPSC58C1 Bernina

64 PIN ST DSMPS connector

Dimensions



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Evaluation board 4: 100 W Auxiliary Power Supply

Available Q1/20

Project details

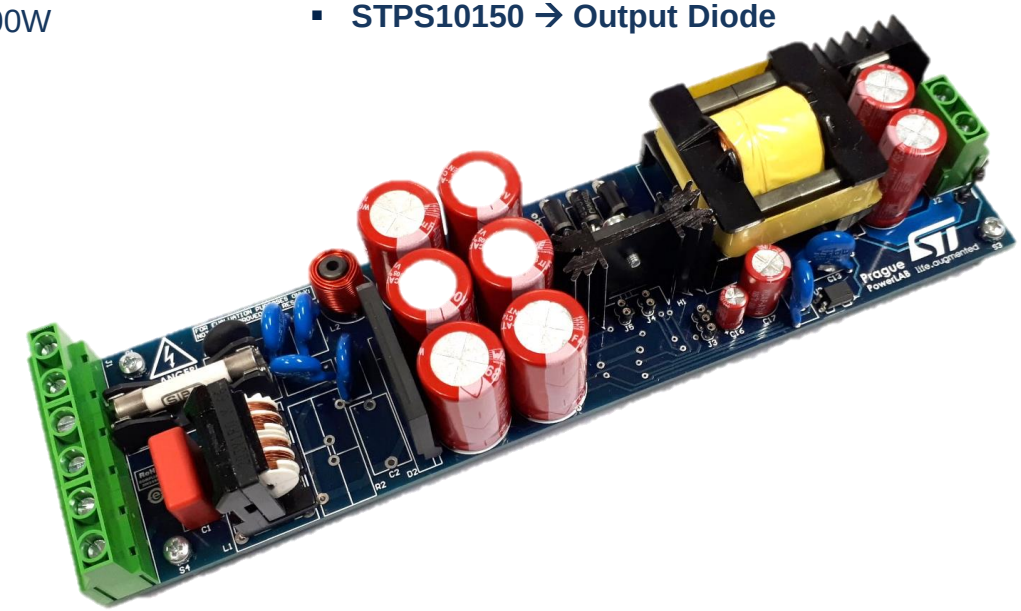
Input voltage
- 185 – 640 Vac
- 150 – 900 Vdc

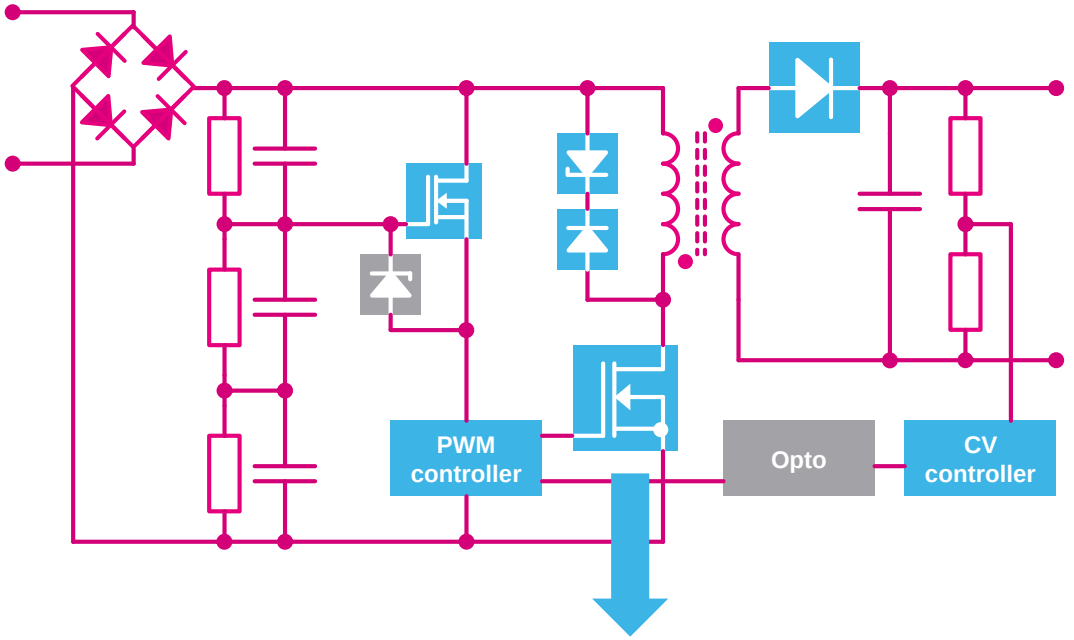
Output power
- Up to 100W

Topology
- Flyback

ST components

- **L6566BH → Quasi-resonant controller**
- **STW12N150K5 → 1500V SJ MOSFET**
- **SCT1000N170 → 1700V SiC MOSFET**
- **STN1HNK60 → Start-up MOSFET**
- **STPS10150 → Output Diode**





1700V SiC MOSFET due to:
Input Voltage +
Reflected voltage +
Spikes

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Summary

- Several **Industrial Vehicles** are now being electrified. A good portion of them will require an **on-board charger**.
- **Industrial OBCs** are typically implemented in a **2-stage** concept: **PFC** followed by **isolated DC/DC**.
- **650V & 1200V Silicon Carbide MOSFETs** provide advantages in both stages. **1700V SiC MOSFETs** can also be used in **Auxiliary power supply.**
- Several **evaluation boards** to approach this application are now ready or in preparation at **STMicroelectronics**.

Thank you

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