Power Semiconductors and ICs for Electric-Vehicle Charging

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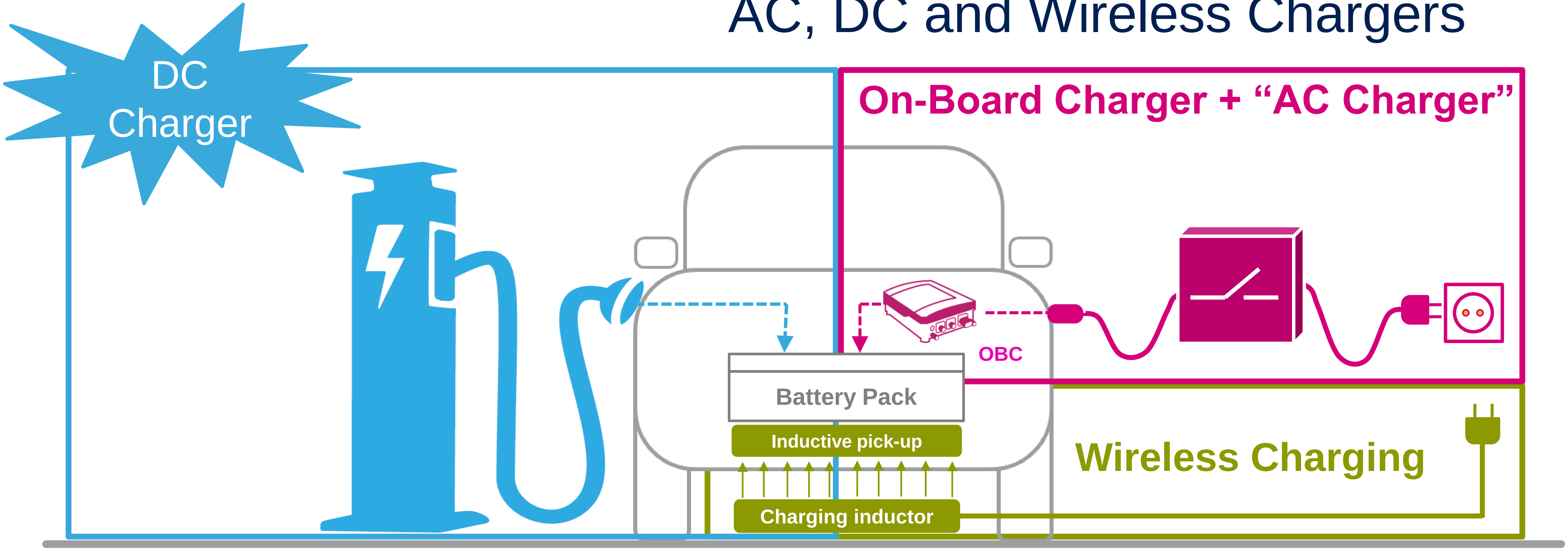
Charging an Electrical Vehicle

AC, DC and Wireless Chargers



Advantages of DC Chargers:

- ✓ Charging power not limited to OBC → short charging times.
- ✓ No extra volume and weight inside the car.
- ✓ Does not require same reliability level of OBC → lower cost per kW

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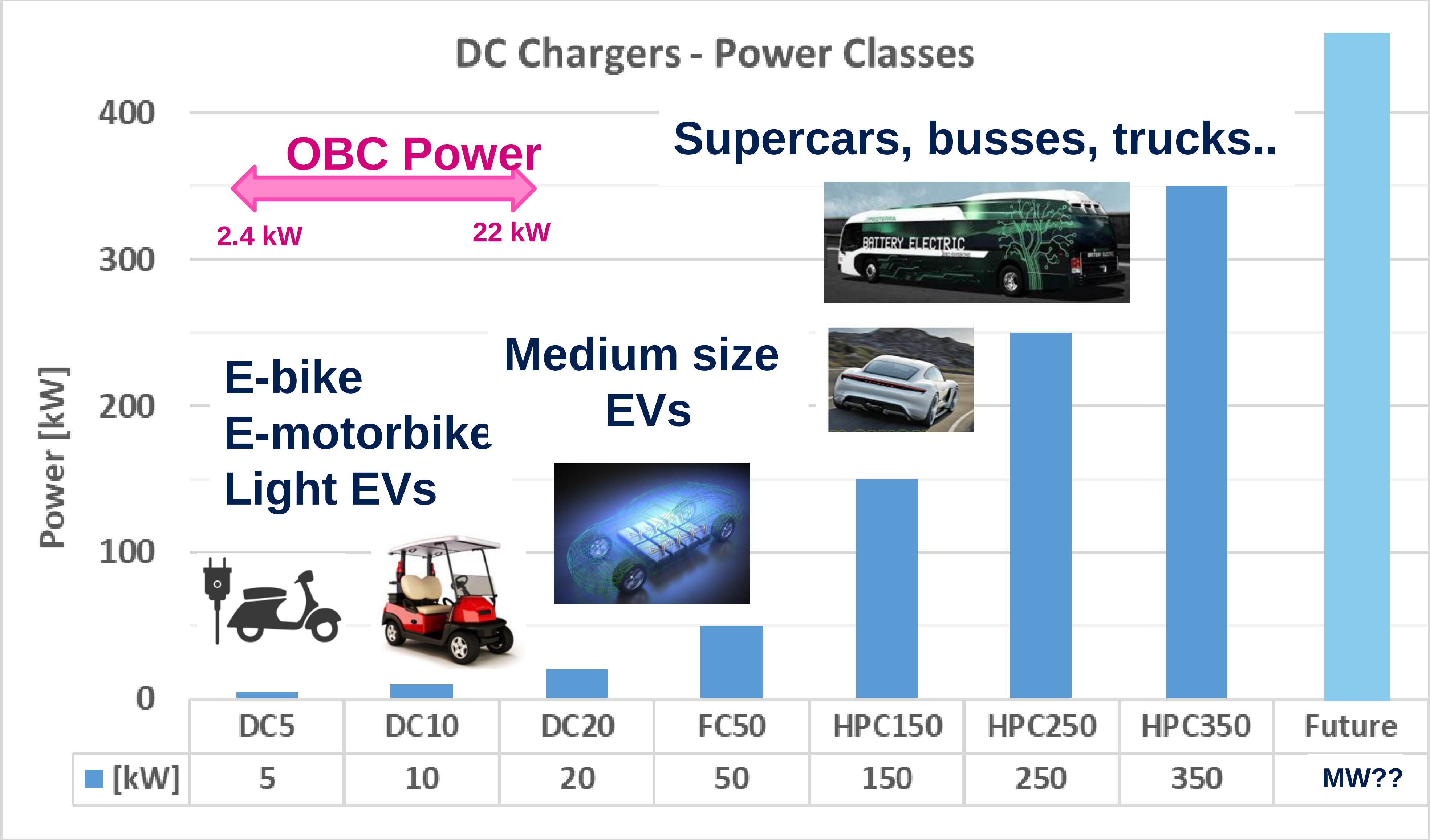
Power of DC Chargers

DC, FC and HPC are CharIn Standards



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High Power DC Chargers

Technical & Economical Issues

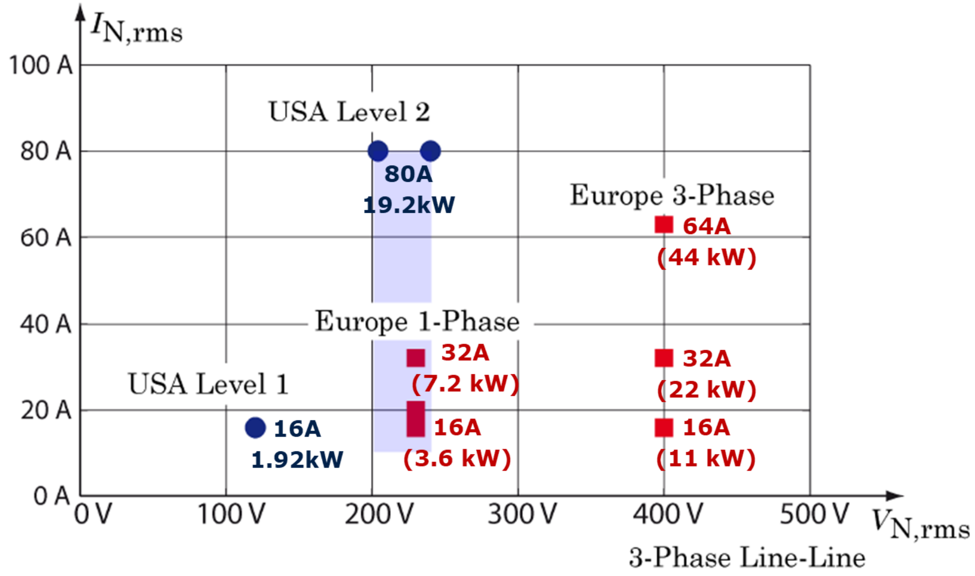
- Grid cables and connectors from **16/32A/64A – 11kW/22kW/44kW in European grid** – are normally **easily accessible**.

- **Above this value**, charger needs to be installed directly to the **transmission line**. This requires a **low frequency transformer**, and results in reasonably **higher cost and higher volume** per kW installed.

- Chargers **above 50kW** are more common to find in **city surrounding** or on the **highways**, where **transmission lines and transformers** are already present. Another possibility is to connect **energy storage systems** to enable extra power.

- On the other side, chargers **below 44kW can be directly connected to the grid**. **Isolation** between **grid and EV** is done through **high frequency transformer**. **More compact and cost advantageous** systems are achieved.

- **Charging time** will be of course **longer**, but this can be **compensated** by the **availability** of chargers nearby **home, office, shopping malls, etc**.



Source: ETH Zurich, modified

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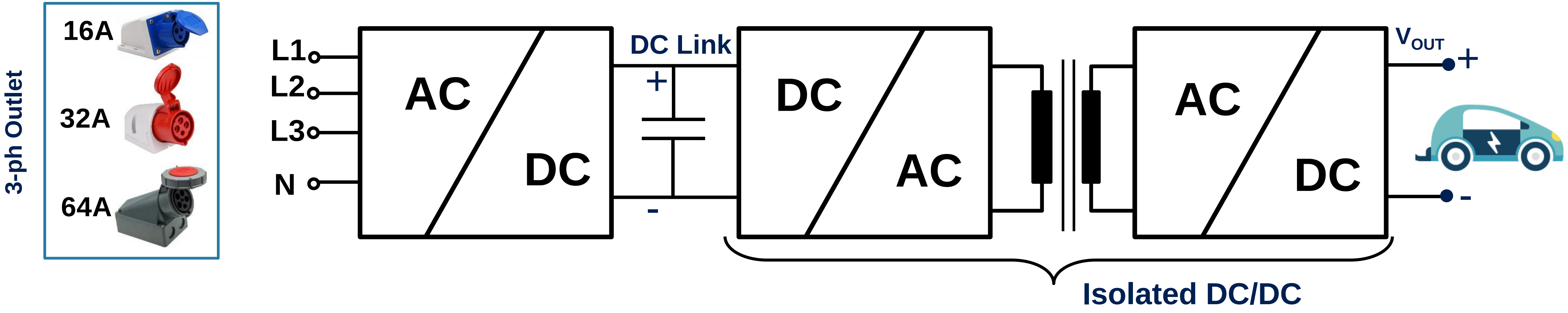
DC Chargers <50kW

System Concept



Parameter	Value
Input voltage	L_x-L_y → 400 V (RMS L_x-N → 230 V_{AC}
Link Voltage	400..1000 V
Nominal Power	11..44 kW
Output Voltage	200..500 V_{DC}*

*according to CharIn

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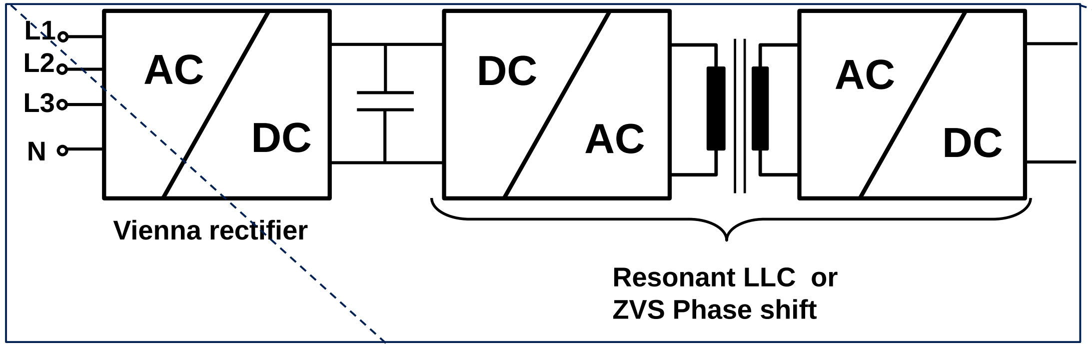
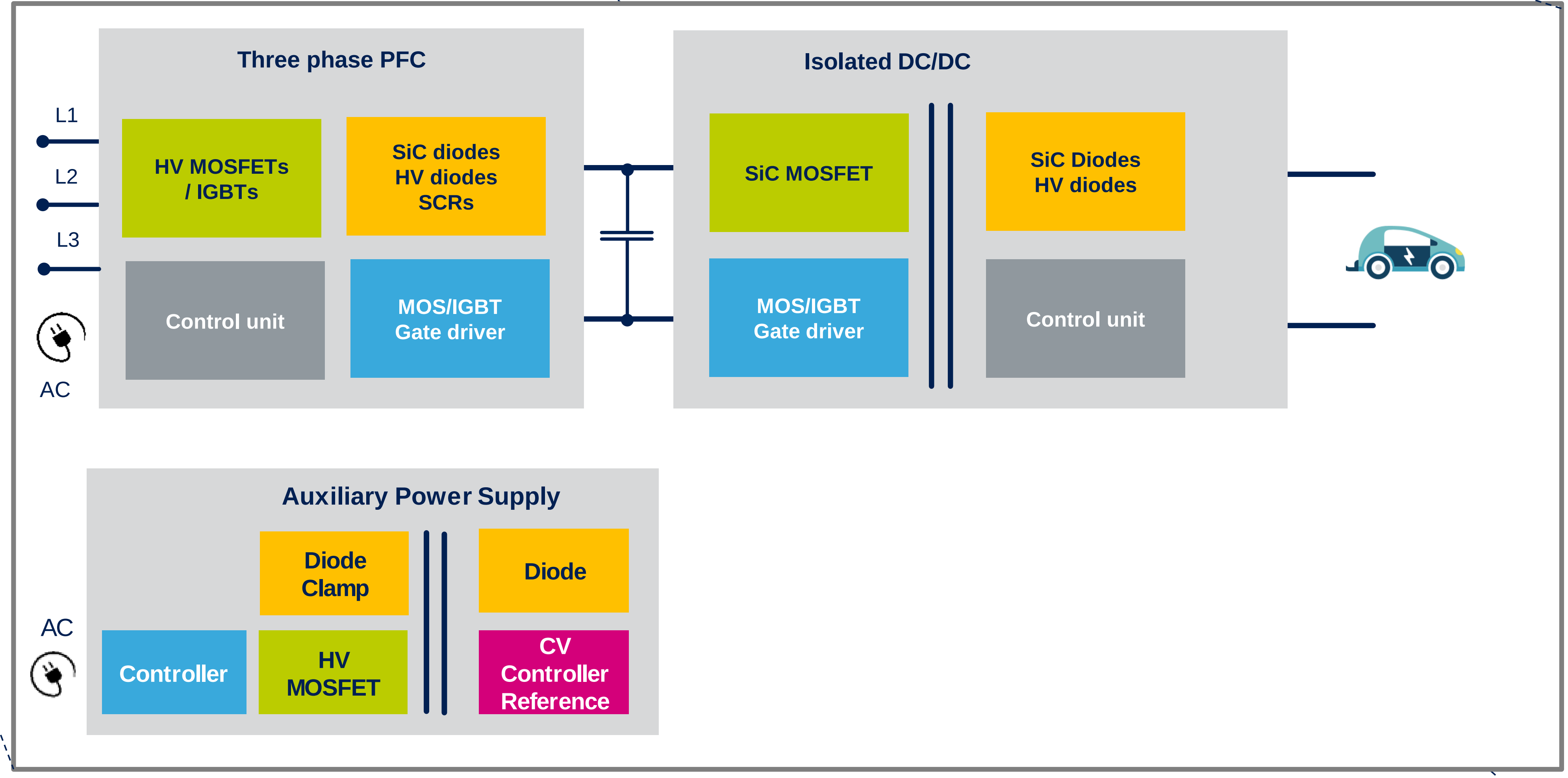
Product Lines





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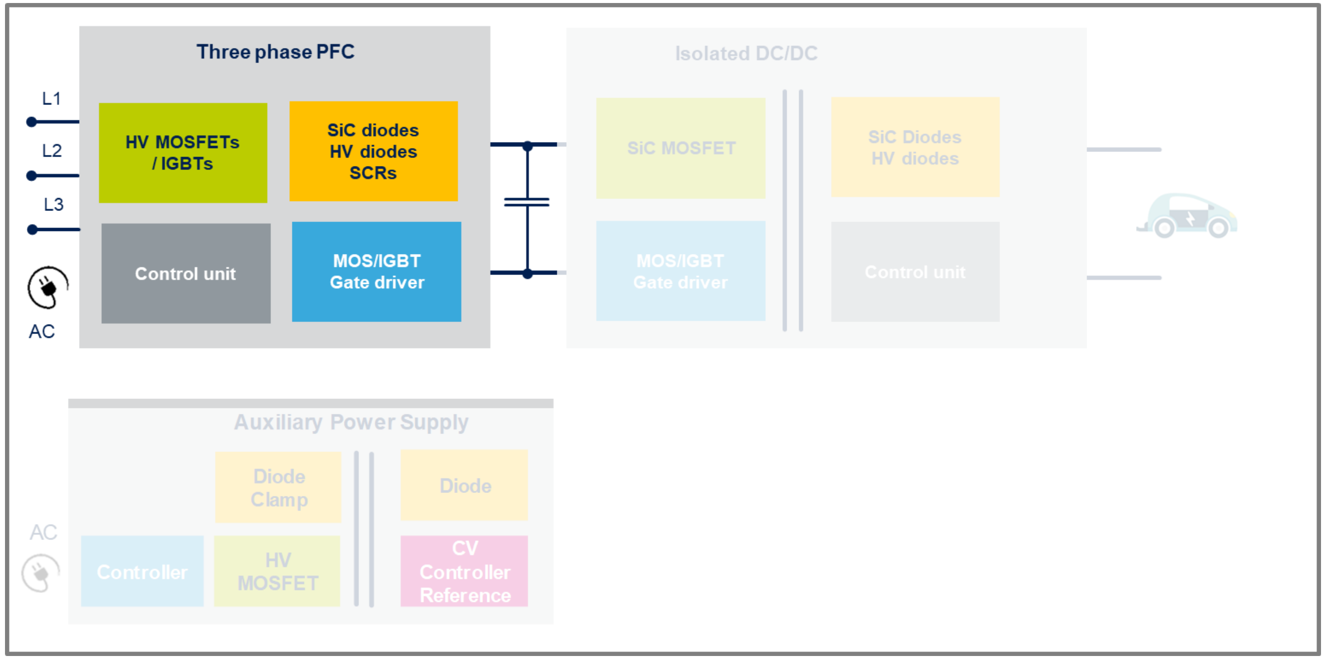
- Electro-vehicle (EV) Charger Introduction
- Main Concept and Topologies
  - AC/DC Stage
  - DC/DC Stage
  - Bi-directional Charger
- Practical Example
- Available Development Tools
- Q&A Session



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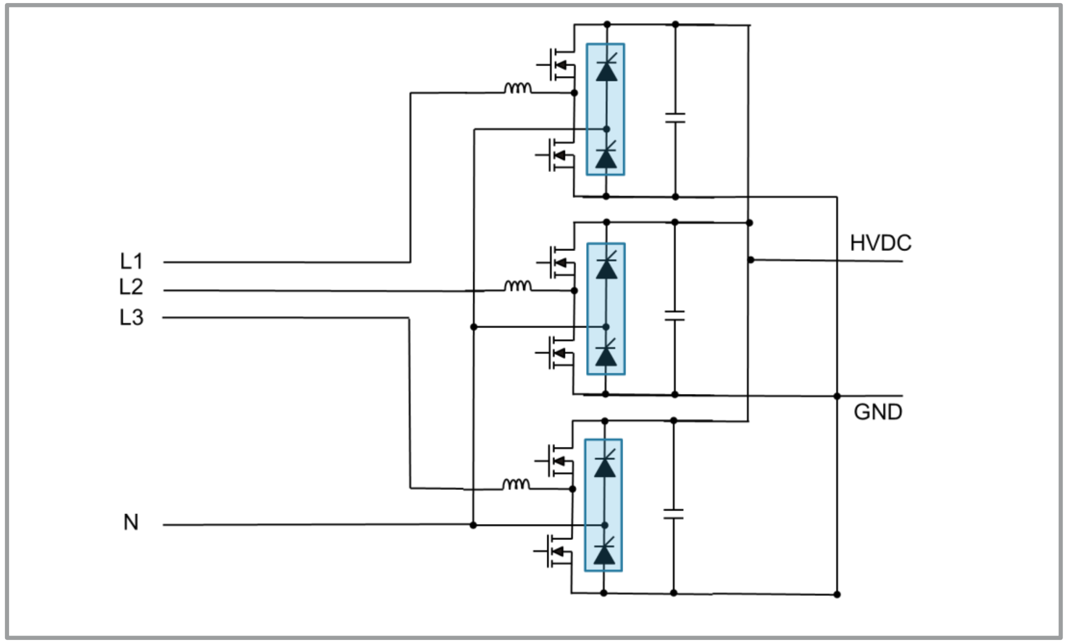
3x Independent 1-phase

Example: 3x PFC Booster



+ 4 devices / phase
+ Flexible grid configuration

- May need of 1200V SiC switches*

* In order to accomplish battery voltage requirements.

3-Level 3-Phase

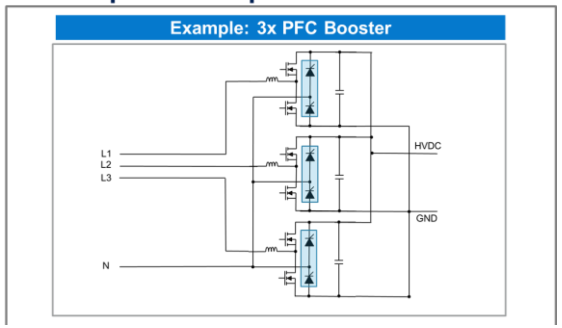
Example: Mod. Vienna Type 1

+ 650V Si Switches.

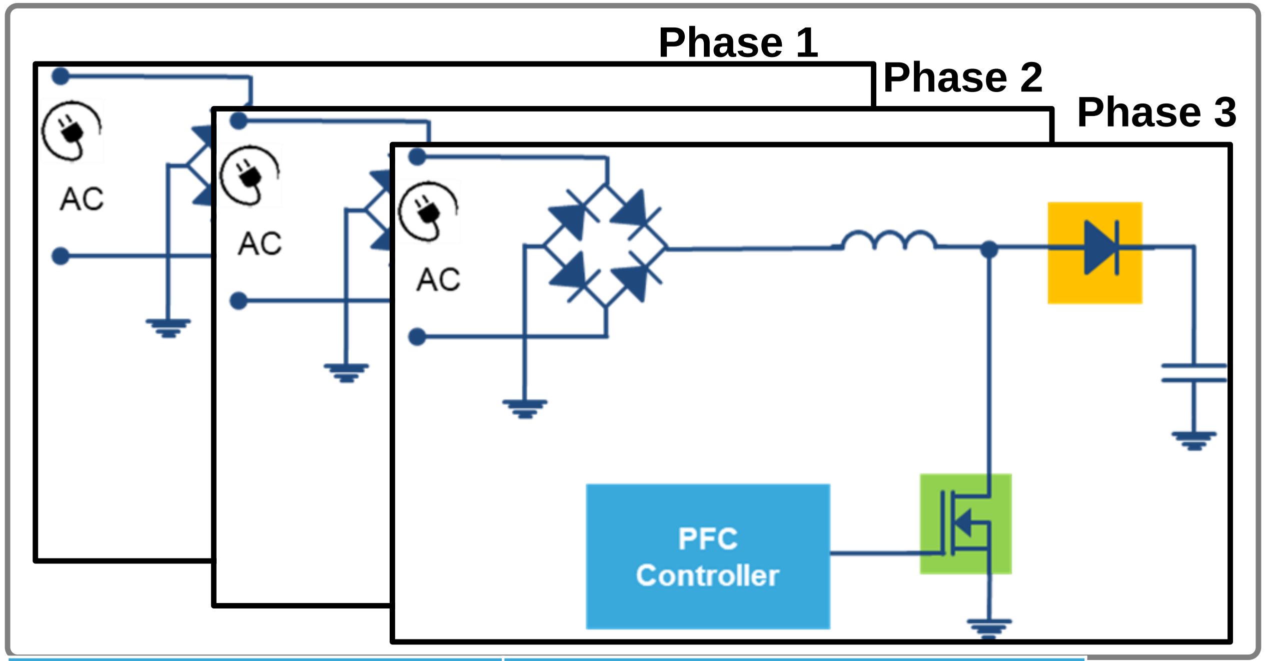
- 6 devices / phase.

3x 1-phase Topologies
Standard PFC

3x Independent 1-phase



Booster PFC



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

xx→ Current class
x → family name

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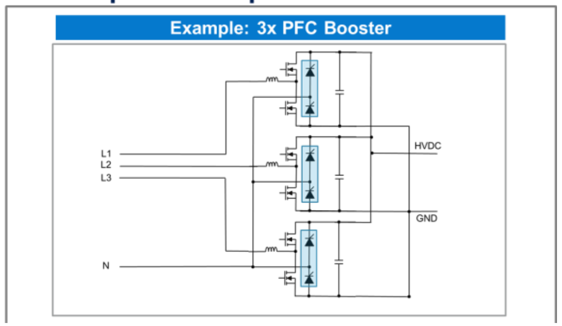
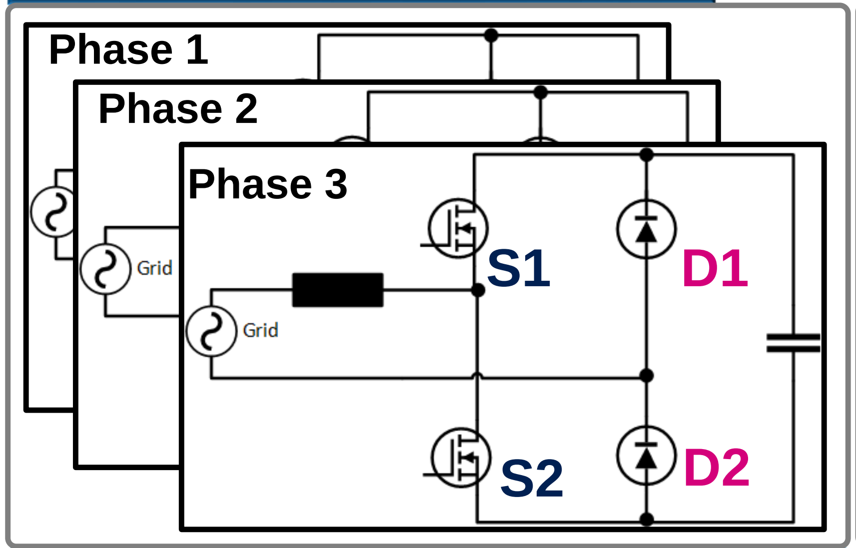
3x 1-phase Topologies

Bridge-less Topologies

3x Independent 1-phase

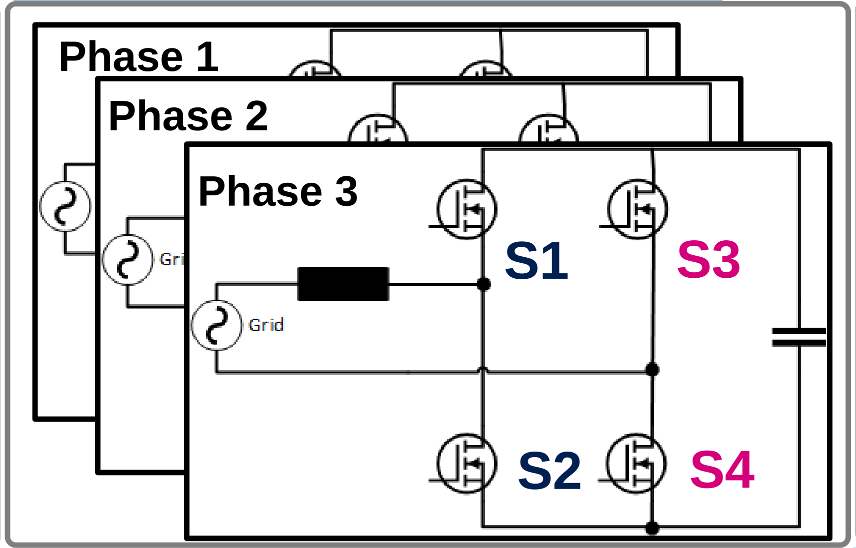


Var. 1 – Cost – Diode Leg



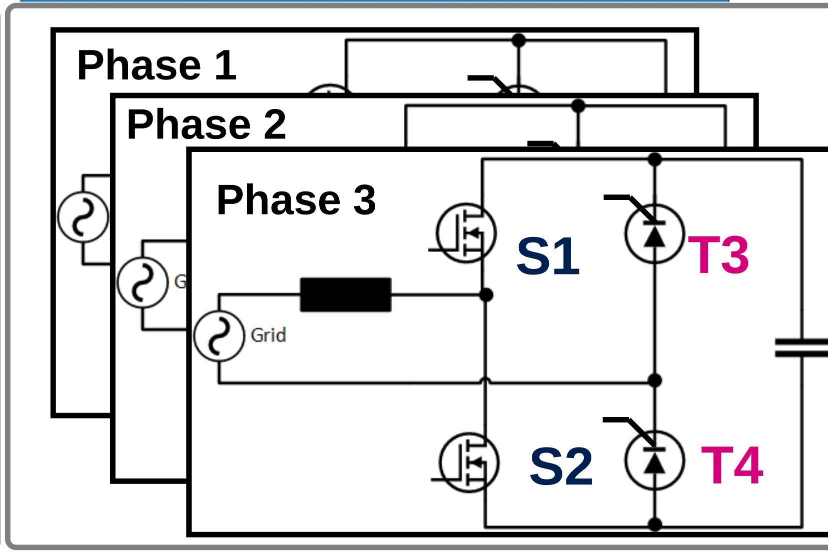
Device	Technology	ST Proposal
S1/S2	1200V SiC MOS	SCTxxN120
D1/D2	1200V Rectifier	STBRxx12W
	Driver	STGAP2S/D
	Control	STM32

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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AC/DC Concepts

3x Independent 1-phase

Example: 3x PFC Booster

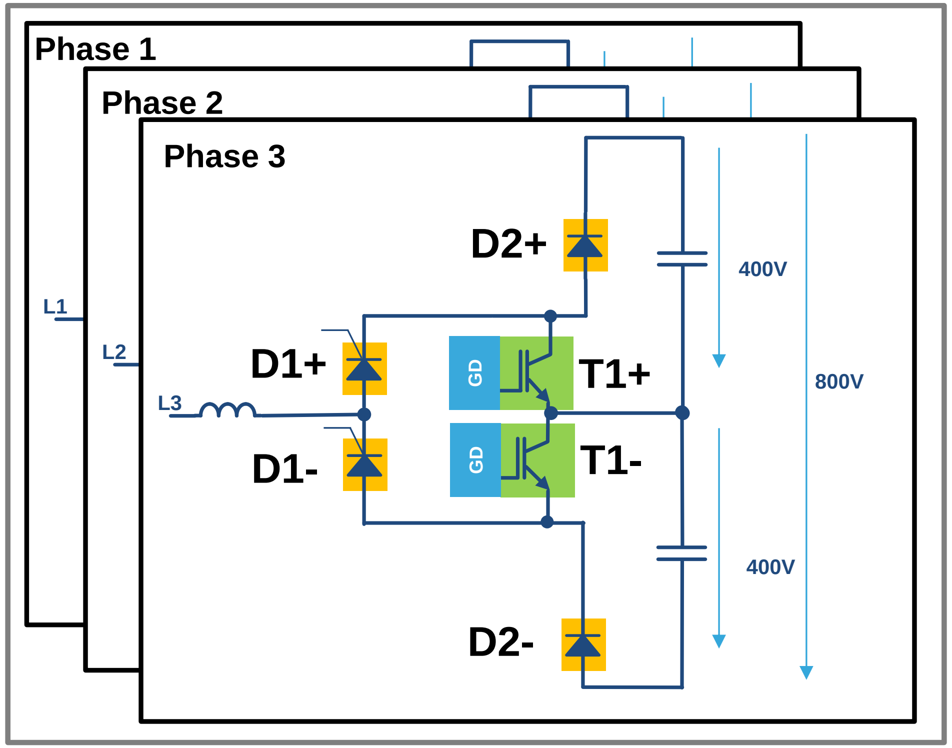
+ 4 devices / phase
+ Flexible grid configuration

- May need of 1200V SiC switches*

* In order to accomplish battery voltage requirements.

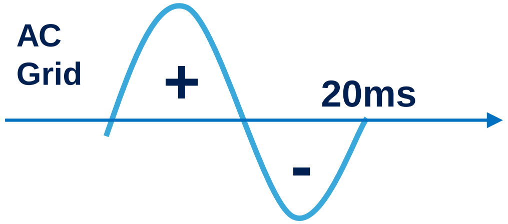
3-Level 3-Phase

Example: Mod. Vienna Type 1



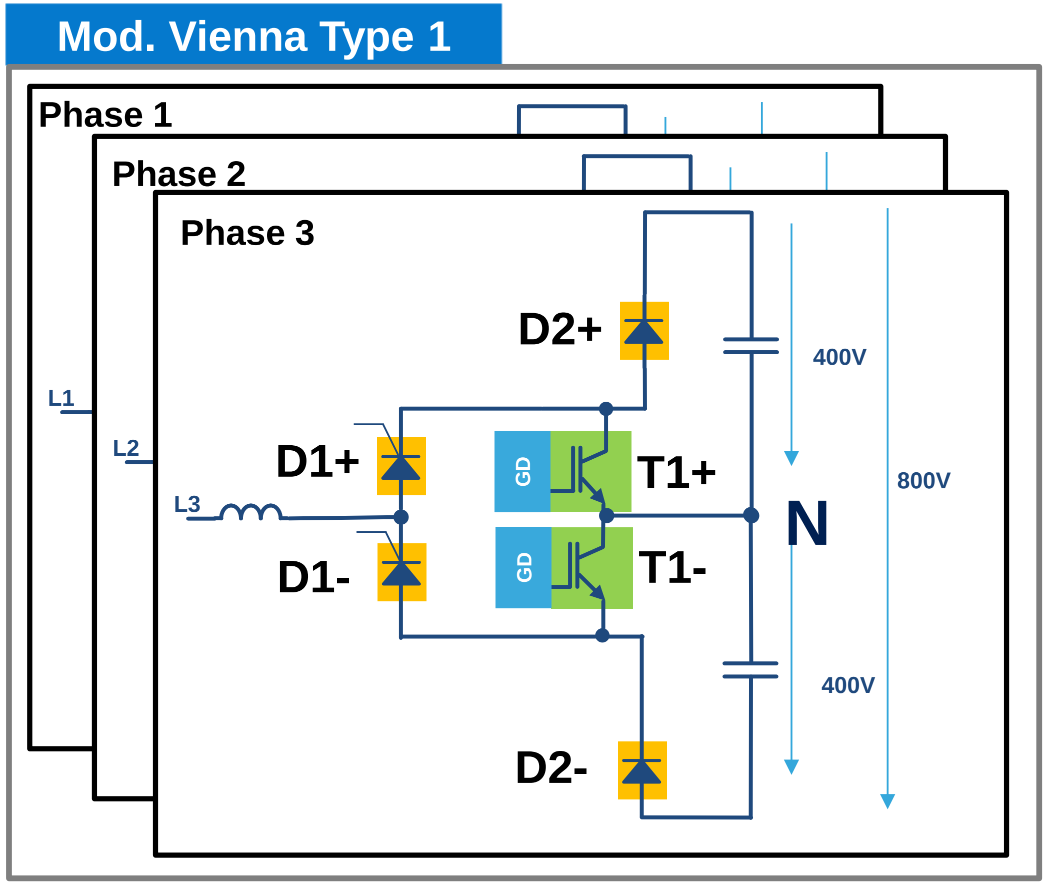
+ 650V Si Switches.

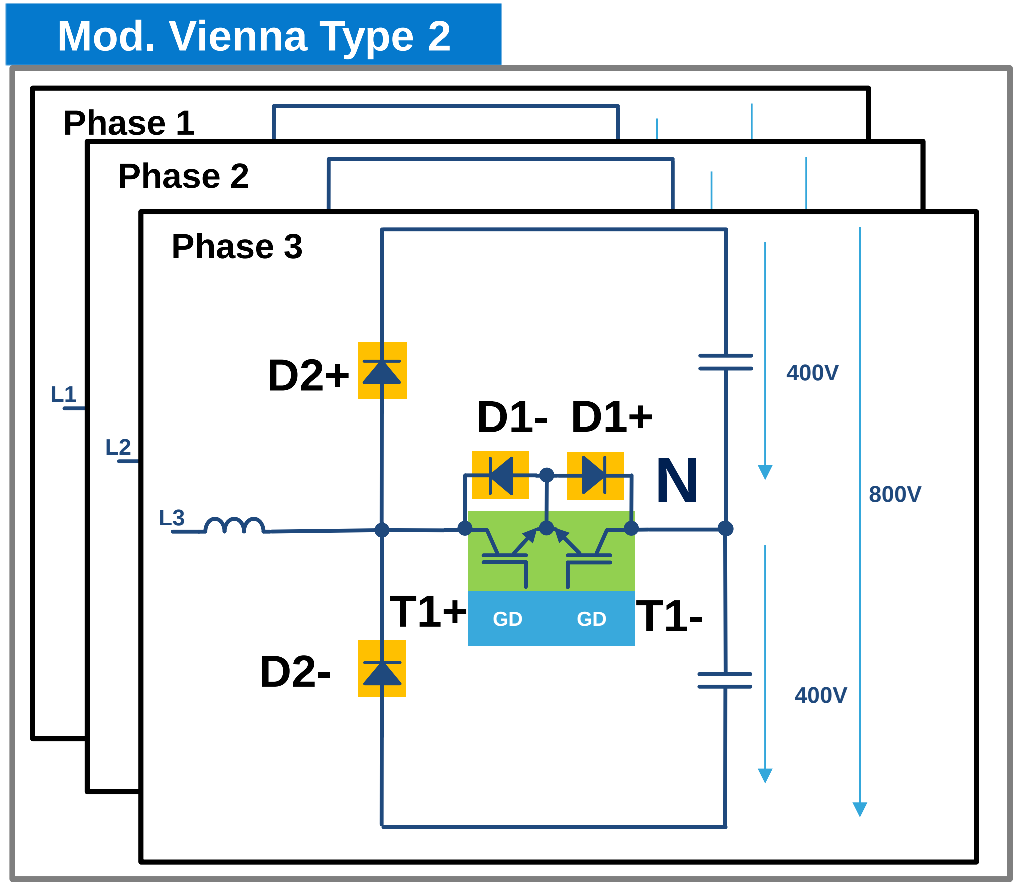
- 6 devices / phase.



Modified Vienna Rectifier

Topology Comparison





+ All 650V rated devices!
→ lower cost

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

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

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

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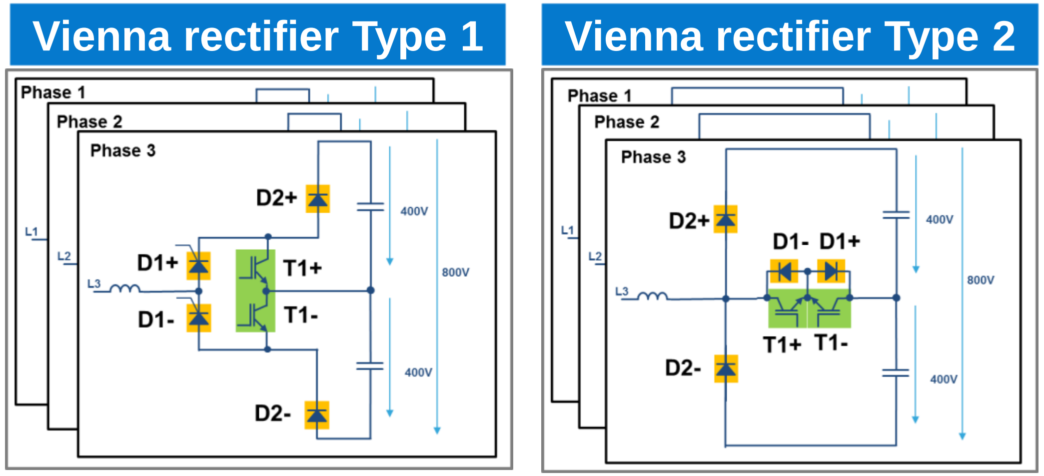
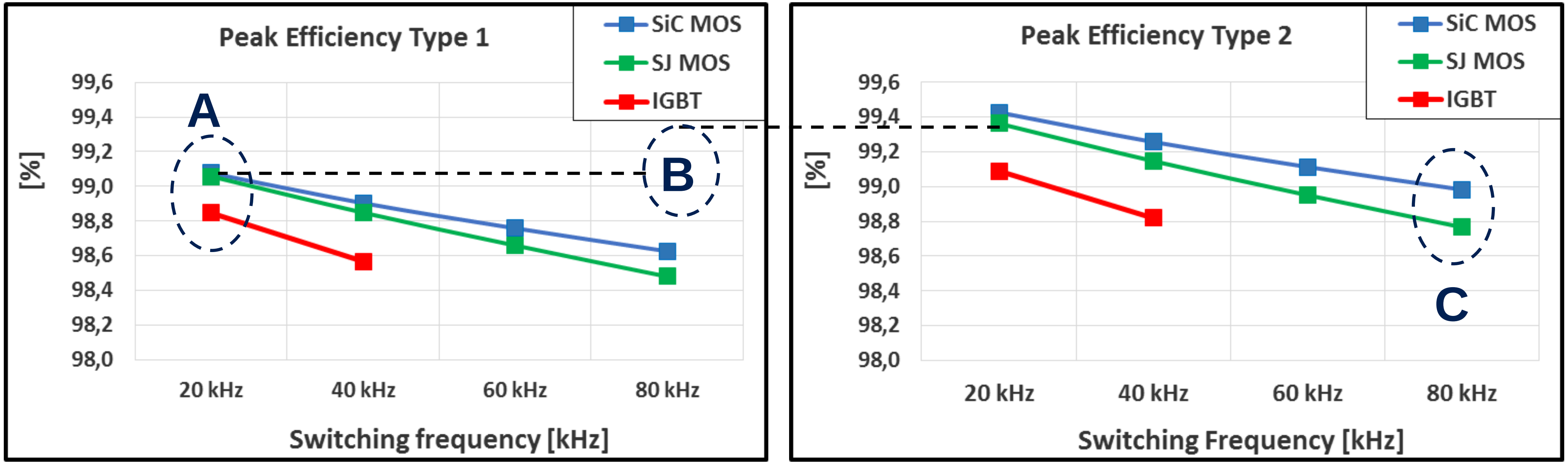
Topology Comparison
Efficiency Comparison @ P_{out}=20 kW



A → Eff. of IGBT: -0.3% than SJ/SiC MOS

B → Eff. of Type 1: -0.3% than Type 2

C → >50 kHz: SiC +0.1%..0.2% than SJ MOS



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

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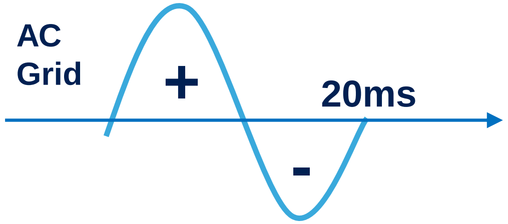
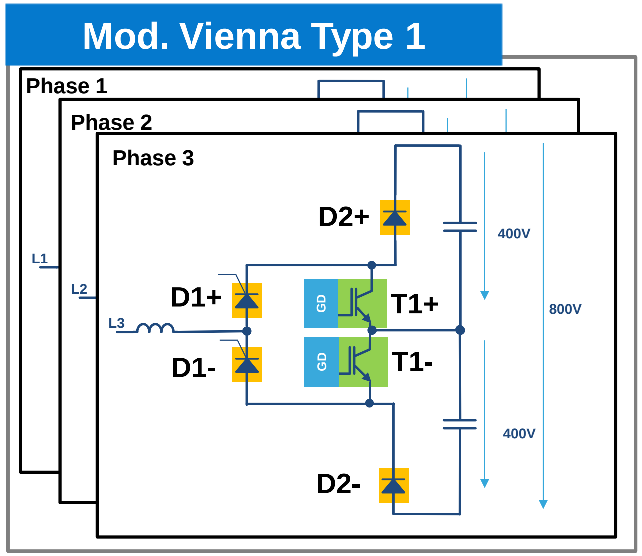
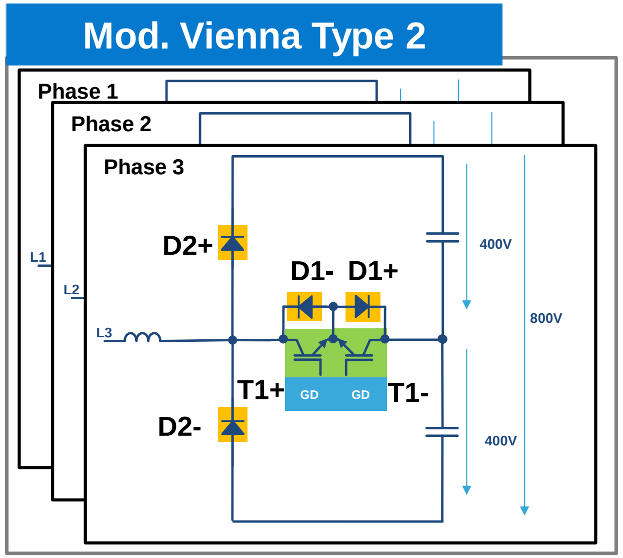
Modified Vienna Rectifier

Device Proposal







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

	Required Semiconductor	ST Solution
T1/D1	650V IGBT 650V SJ MOS 650V SiC MOS	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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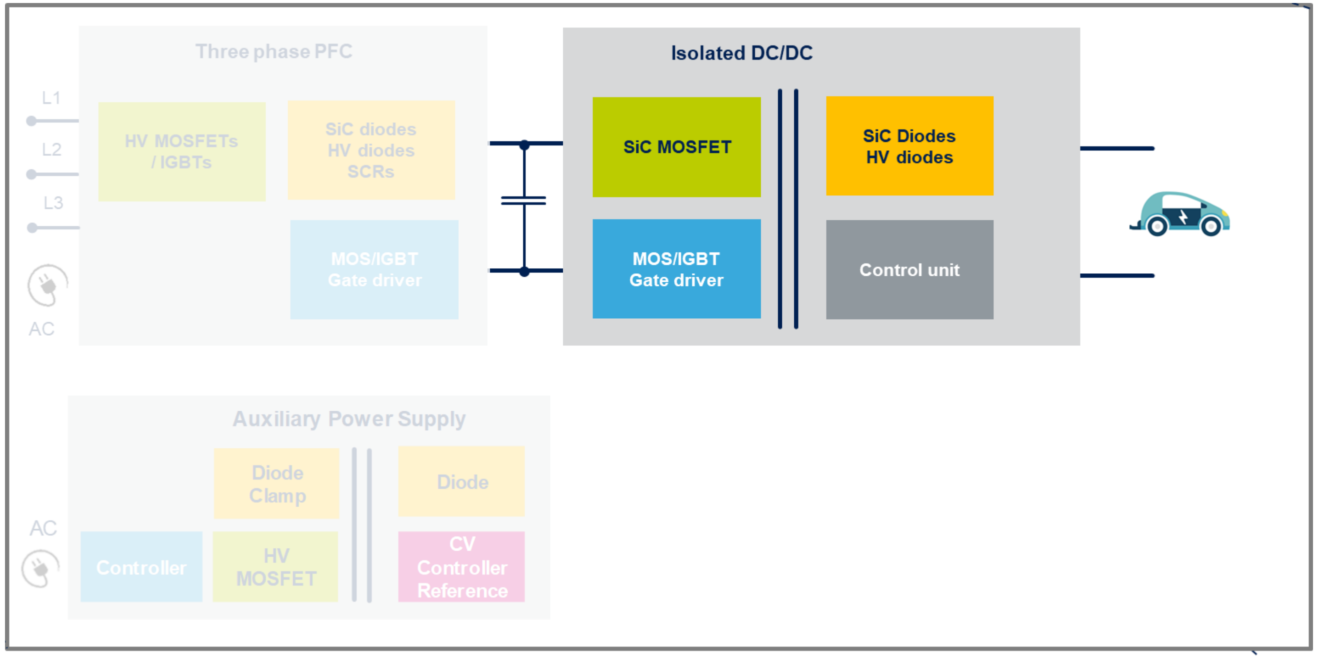

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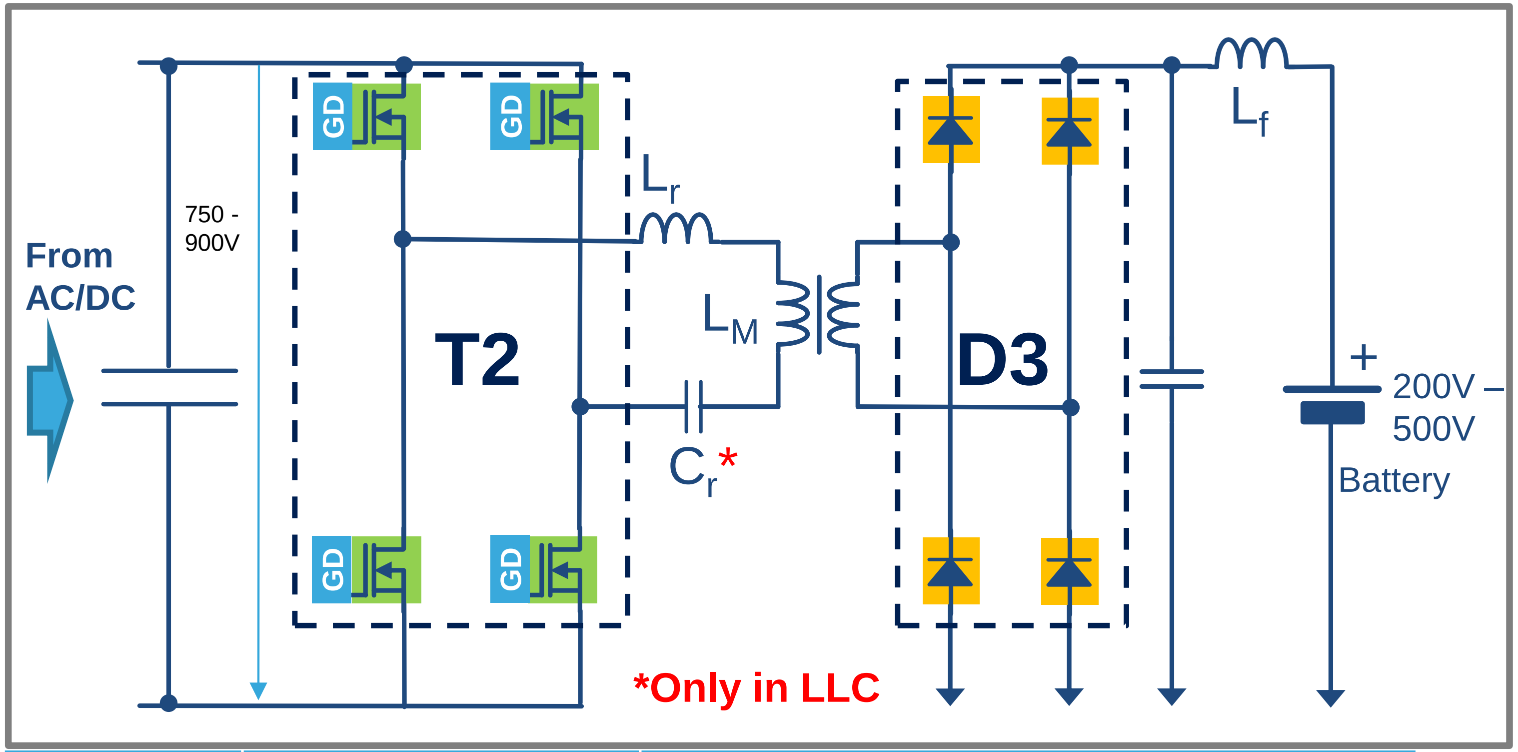
DC/DC Stage Topologies

LLC/ZVS

Resonant LLC / ZVS



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

xx→ Current class

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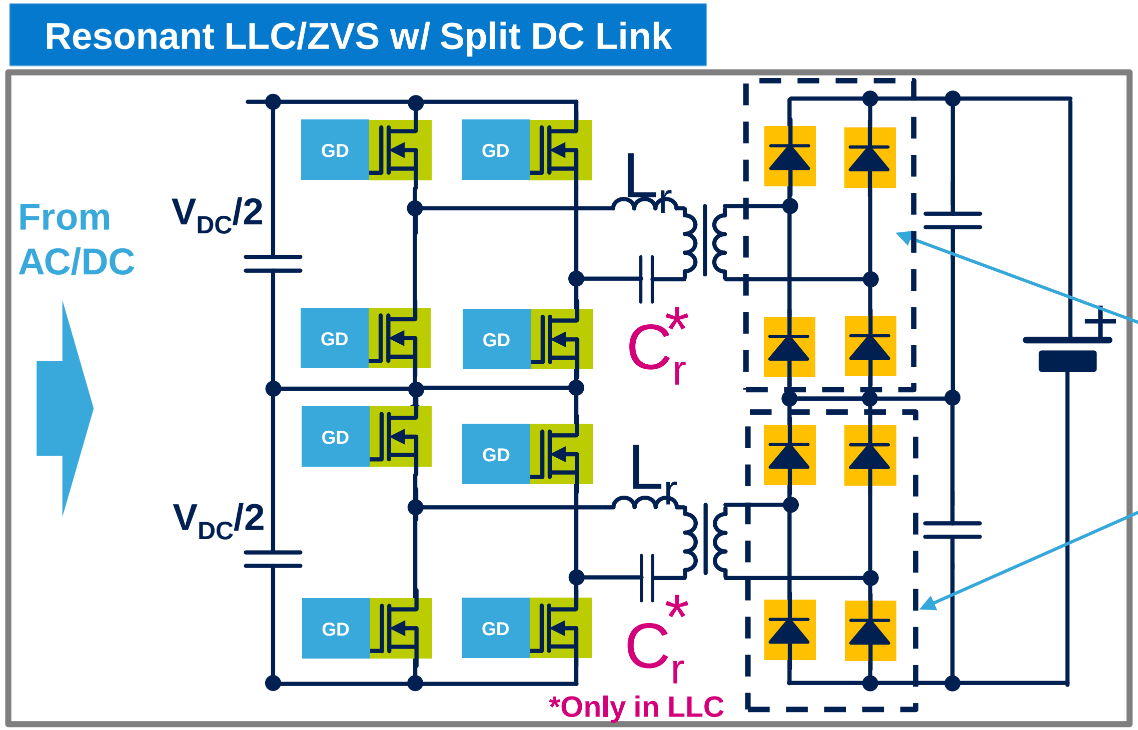
DC/DC Stage Topologies

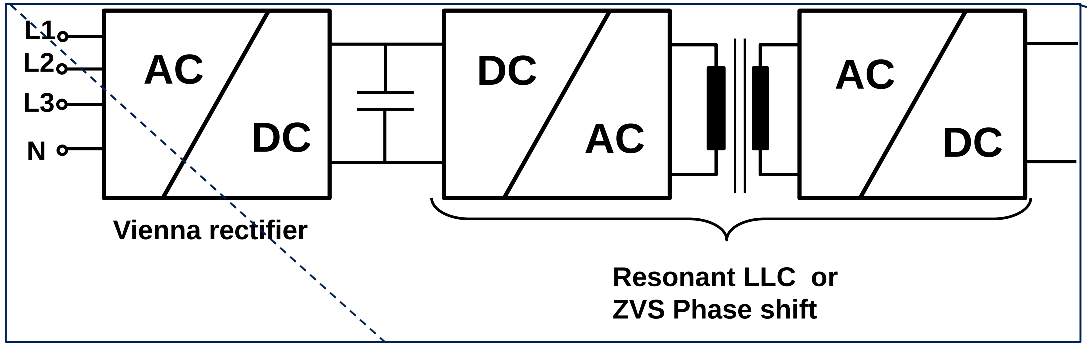
Dual LLC/ZVS With Split DC Link

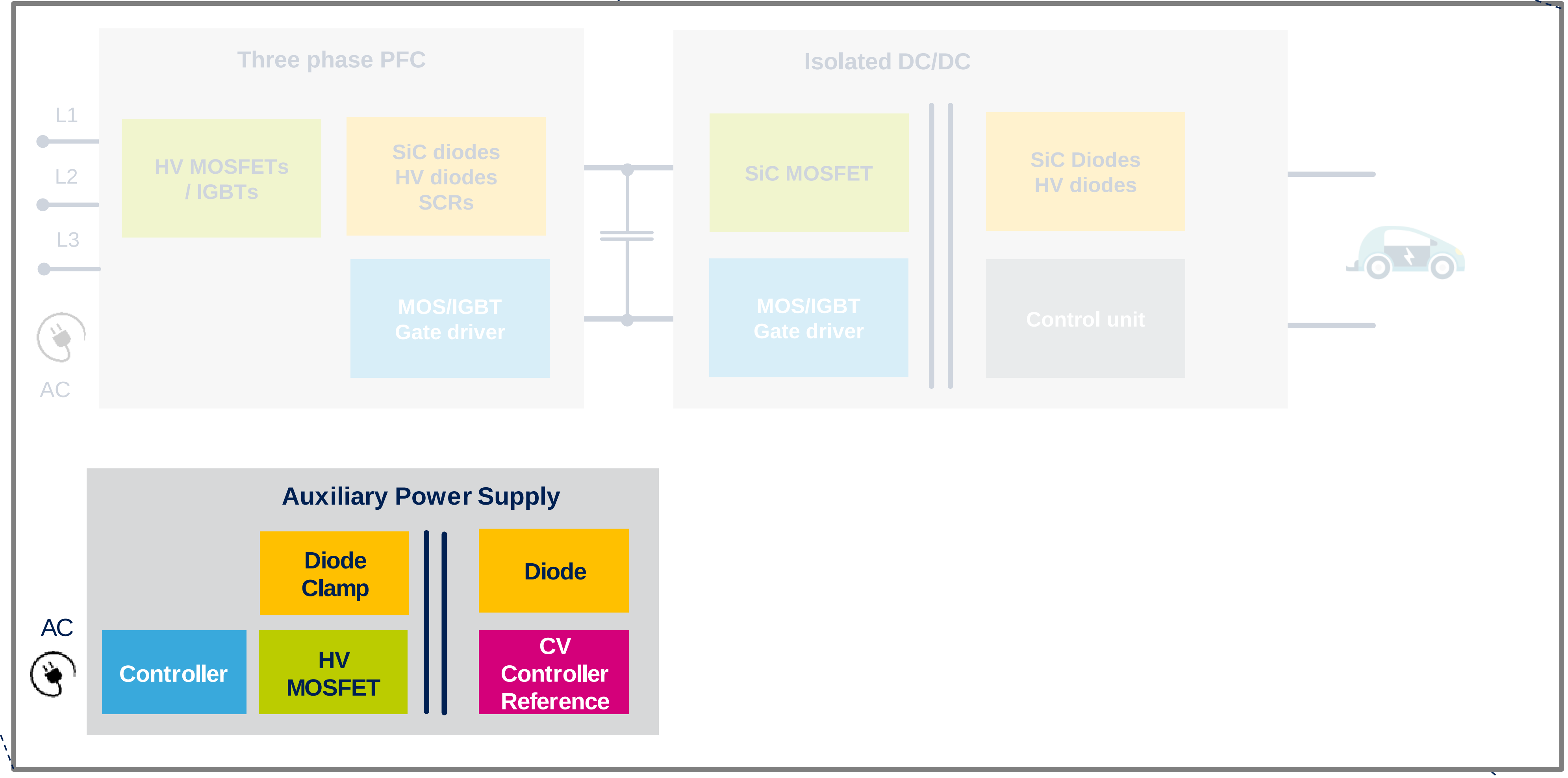


Can be connected in series or parallel, to accomplish high voltage batteries.

	Required Semiconductor	ST Solution
Primary switches	650V SJ MOS	STWxxN65DM6
Output Diodes	600V FRD 1200V SiC Diodes	STTHxxRQ06 (LLC) STPSCxxH12C (ZVS)
GD	Isolated driver	STGAP2S/D
Control	μ-Controller	STM32 (Digital)

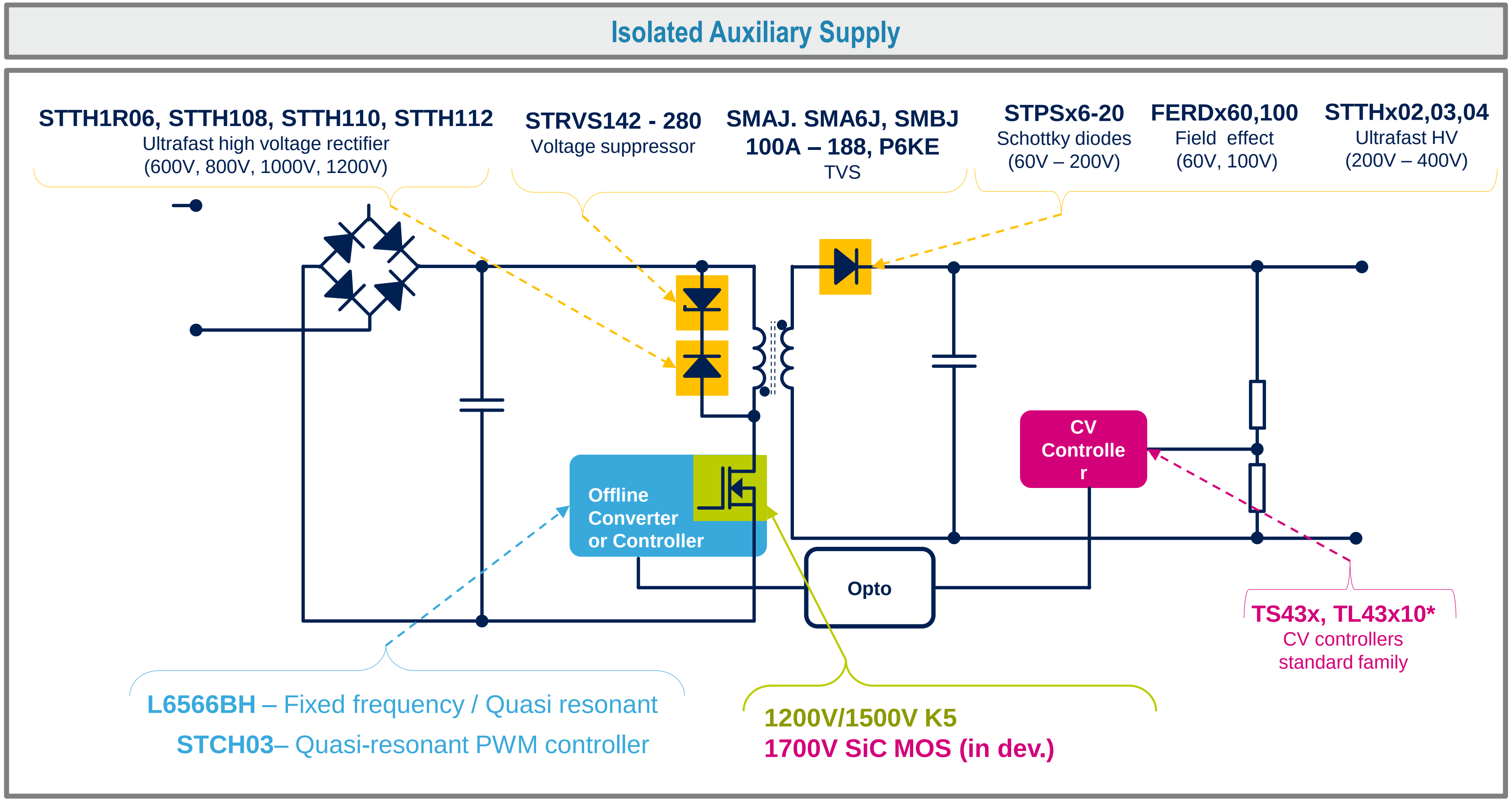
Product Lines





Auxiliary Power Supply

Circuit Topology and Proposed Devices



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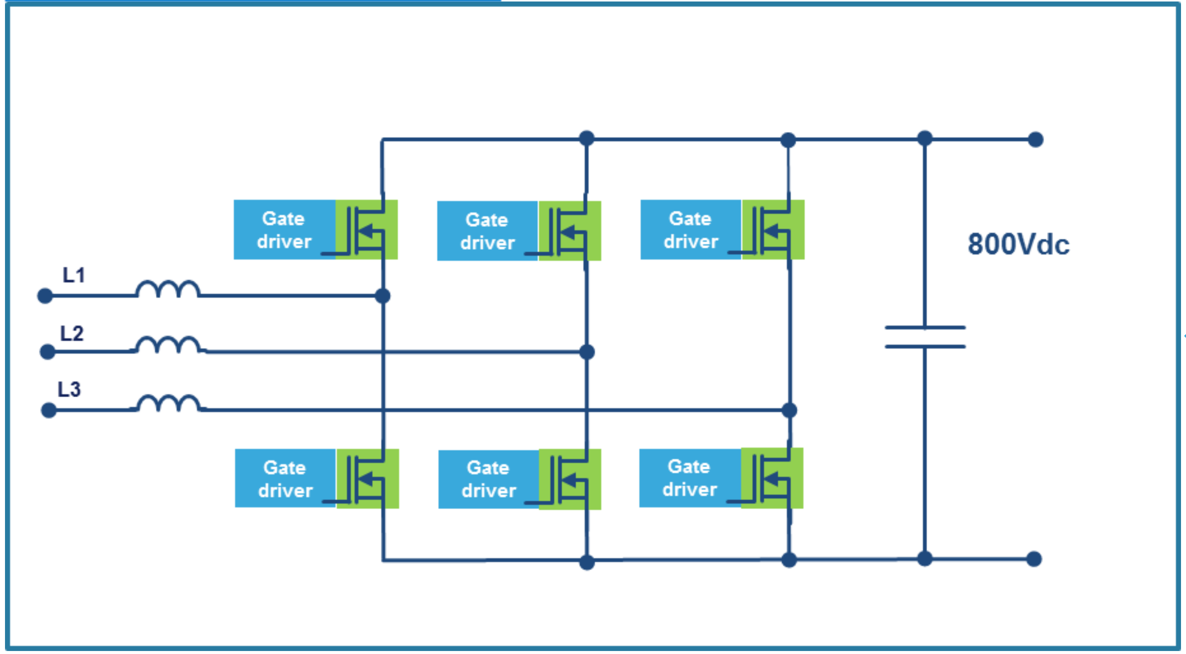
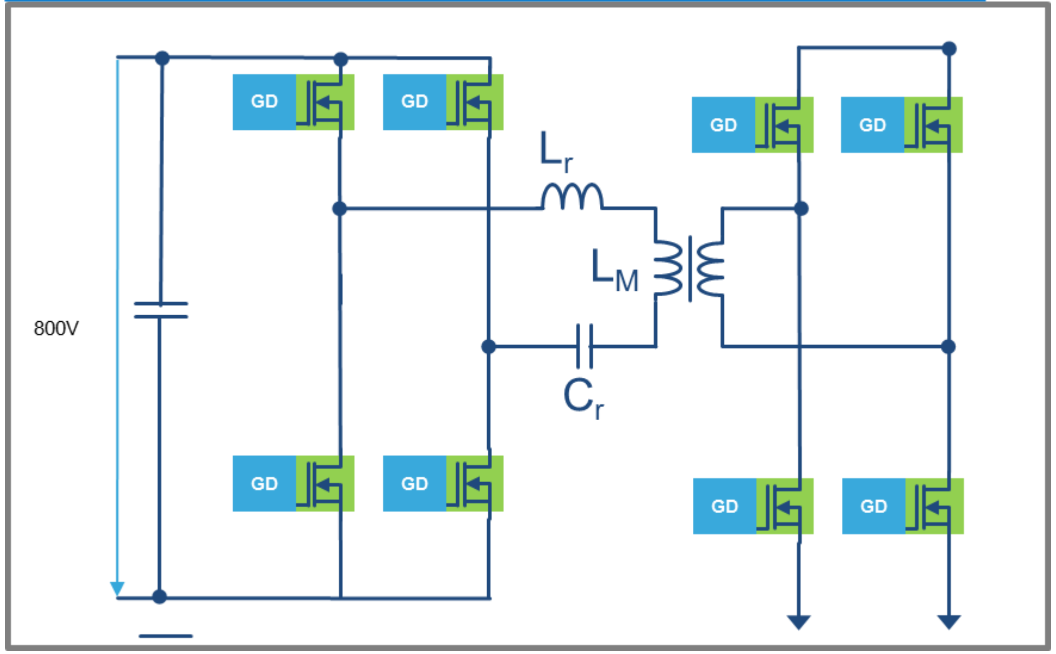
Bi-directional Charger

AC/DC + DC/DC

Bi-directional B6



Dual Active Bridge (DAB) / Bi-directional LLC



Stage	Required Semiconductor	ST Solution
B6	1200V SiC MOS	SCTxxN120
LLC/ZVS	650V SiC MOS 1200V SiC MOS	SCTxxN65G2V [400V Batt.] SCTxxN120 [800V Batt.]
Both	Iso Gate Driver	STGAP2S/D
Control	µ-Controller	STM32

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Application Example

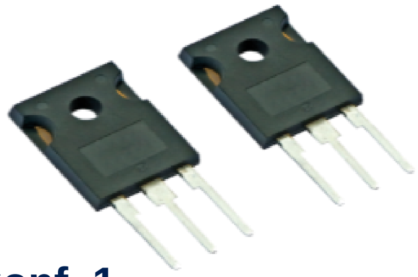
DC Chargers for Electrical Vehicles

Parameter	Symbol	Value
Input voltage	V_{in}	$230V_{ac}$ Ph-N $400V_{ac}$ ph-ph
Max. Input Current	$I_{in.max}$	32A/ph
Max Power	$P_{in.max}$	7.36 kW/ph 22 kW total
DC Link Voltage	V_{DC}	400..1000Vdc
Output Voltage	V_{out}	200..500Vdc

Configuration	SiC MOSFET	$R_{ds,on.typ}$ @ Tj=25°C	Package	Number in parallel
Conf. 1	SCT50N120	52 mΩ @ Vgs=20V	HiP247	2x
Conf. 2	SCTW70N120G2V-4	25 mΩ @ Vgs=18V	TO-247-4 (Kelvin Source)	1x

New! Samples available

Comparison on Device Level



Conf. 1

Conf. 2

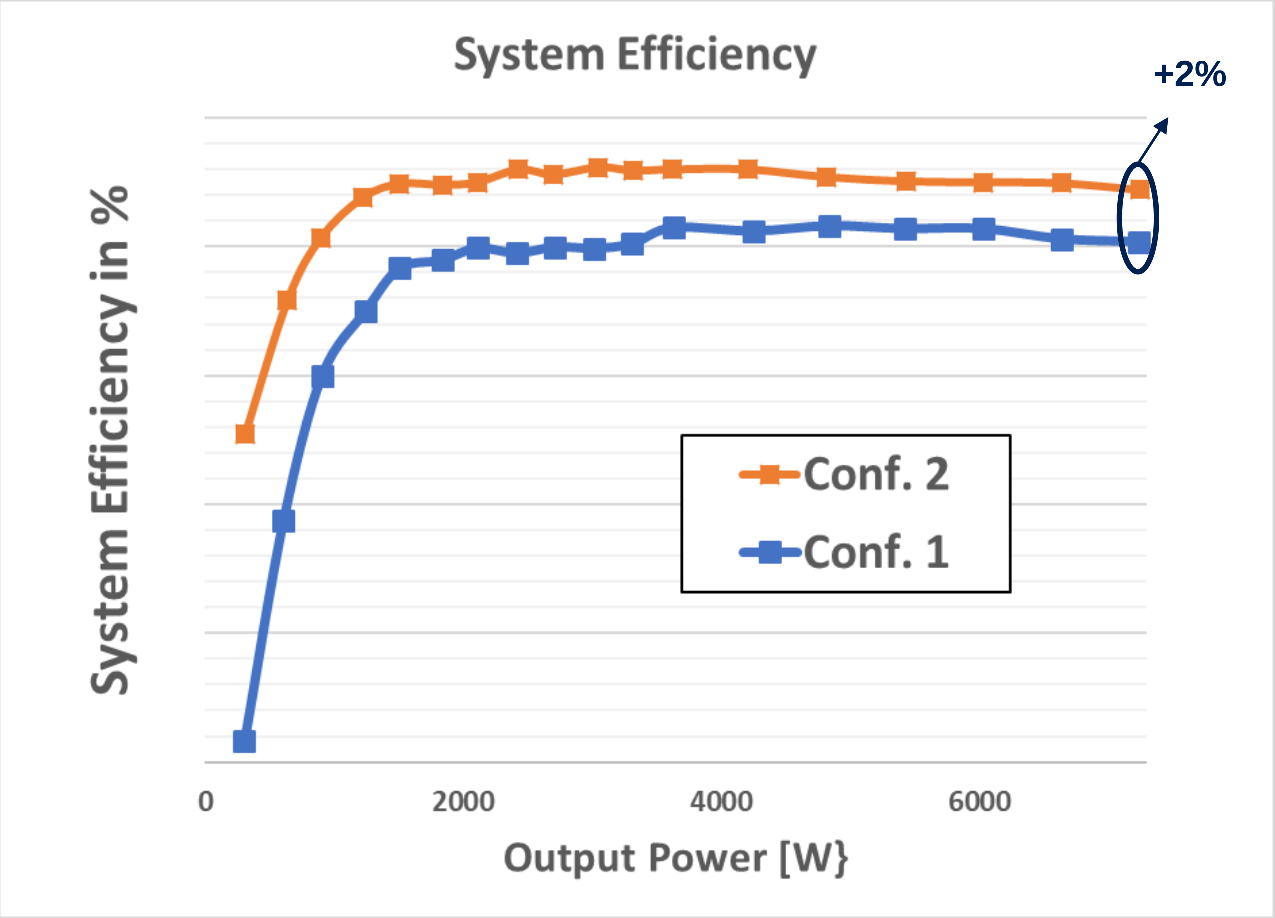
Parameter	Conditions	SCT50N120 (x2)	SCTW70N120G2V-4
$R_{ds,on}$	$V_{gs}= V_{g,op}$, $I_d=I_{d,nom}$, $T_j=25°C$	52 mΩ (26 mΩ)	25 mΩ
$R_{th,j-c}$	---	0.55 K/W (0.27 K/W)	0.45 K/W
$R_{th,c-h}$	---	~ 1 K/W (~0.5 K/W)	~ 1K/W

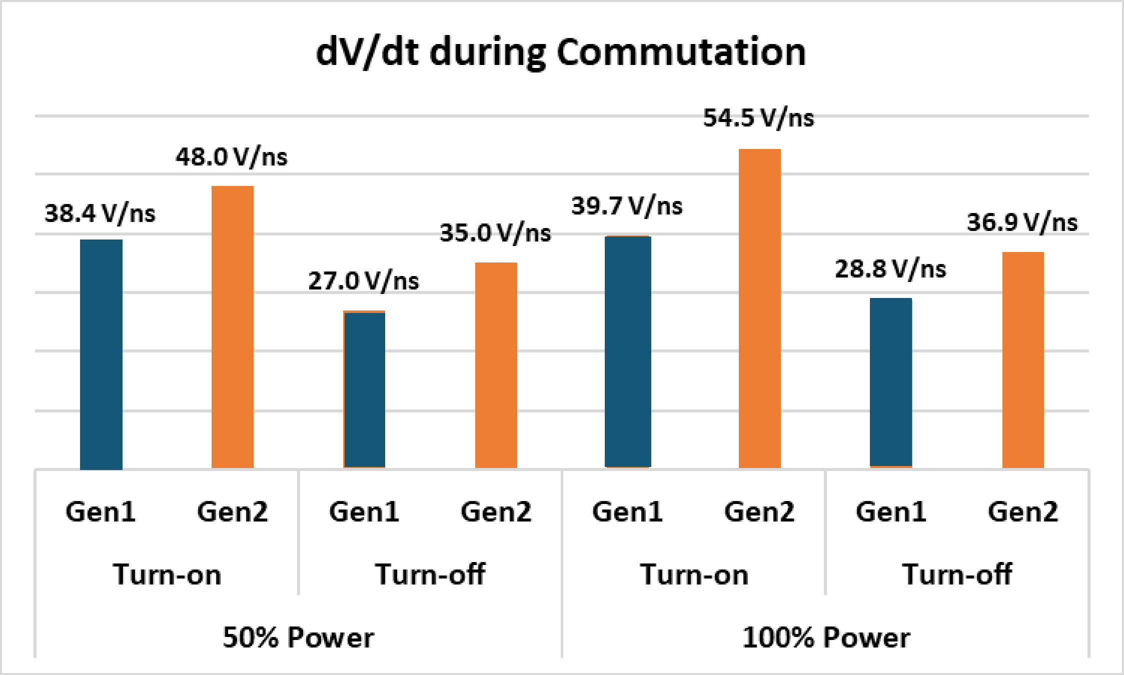
Dynamic Improvements must compensate thermal disadvantages of Conf. 2!

Parameter	Conditions	SCT50N120 (x2)	SCTW70N120G2V-4
C_{ISS}	V_{ds}= 800V, V_{gs}=0, f=1MHz	1900 pF (3800 pF)	3500 pF
C_{OSS}		170 pF (340 pF)	180 pF
C_{RSS}		30 pF (60 pF)	30 pF

Experimental Results

Comparison Gen 1 Vs. Gen 2 SiC MOS





Advantages on System Level

Parameter	Gain
Amount of switch devices	50% less
Heat-sink size	40% smaller
PCB area	26% smaller
Commutation loop size	43% smaller

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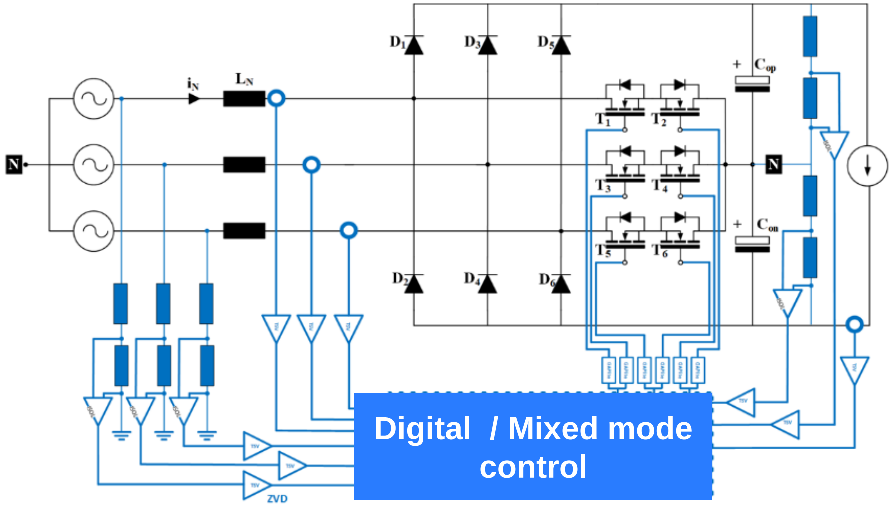
Development Tools & Evaluation Boards

15 kW 3-ph PFC Converter

[Mod. Vienna Type 2]

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



21 kW On Board Charger

In Development

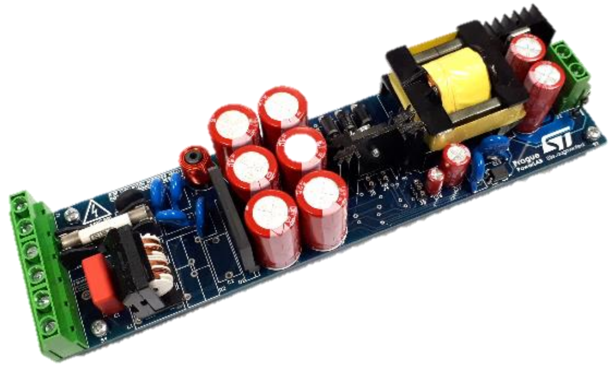
[Totem pole + LLC Resonant]

- STTH30L06GY (rectifier);
- TN3050H-12GY (thyristor);
- STB47N60DM6AG (SJ MOS);
- STPSC20065GY (SiC Diode);
- SPC58NN84E7 (µ-Controller);
- SCTH35N65G2V-7AG (SiC MOSFET).

100W AUX Power Supply

[Flyback]

Coming soon



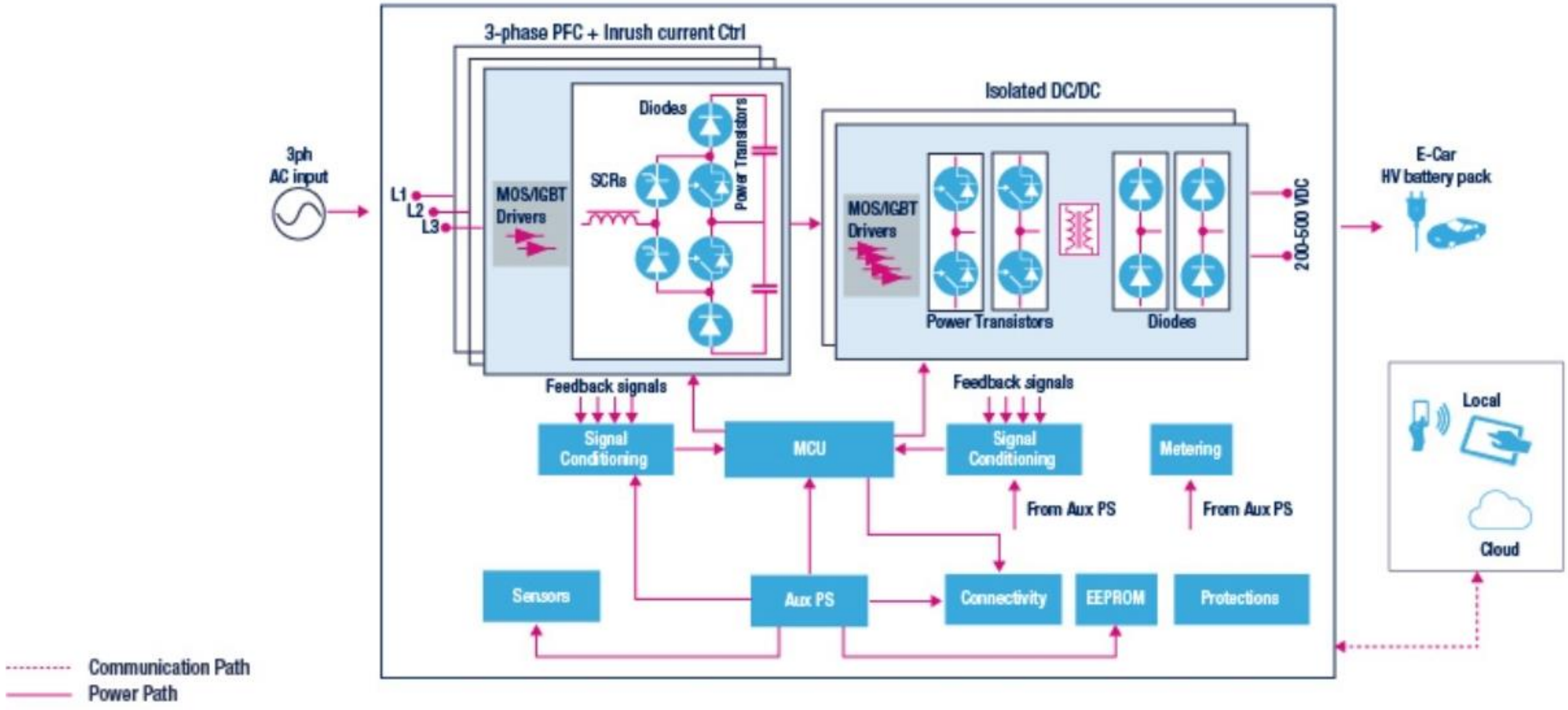
- L6566BH
- STW12N150K5
- STN1HNK60
- STPS10150
- TL431
- STTH112
- 1.5KE120A

Product Links

- **Auxiliary Power Supply**
- 1200V/1500V Super Junction MOSFETs
- Protection Diodes
- Off-line controllers
- Power Schottky diodes

- **Power Circuitry**
- 1200V & 650V Gen 2 SiC MOSFETs
- 1200V & 650V SiC Diodes
- 650V IGBTs
- 600V FRDs
- 650V Super Junction MOSFETs
- Isolated gate drivers
- STNRGPF01 Controller
- STM32 Microcontrollers

Application Tree – EV Charger



https://www.st.com/en/applications/energy-generation-and-distribution/dc-fast-charging-station.html

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Thank You for Your Attention!

Please Place Your Questions and Comments