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EV ENGINEERING

Maximizing Your DC Fast Charger Performance: Innovative Three-Phase PFC Topologies

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Vincotech

Maximizing Your DC Fast Charger Performance:

Innovative Three-Phase PFC Topologies

Agenda

01 / **EV DC Charging**

- Market Overview
- Trends
- System Architectures

02 / **Three-phase PFC Topologies**

- Overview
- Two-Level (2L) vs. Three-Level (3L)
- Benchmark
- Summary

03 / **Vincotech’s Solution**

- Three-phase PFC Product Portfolio

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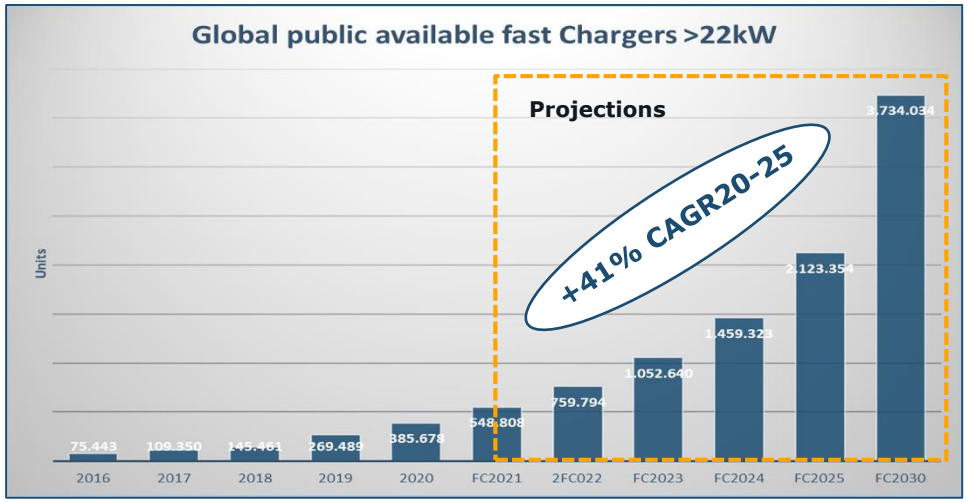
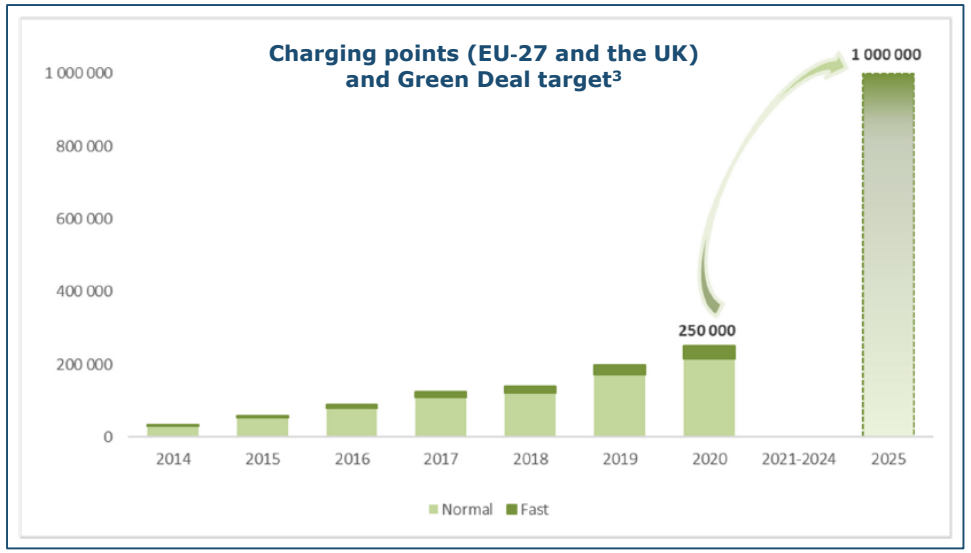
01 / EV DC Charging: **Market Overview**

- The growing EV/HEV market is driving the roll-out of charging infrastructure which is the backbone of the e-mobility
- Global sales of electric cars hit 6.6 million in 2021, more than tripling their market share from two years earlier[1]
- The authors of the European Green Deal[2] policy initiative expect some 13 million zero- and low-emission vehicles to be on European roads by 2025. They will require around a million public recharging and refueling stations
- The global public available fast charger (>22kW) units are expected to growth from 386k units in 2020 to 2.123k units in 2025 which will be a 41% CAGR for the forecasted period



Source: IEA Global EV Outlook 2021

- Unfortunately, the deployment of charging infrastructure lacks behind the targets



➔ Charging infrastructure has to increase the pace to catch the targets for the wide roll out of e-mobility

[1]https://www.iea.org/commentaries/electric-cars-fend-off-supply-challenges-to-more-than-double-global-sales

[2]https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

[3]https://op.europa.eu/webpub/eca/special-reports/electrical-recharging-5-2021/en/

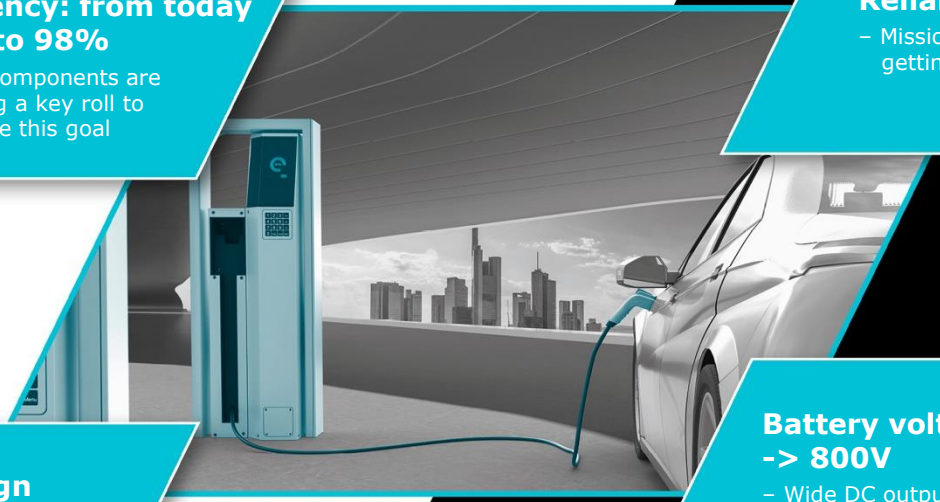
01 / DC-Charger: **Trends and Key Drivers**

Charging will shift towards public and workplace options, as more people without access to home charging start to buy EVs.

There will be a growing need for **DC fast chargers** with nominal power >22kW in the next years

For high power chargers (>30kW):

- The **modular design** is dominant over the monolithic design approach thanks to its benefits of high design flexibility and scalability
- The **power module** solution is preferred rather than the discrete solution with the benefits of optimal thermal management, simplified mechanical assembly, and low parasitic inductance
- **SiC power modules** will gain 16% of the total power module market by 2025* driven by Charging Infrastructure and EV/HEV



Bi-directional charging
- Not yet a global trend
- V2L, V2G or V2H

Efficiency: from today 95% to 98%
- WBG components are playing a key roll to achieve this goal

Reliability
- Mission profiles are getting harder

Modular design
- In the modular approach, a charger is built of several charger stacks connected in parallel

Battery voltage 400V -> 800V
- Wide DC output voltage range (200V->920V)

High power charging stations
- Fast charging
- Public charging and workplace charging
- Destination charging

*Yole report “Status of the power electronics industry: Market and Technology Report 2020”

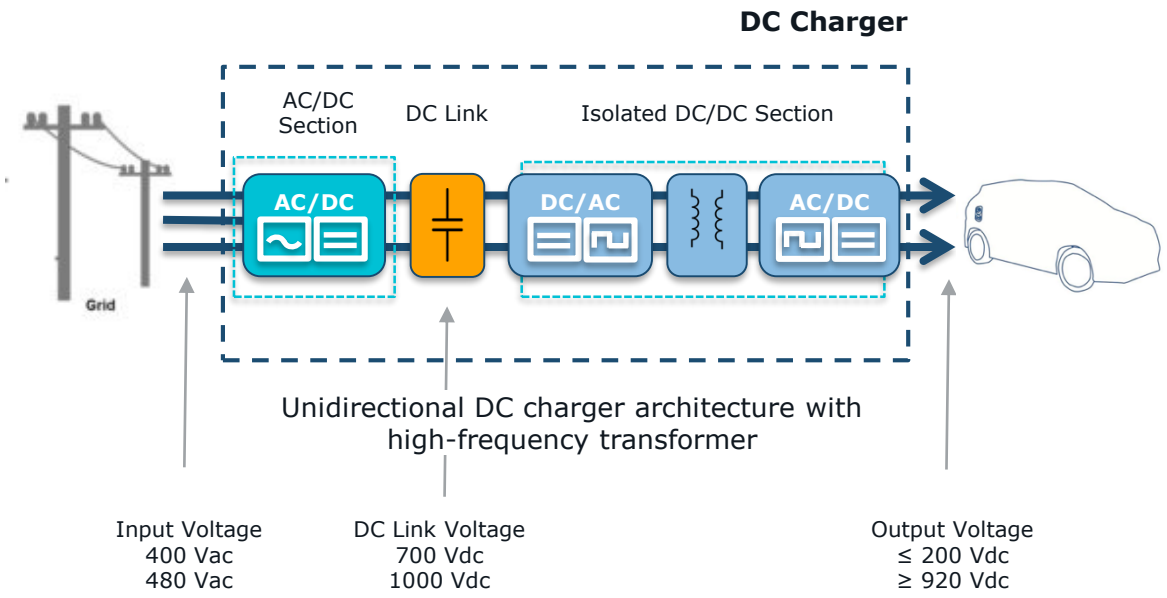
01 / DC-Charger System Architectures

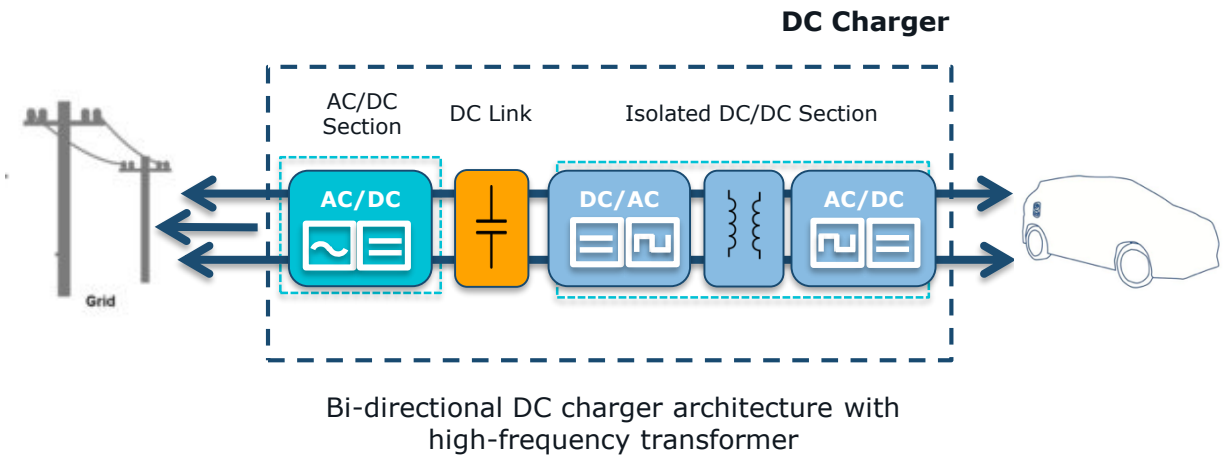
Basic requirements for a charger

- Provide galvanic isolation between the grid and the EV
- Regulate the current and voltage to the battery
- Perform power factor correction (PFC)

Nowadays, the most common system configuration for a DC fast charger contains two conversion stages

- AC/DC: Three-phase active rectification, which performs Power Factor Correction (PFC) and boosts the DC link Voltage
- DC/DC: Isolated DC-DC conversion via high-frequency transformer, which adapts the output voltage and current to the needs of the EV battery





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- **Two-Level (2L) vs. Three-Level (3L)**
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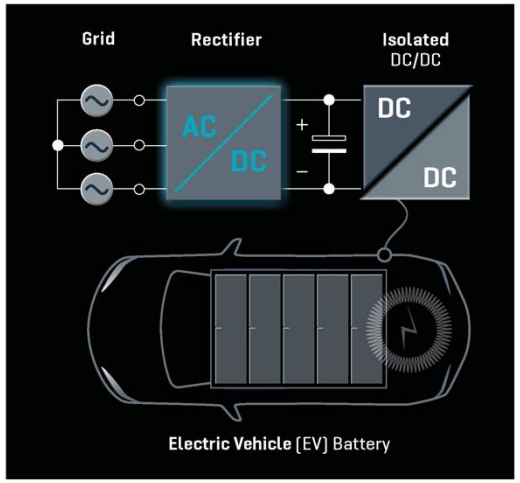
02 / Three-phase PFC Topologies Overview

Why three-phase PFC topologies are becoming great interest in the recent years?

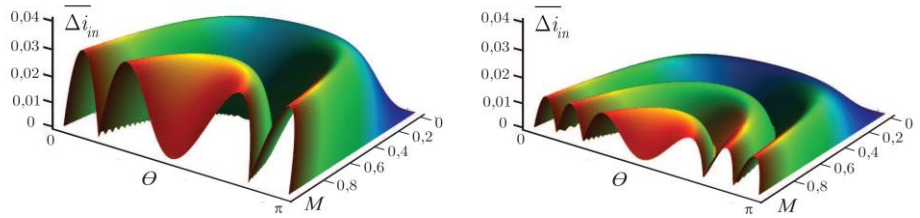
- Fast growing applications like DC fast chargers are accelerating the adoption of three-phase PFC topologies by the requirements for high power density and efficient and effective power distribution and power conversion



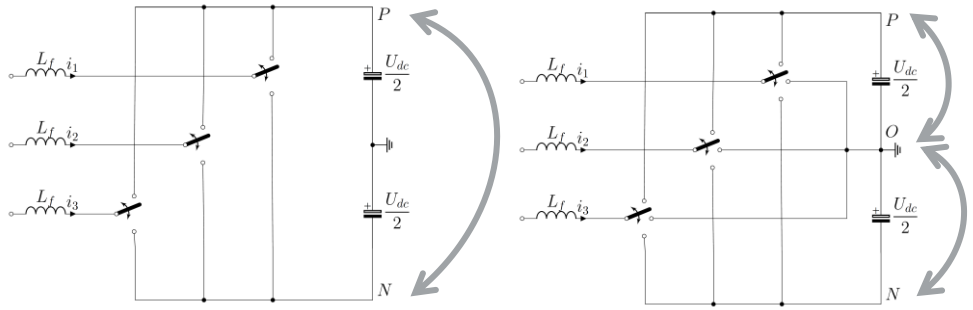
There are several three-phase PFC topologies available, which can be divided mainly in two groups: **two-level (2L) and three-level (3L) topologies**

Each of these topologies will influence

- the blocking voltage rating of the semiconductors e.g. 650 V or 1200 V and as a result, the switching losses and the efficiency
- the total system costs, e.g. PFC inductor size and costs
  - At a given frequency the current ripple at 2L is twice as high as in 3L applications which has an impact on the inductor core material and size
- the thermal management, e.g. heat sink size
- the design e.g. uni- or bi-directional



Inductor current ripple for **2L and 3L** PFC

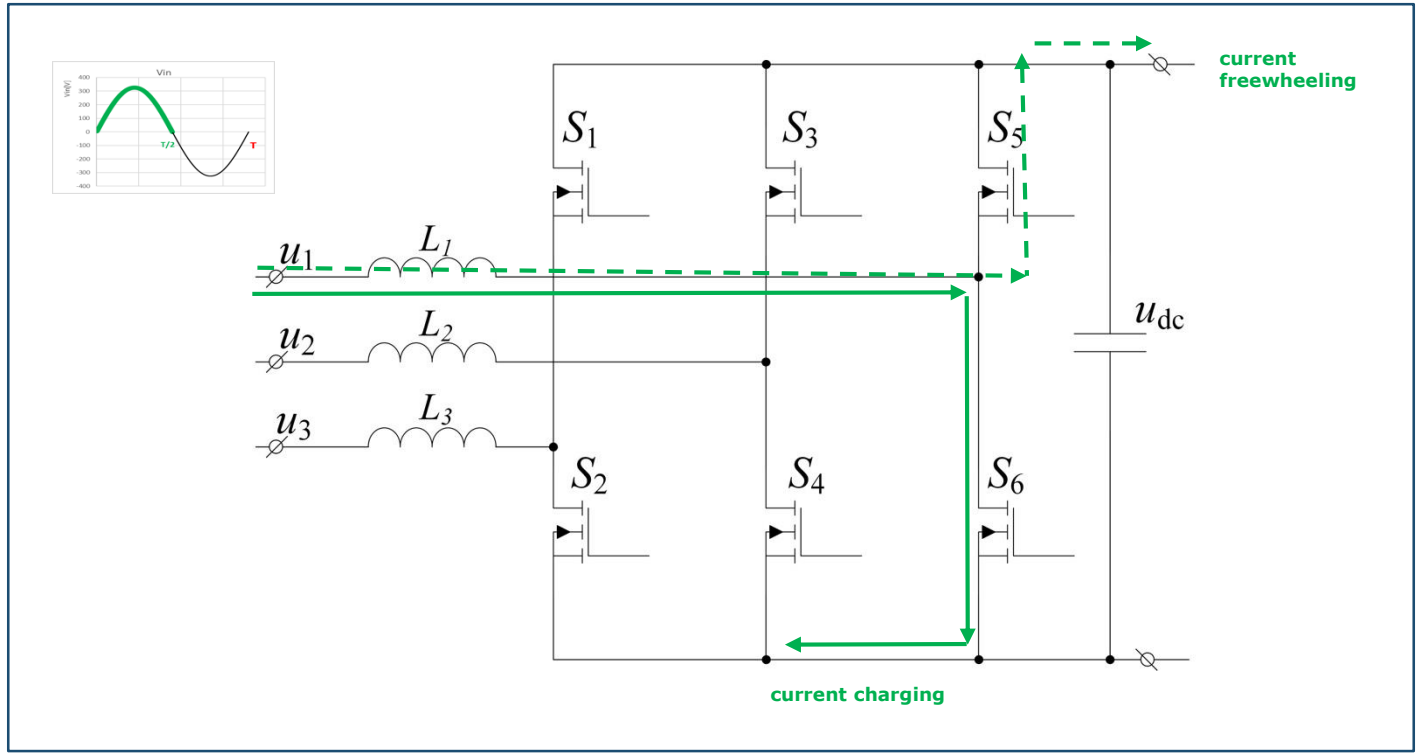


2L and 3L Converter with Ideal Switches

02 / Two-Level (2L) vs. Three-Level (3L)

2L three-phase PFC topologies: The most common used 2L PFC topology is 6PACK PFC - Active Front End (AFE)

- It is the simplest topology and widely used in motion control as a motor inverter. It can be used as PFC in reverse mode
- All switches are 1200V rated which has an impact on the losses. On the other hand only one switch per phase is involved in the power flow at any time
- The control is straight-forward
- Bidirectional by nature



02 / Two-Level (2L) vs. Three-Level (3L)

3L three-phase PFC topologies: Wide range of choice among different 3L PFC topologies

Neutral Boost PFC (**NPFC**, or T-Type)

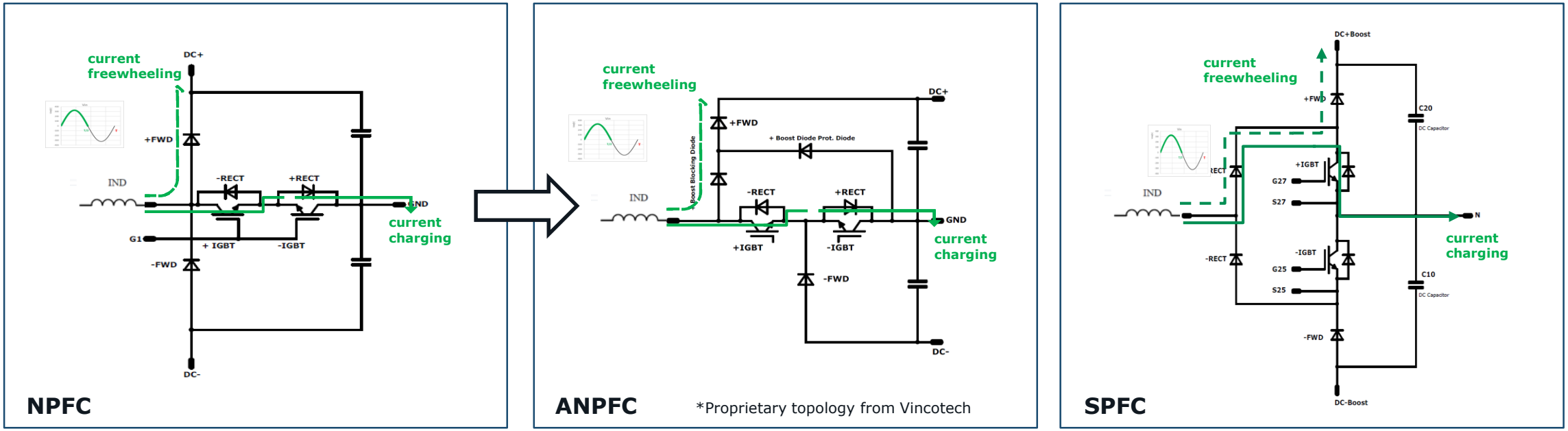
- NPFC uses back-to-back switches, having the same emitter and thus needs only single gate driver
- The switches are 650V rated and the boost diodes 1200V
- The conduction losses are low, as only one component at a time is in series in the current path

Advanced Neutral Boost PFC (**ANPFC)***

- ANPFC is a modified NPFC with 650V rated boost diodes
- Two components are always in series in the current path, thus higher conduction losses than NPFC
- Less costs for the 650V devices vs the 1200V devices

Symmetric Boost PFC **(SPFC,** or I-Type)

- Switches and Diodes are 650V rated
- Two components are always in series in the current path, thus higher conduction losses than NPFC
- Needs separate gate drive for the LS and HS switch

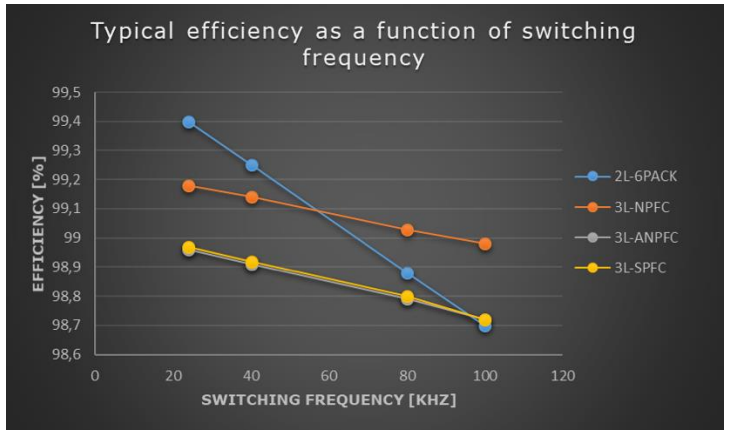


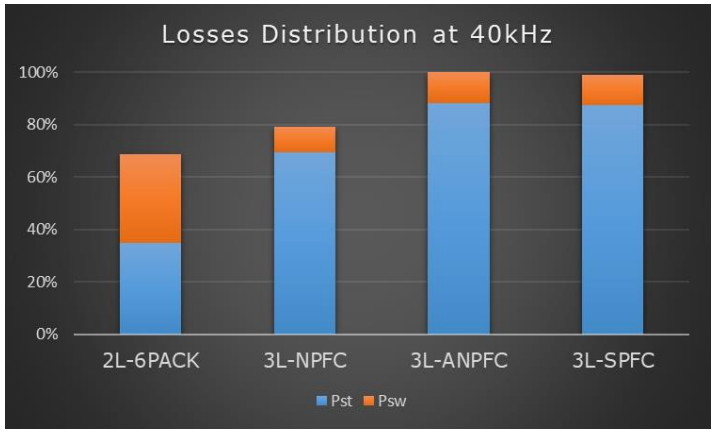
*Proprietary topology from Vincotech

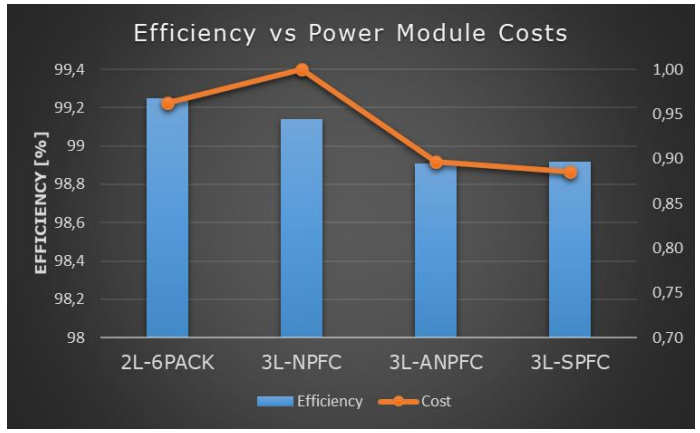
02 / Benchmark

Benchmark of 2L vs 3L in terms of **efficiency and power module costs**

- 30 kW Charger unit (Vin 230A, DC Link 800V, Ths 80°C, **Tjmax <130°C**)
- Similar chip technology for the main devices
  - 2L-6PACK: 1200V/16mOhm SiC MOSFET
  - 3L-NPFC: 650V/22,5mOhm SiC MOSFET and 1200V/60A SiC Diode
  - 3L-ANPFC and –SPFC: 650V/22,5mOhm SiC MOSFET and 650V/60A SiC Diode





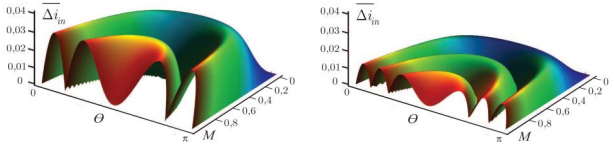


- 2L-6PACK is showing the best efficiency for fsw up to 60kHz, but has also the highest costs compared with the 3L
- NPFC has high efficiency also for higher fsw but with the drawback of higher costs because of the 1200V diodes
- ANPFC and SPFC are showing same efficiency, but ANPFC with single gate drive has a total cost advantage vs SPFC

02 / Benchmark

Benchmark of 2L vs 3L in terms of inductor size and total costs

- PFC Inductor cost depends on the size and the required core material
- Core material suitable for higher ripple and frequency leads to higher cost and bigger size



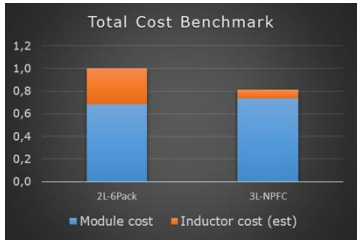
Inductor current ripple for **2L and 3L** PFC

Compact size efficient charger solution could be:

- Inductor core material is given (e.g. Ferrite core) ➔ Inductor size and cost can be reduced
- Efficiency target: 99%

	2L ➡	3L
Inductor size and costs	100%	50%
Switching frequency	100% e.g. 50kHz	200% e.g. 100kHz
Inductor size and costs	100%	**25%**

- ✓ 2L-6PACK: 1200V SiC MOSFET
- ✓ 3L-NPFC: 650V SiC MOSFET and 1200V SiC Boost Diodes

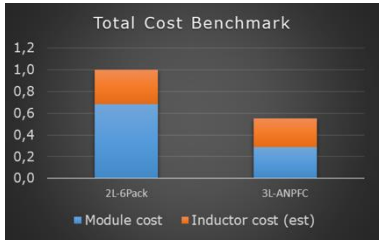


Cost effective charger solution could be:

- Inductor size is given ➔ Module price and Inductor core material price can be slightly reduced (soft iron powder core)
- Efficiency target: 99%

	2L ➡	3L
Switching frequency	100% e.g. 50kHz	50% e.g. 20kHz
Inductor core material (price)	100%	**~90%**
Semiconductor (price)	100%	**60%**

- ✓ 2L-6PACK: 1200V SiC MOSFET
- ✓ 3L-ANPFC: 650V fast IGBT and 650V fast Boost Diodes



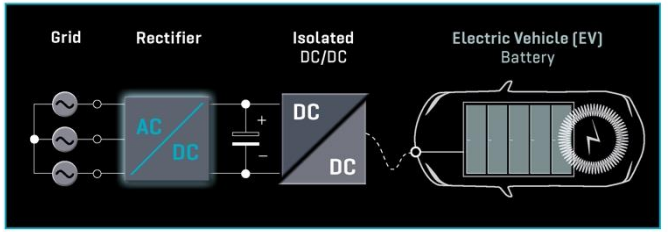
02 / Summary

The table summarizes the pros and cons of each topology discussed in this presentation

	AFE (6PACK)	NPFC	ANPFC	SPFC
Switching levels	2L	3L	3L	3L
Main Switch Voltage [V]	1200	650	650	650
Main Diode Voltage [V]	1200	1200	650	650
Number of devices per phase (fast switches , fast diodes, rectifier diodes, protection diodes)	4	6	8	8
Gate drives / per phase	2	1	1	2
Bidirectional	Yes / no extra cost	Yes / with additional components => extra cost	Yes / with additional components => extra cost	Yes / with additional components => extra cost
Efficiency	>99% (up to fsw 60kHz)	>99% (up to fsw 100kHz)	>98,7% (up to fsw 100kHz)	>98,7% (up to fsw 100kHz)
Overall BOM costs / total cost	High / High	High / Low	Low / Low+	Low / Low

These values are subject to change in particular applications

Conclusion:



- ✓ The AC/DC stage of a DC fast charger can be addressed with several three-phase PFC topologies
- ✓ Depending on the application requirements the pros and cons of the multiple designs have to be considered
- ✓ In practice, the **3L three-phase PFC** topologies combined with **SiC chip technology** show the best trade-off between efficiency and overall total system costs

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03 / Vincotech's Solution

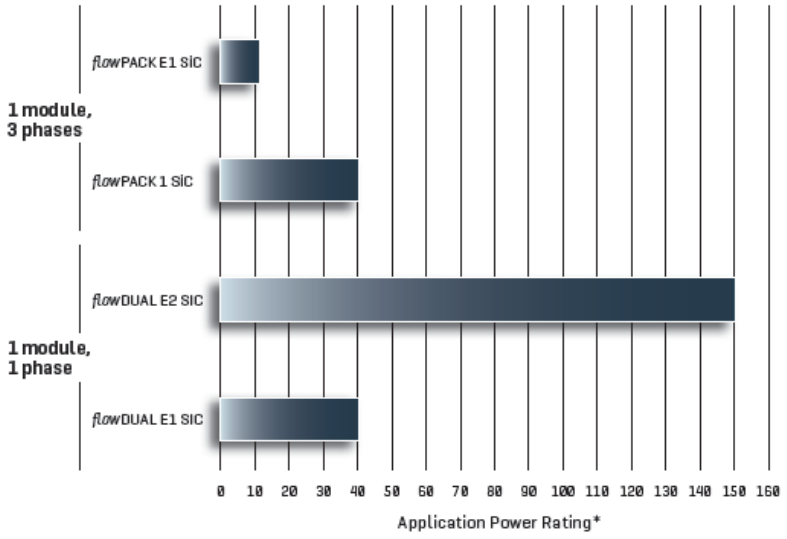
- **Three-phase PFC Product Portfolio**

03 / Three-Level PFC Product Portfolio

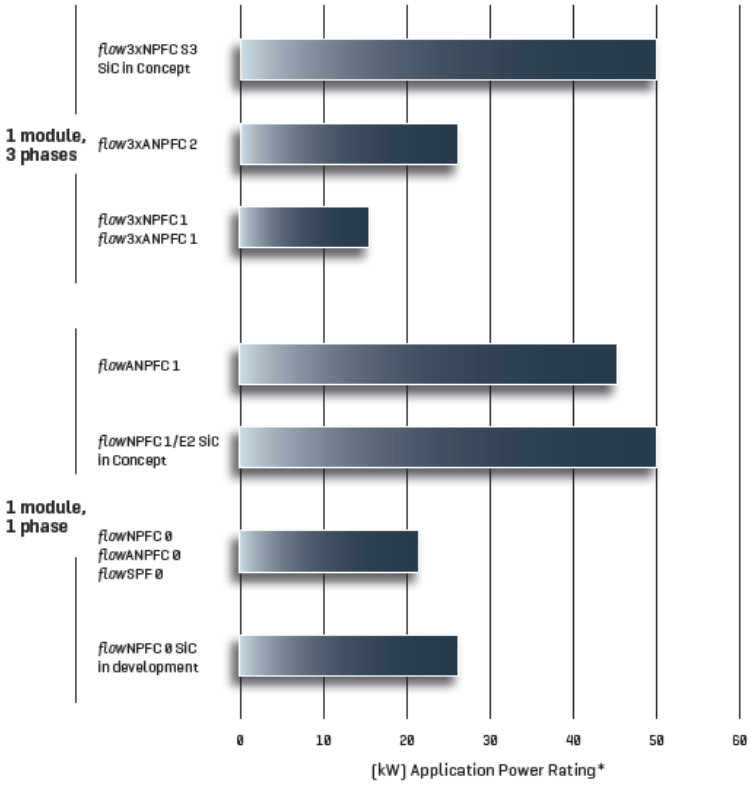
Vincotech is the go-to partner for DC charger power module solutions

Our products support various state-of-the-art topologies used in each of the two power stages in a DC fast charger

Two-level PFC portfolio with SiC MOSFET
(sixpack and half-bridge) for the AC/DC stage



Comprehensive three-level PFC portfolio for the AC/DC stage



Vincotech power modules are well established in many DC Charger applications from EV Charging key players who benefit from:

- ✓ **Higher switching frequency**, lower filtering effort/costs
- ✓ **Multi-sourced SiC-components** for more freedom of choice and lower supply chain risk
- ✓ **Factor >3 improved** power cycling capability for higher lifetime
- ✓ **Press-fit pins and pre-applied TIM** to reduce production cost
- ✓ **Integrated DC capacitors** to mitigate voltage overshoot

EMPOWERING **YOUR** IDEAS

THANK YOU.

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