SPEC

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Power Electronics Empowered EV Charging

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ACKNOWLEDGEMENT

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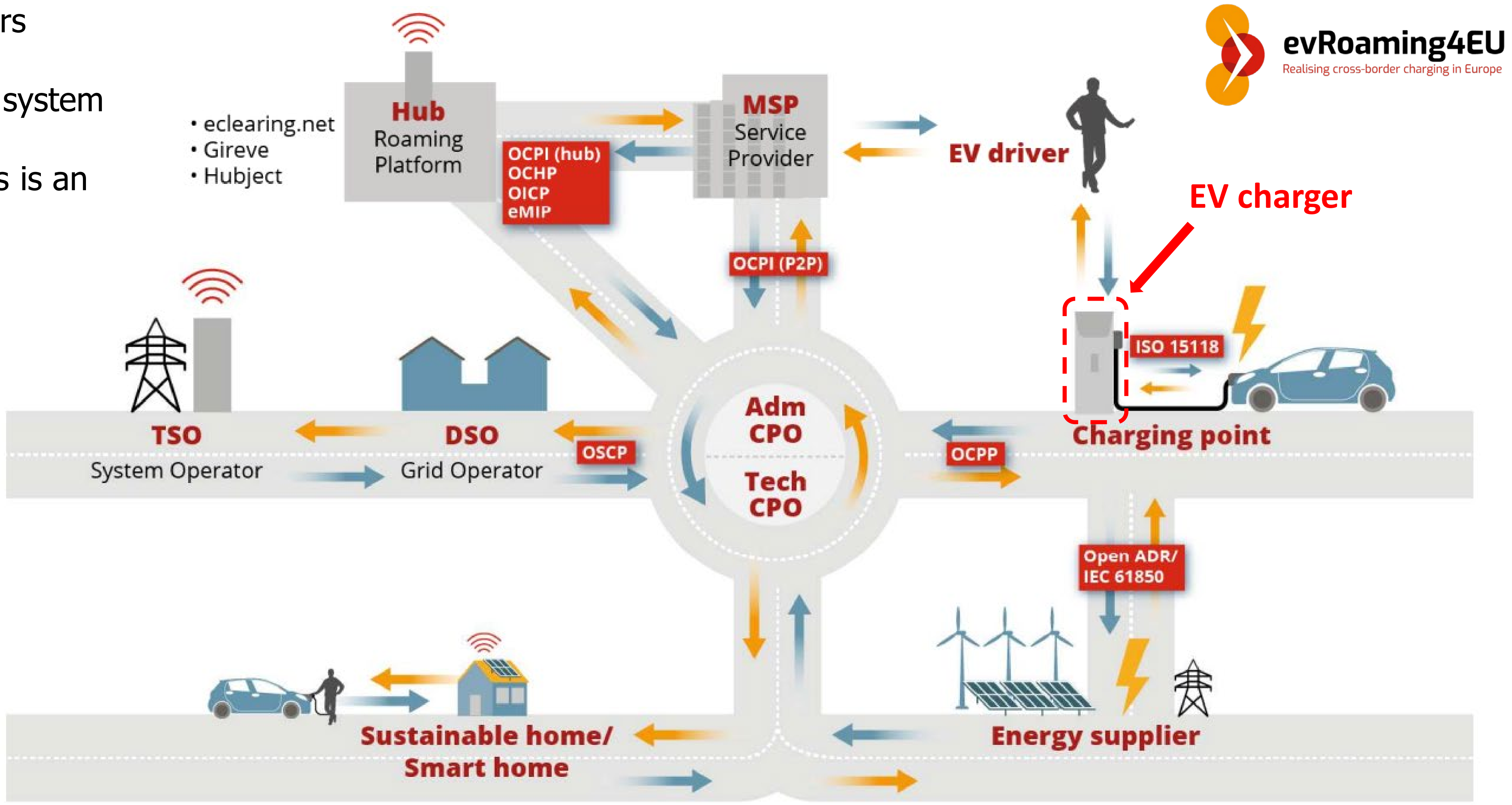
E-MOBILITY ECO-SYSTEM

- Many stakeholders
- A cyber-physical system
- Power electronics is an enabler



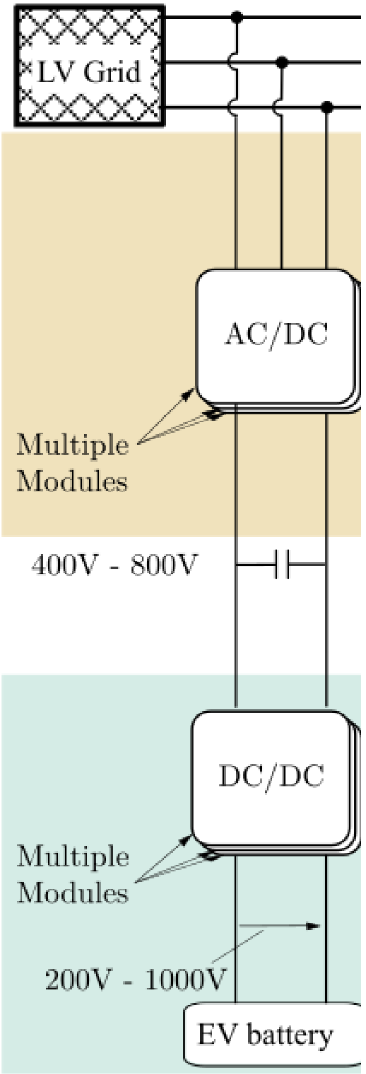
POWER CONVERSION

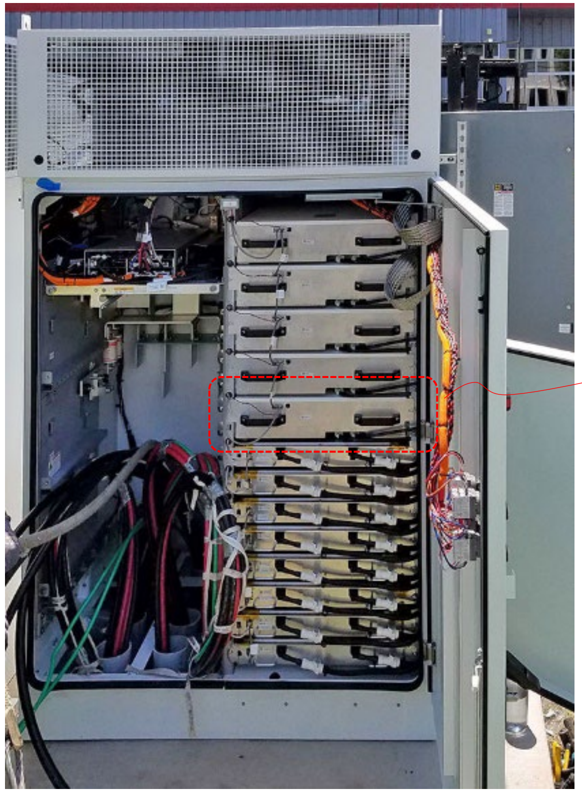
Duties of AC/DC

- To ensure low harmonics
- To ensure high power factor
- Grid support (advanced)

Duties of DC/DC

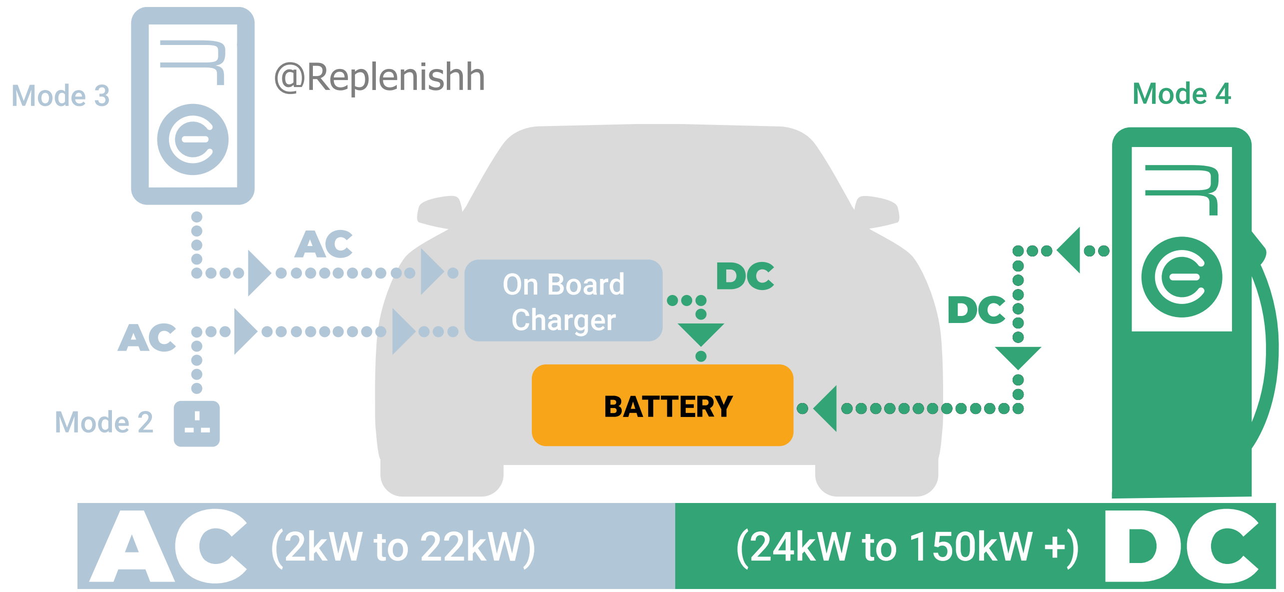
- To control charging current
- To ensure high efficiency even the battery voltage varies a lot

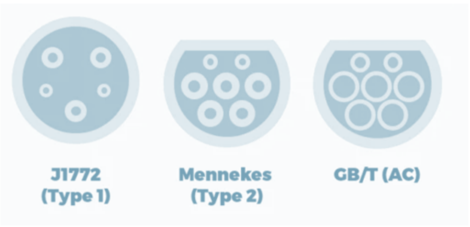


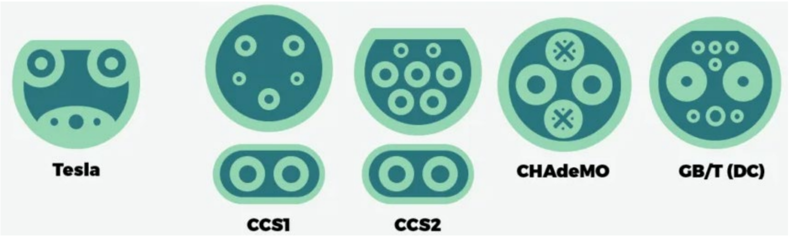


@Tesla

AC VS DC CHARGERS





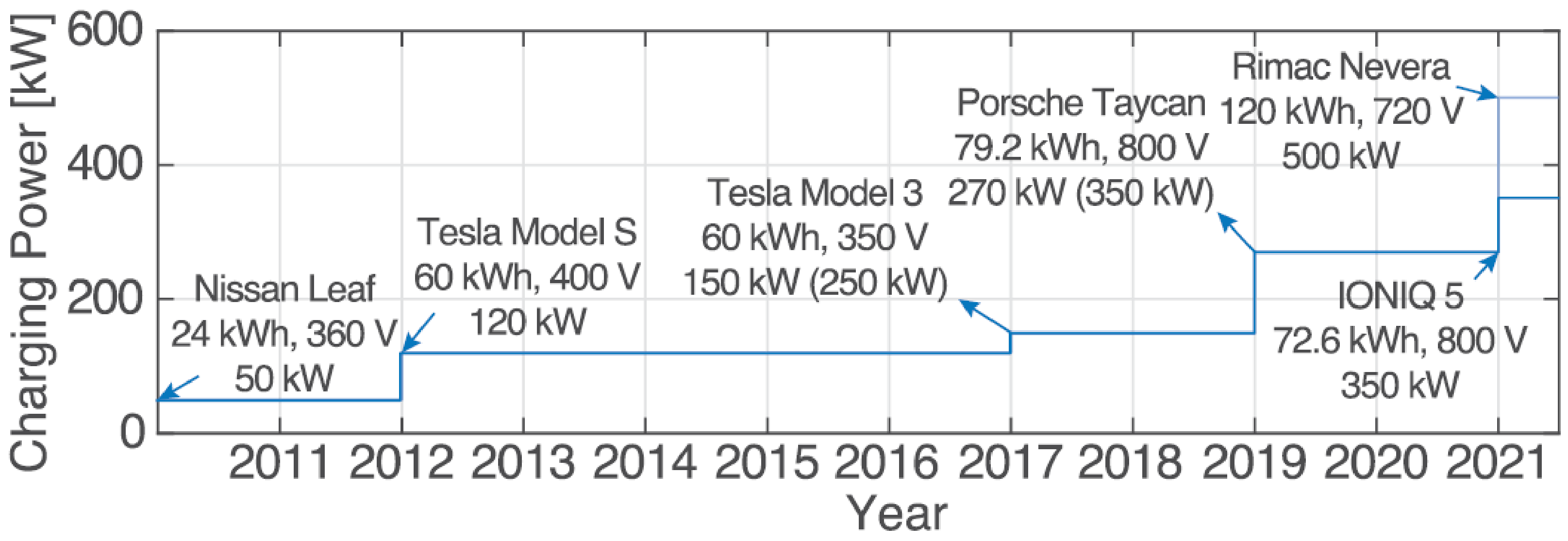


Residential AC charger
(2 kW)

Commercial AC charger
(11 kW)

DC fast charger
(350 kW)

CHARGING POWER IS INCREASING



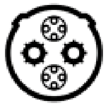
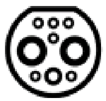
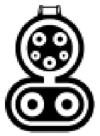
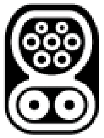
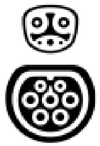
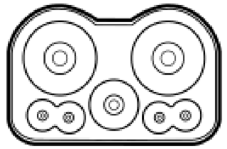
Source: Rivera et al.: Charging Infrastructure and Grid Integration for Electromobility, Proceedings of IEEE, 2023

ABB Terra HP
Max. charging
power 350kW

EVBox Ultroniq
Max. charging
power 350kW

Project Ultra-E:
2 x 350kW CCS
chargers in Leiderdrop

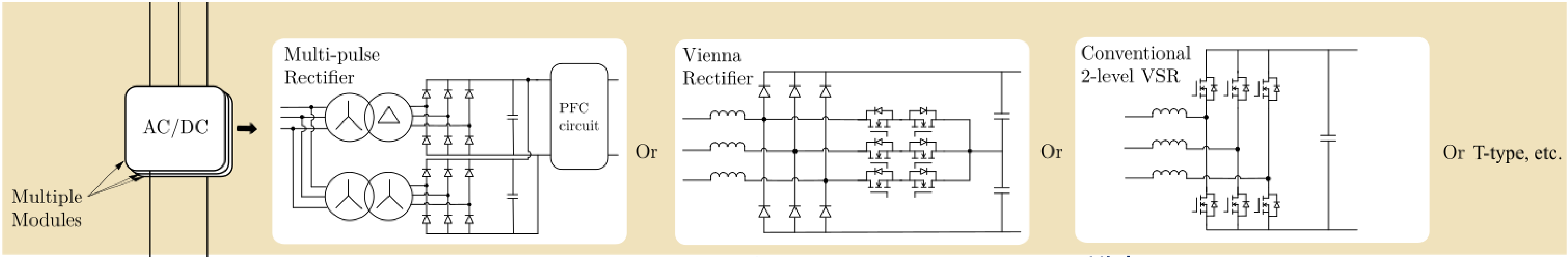
CHARGING POWER IS INCREASING

Standard	CHAdeMO	GB/T	CCS Type 1	CCS Type 2	Tesla	ChaoJi
Compliant Standards	IEEE 2030.1.1 IEC 62916-3	IEC 62916-3	SAE J1772 IEC 62916-3	IEC 62916-3	No related items	CHAdeMO and GB/T (IEC and CCS not yet but is ongoing)
Connector Inlet						
Maximum Voltage (V)	1000	750	600	900	410	1500
Maximum Current (A)	400	250	400	400	330	600
Maximum Power (kW)	400	185	200	350	135	900
Maximum Market Power (kW)	150	125	150	350	120	N.A.
Communication Protocol	CAN		PLC		CAN	CAN
V2X Function	Yes	No			Unknown	Yes
Start year	2009	2013	2014	2013	2012	2020

Source: Netherlands Enterprise Agency, *The Electric vehicle charging – Definitions and explanations*, version January 2019, 2019

L Wang, et al., “Grid Impact of Electric Vehicle Fast Charging Stations: Trends, Standards, Issues and Mitigation Measures-An Overview”, IEEE-OJPE, 2021

POWER ELECTRONICS TOPOLOGIES

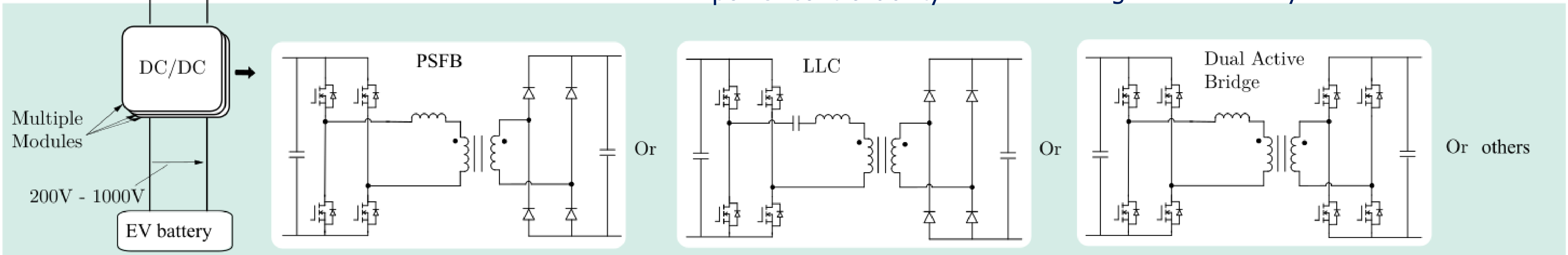


400V - 800V

- Low cost
- Unidirectional

- Medium cost
- Unidirectional with limited Q power controllability

- High cost
- Bidirectional (**V2G enabled**)
- High controllability



- ZVS, difficult in lagging leg
- high conduction loss
- Unidirectional

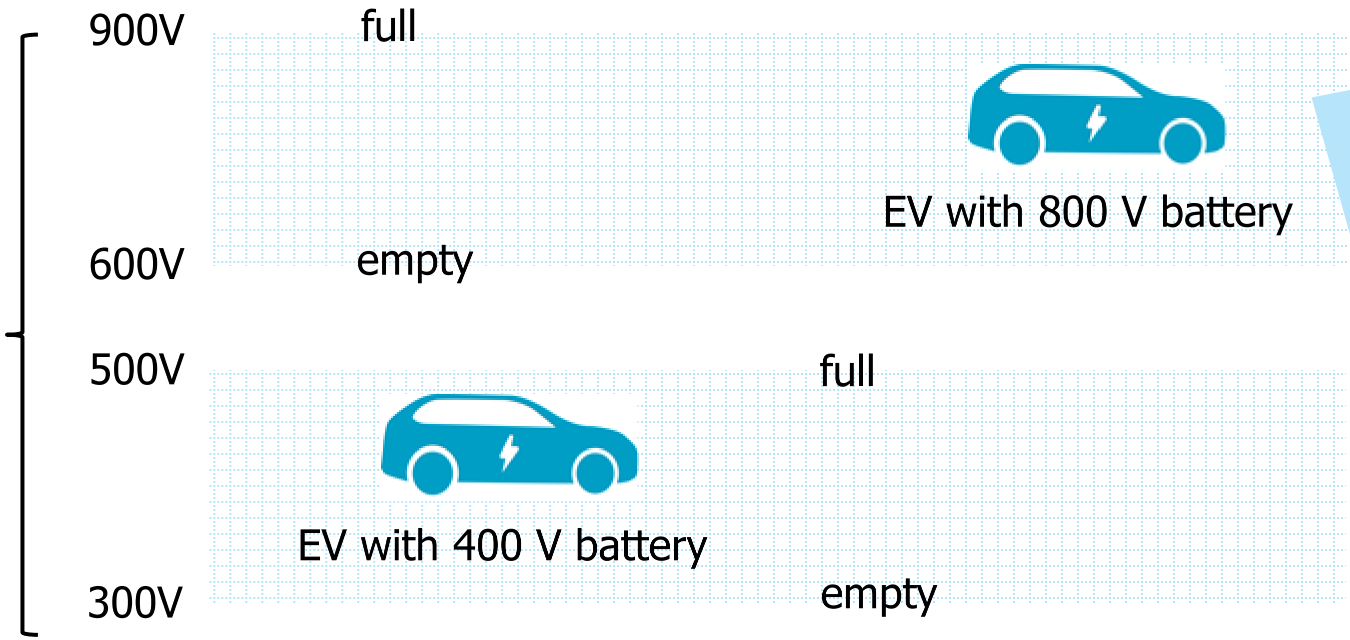
- ZVS
- low conduction loss
- Unidirectional
- Narrow voltage range

- ZVS
- high conduction loss
- Bidirectional (**V2G enabled**)
- Simple bidirectional power control

L Wang, et al., "Grid Impact of Electric Vehicle Fast Charging Stations: Trends, Standards, Issues and Mitigation Measures-An Overview", IEEE-OJPE, 2021

POWER ELECTRONICS TOPOLOGIES

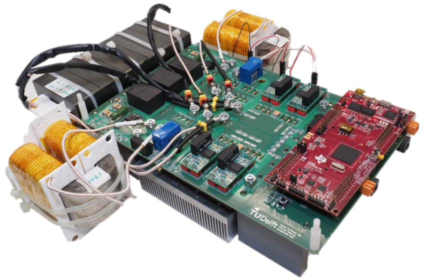
- EVs with 800V battery are increasing in number. Chargers that can cover 300V~900V will have a better market



- Porsche: Taycan
- Tesla: Cyber truck
- Kia: EV6, EV9
- Hyundai: IONIQ 5/6
- BYD: ATTO 3, Dolphin, Seal, etc.
- XPeng: G9
- etc.

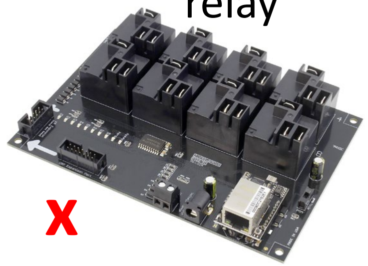
RECONFIGURABLE TOPOLOGY

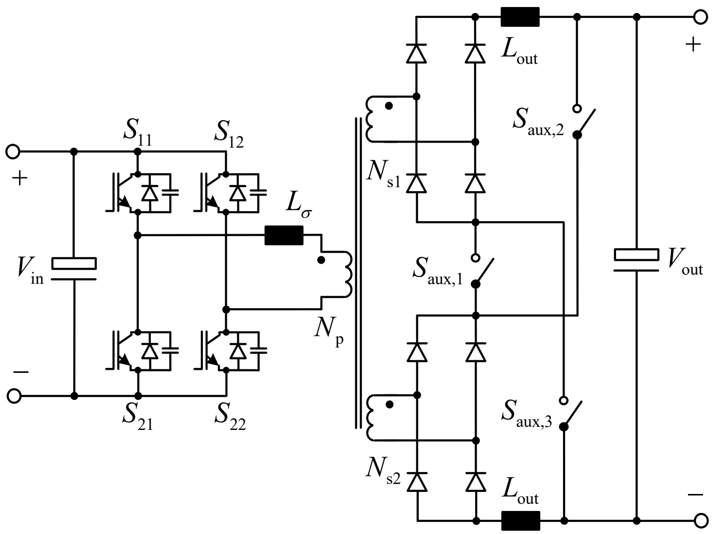
- By switching between parallel and series connection of the two output ports, to reduce the voltage variation of each port

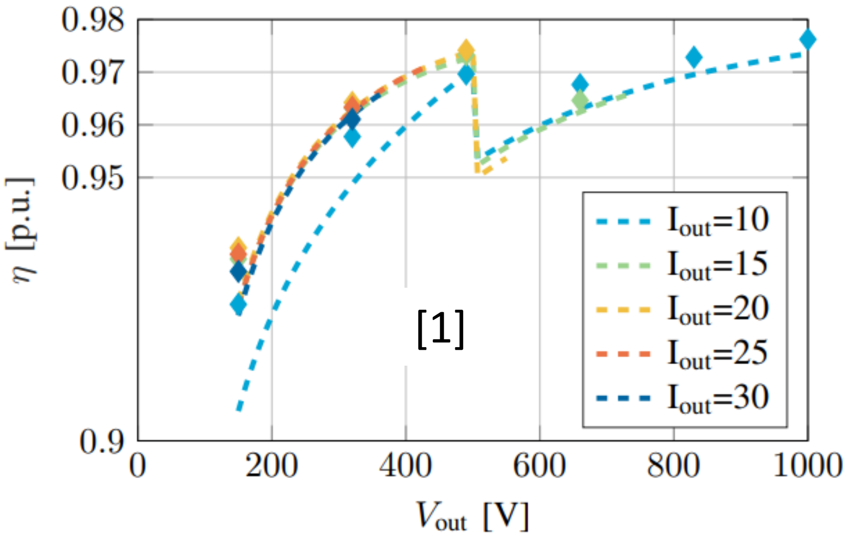


10 kW FSFB module

relay



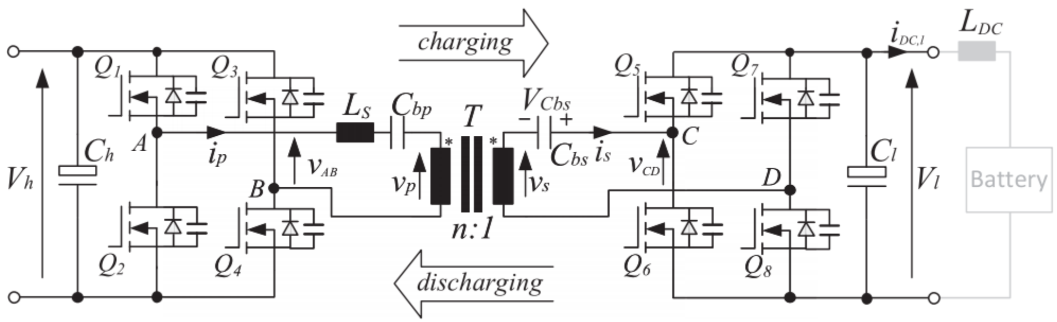




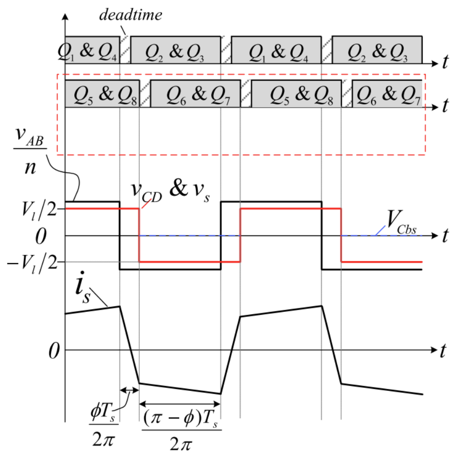
D Lyv, et al., "Design and Implementation of a Re-configurable Phase-Shift Full-Bridge Converter for Wide Voltage Range EV Charging Application," TTE, 2022

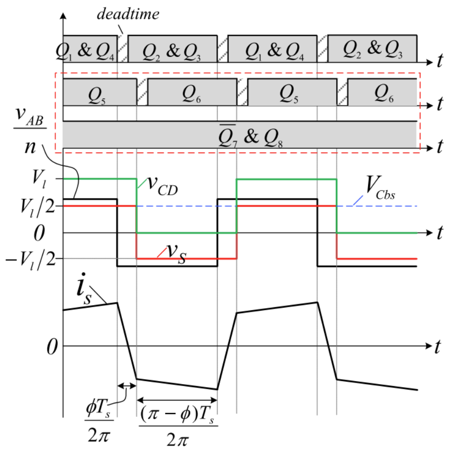
Reconfigurable Topology

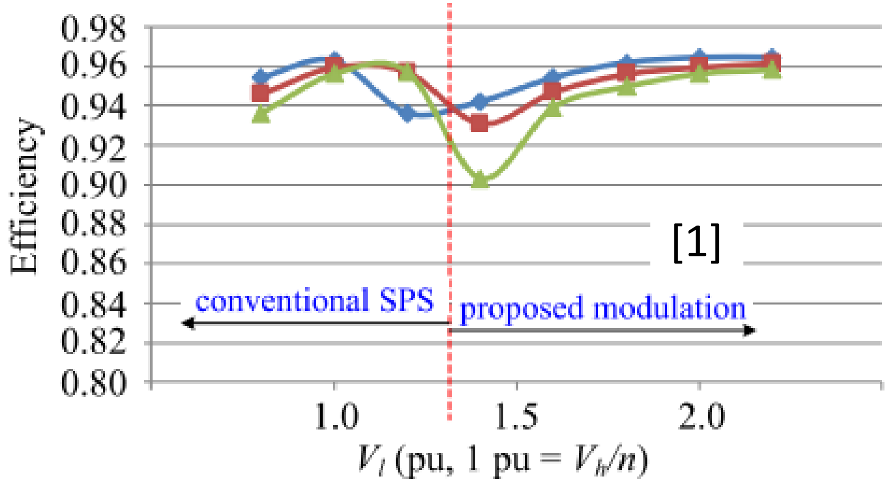
- By changing the operation between full and half bridge, to reduce the voltage variation of the transformer



5 kW DAB module





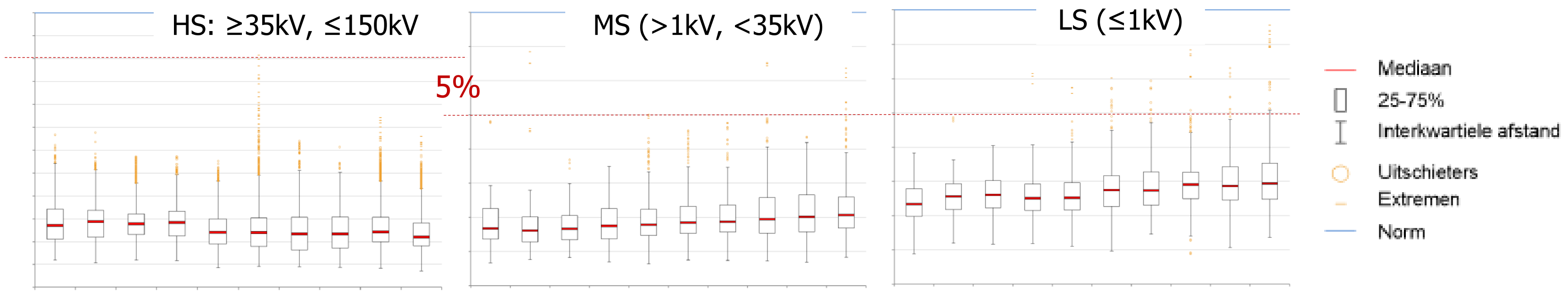


Z Qin, et al., "A Dual Active Bridge Converter With an Extended High-Efficiency Range by DC Blocking Capacitor Voltage Control," IEEE TPEL, 2018

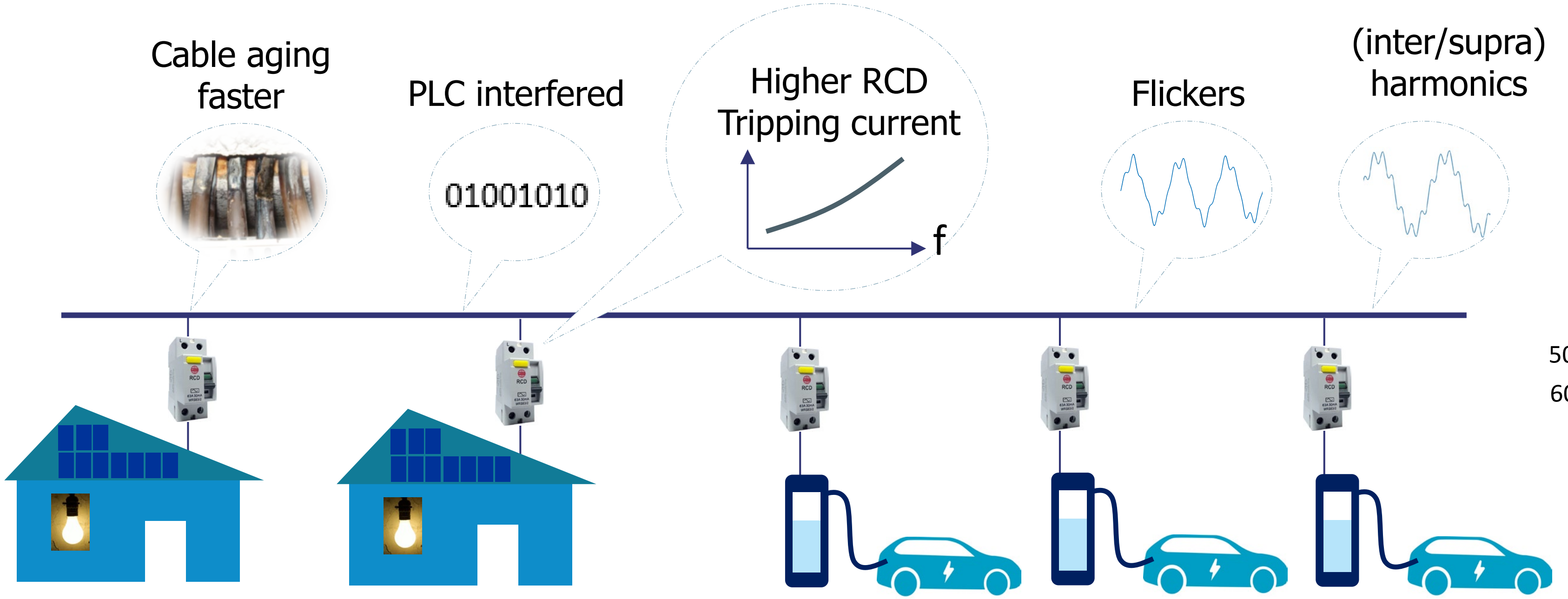
POWER QUALITY ISSUES

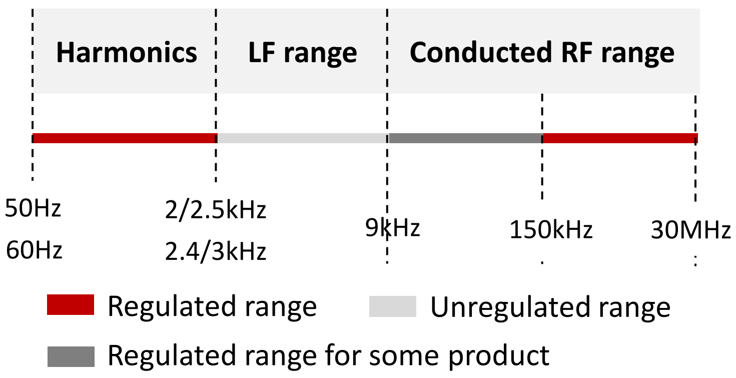
- EV charging are associated with power quality issues, especially flickers and supraharmonics

- Statistics show that harmonics in high voltage grids are reducing, while they are increasing in low and medium voltage grids



Jaartal THD 95% (2011~2020)
Source: Spanningskwaliteit in Nederland - Resultaten 2020

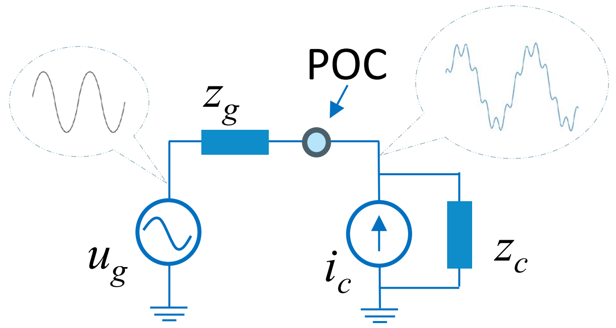




HARMONIC CURRENT LIMITS

- Voltage distortion is an essential concern. Current harmonic limits depending on the short circuit ratio

- Statistics show that harmonics in high voltage grids are reducing, while they are increasing in low and medium voltage grids



Harmonic Current Limits in IEEE-519

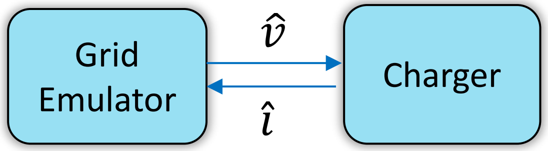
	Maximum harmonic distortion of the individual harmonic order in percent of I_L					
I_{SC}/I_L	$3 \le h < 11$	$11 \le h < 17$	$17 \le h < 23$	$23 \le h < 35$	$35 \le h < 50$	TDD
< 20	4.0	2.0	1.5	0.6	0.3	5.0
$20 < 50$	7.0	3.5	2.5	1.0	0.5	8.0
$50 < 100$	10.0	4.5	4.0	1.5	0.7	12.0
$100 < 1000$	12.0	5.5	5.0	2.0	1.0	15.0
> 1000	15.0	7.0	6.0	2.5	1.4	20.0

Note:
- Limits for even harmonics are 25% of the odd harmonic limits
- DC offset in current is not allowed
- I_L: maximum demand load current
- I_{SC}: maximum short circuit current at PCC

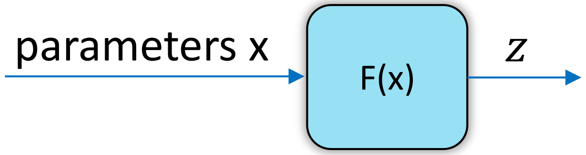
L Wang, et al., "Grid Impact of Electric Vehicle Fast Charging Stations: Trends, Standards, Issues and Mitigation Measures-An Overview", IEEE-OJPE, 2021

Gray box impedance modelling

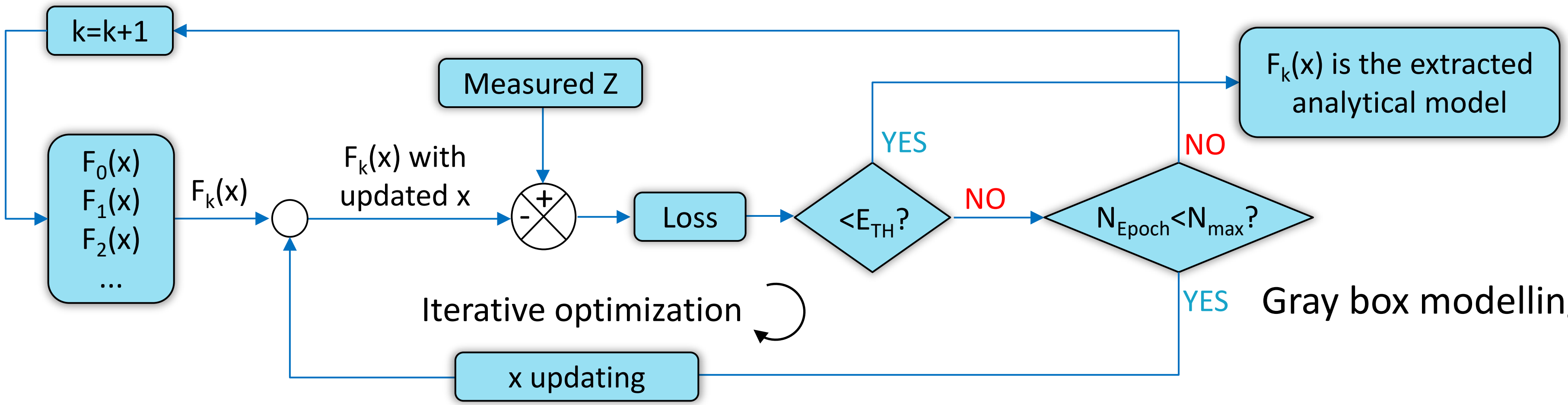
- White box modelling needs the hardware and control parameters as input, but usually unavailable
- Black box modelling does not need the parameters, but cannot cover all the operation range
- Gray box modelling has advantages of both of them



Black box modelling $z = \frac{\hat{v}}{\hat{i}}$



White box modelling

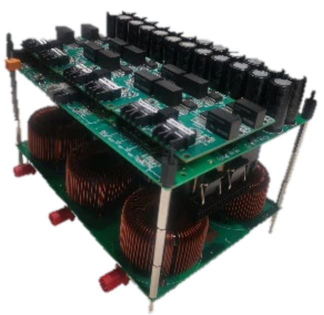


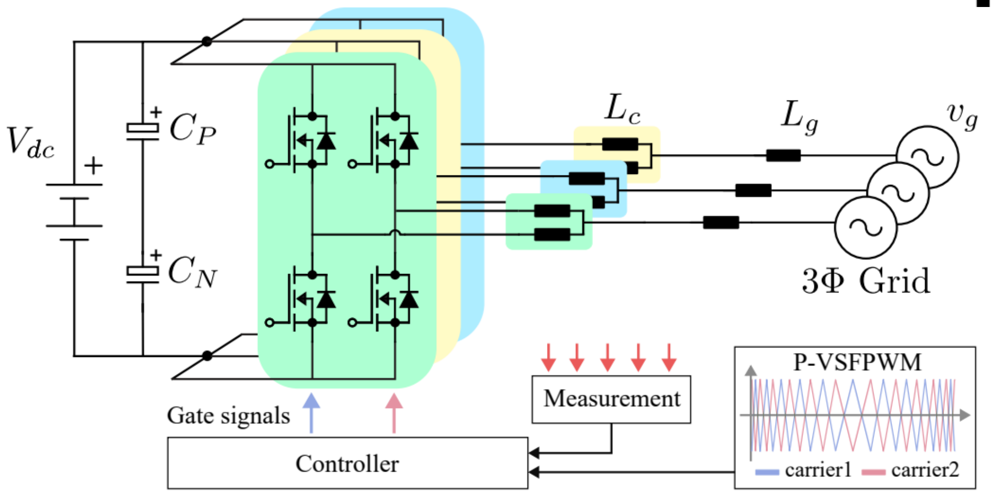
Gray box modelling [1]

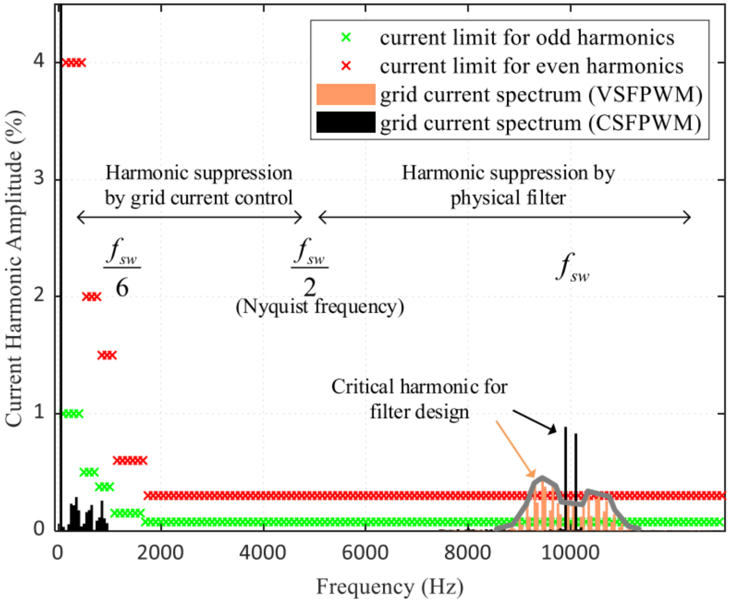
L Wang, et. al. "A gradient-descent optimization assisted gray-box impedance modeling of ev chargers," TPEL, 2023

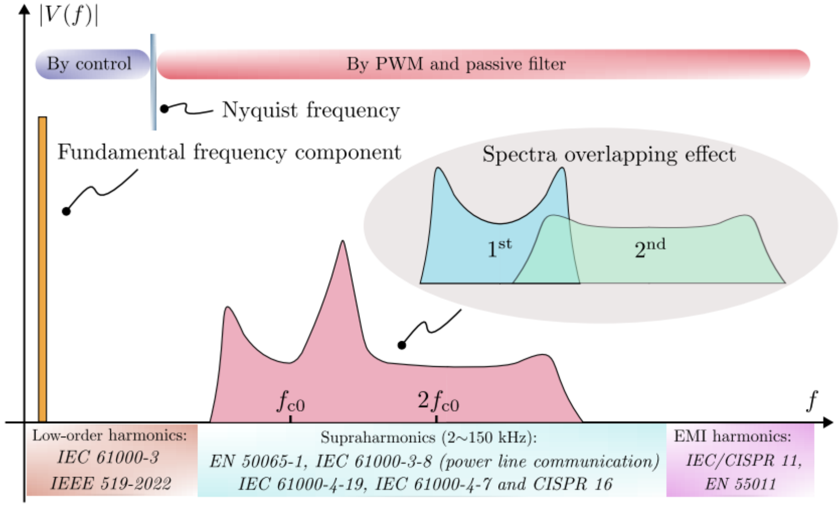
SUPRAHARMONICS MITIGATION

- Fixed switching frequency creates harmonics with high peak
- Variable switching frequency does not change the THD, but will spread out the harmonics around the switching frequency









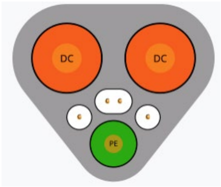
Y Wu, et. al. "Frequency Design of Three-phase Active Front-End Converter with Reduced Filter in EV Chargers," TTE, 2024

MEGA WATT CHARGING

- Medium voltage (10kV) grid connection
- Very high current due to low battery voltage (< 1500V)
- Automated connection due to reduce time loss
- Battery integration to reduce the demand for connected grid capacity

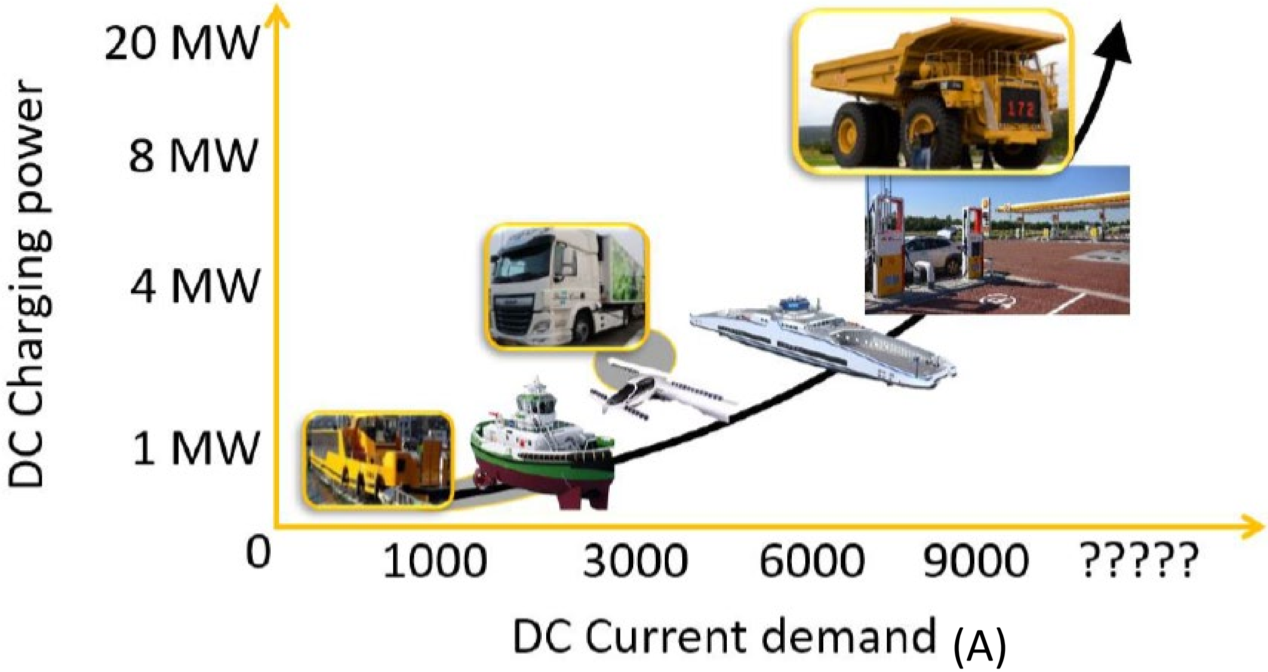
@Cavotec

@Zinus



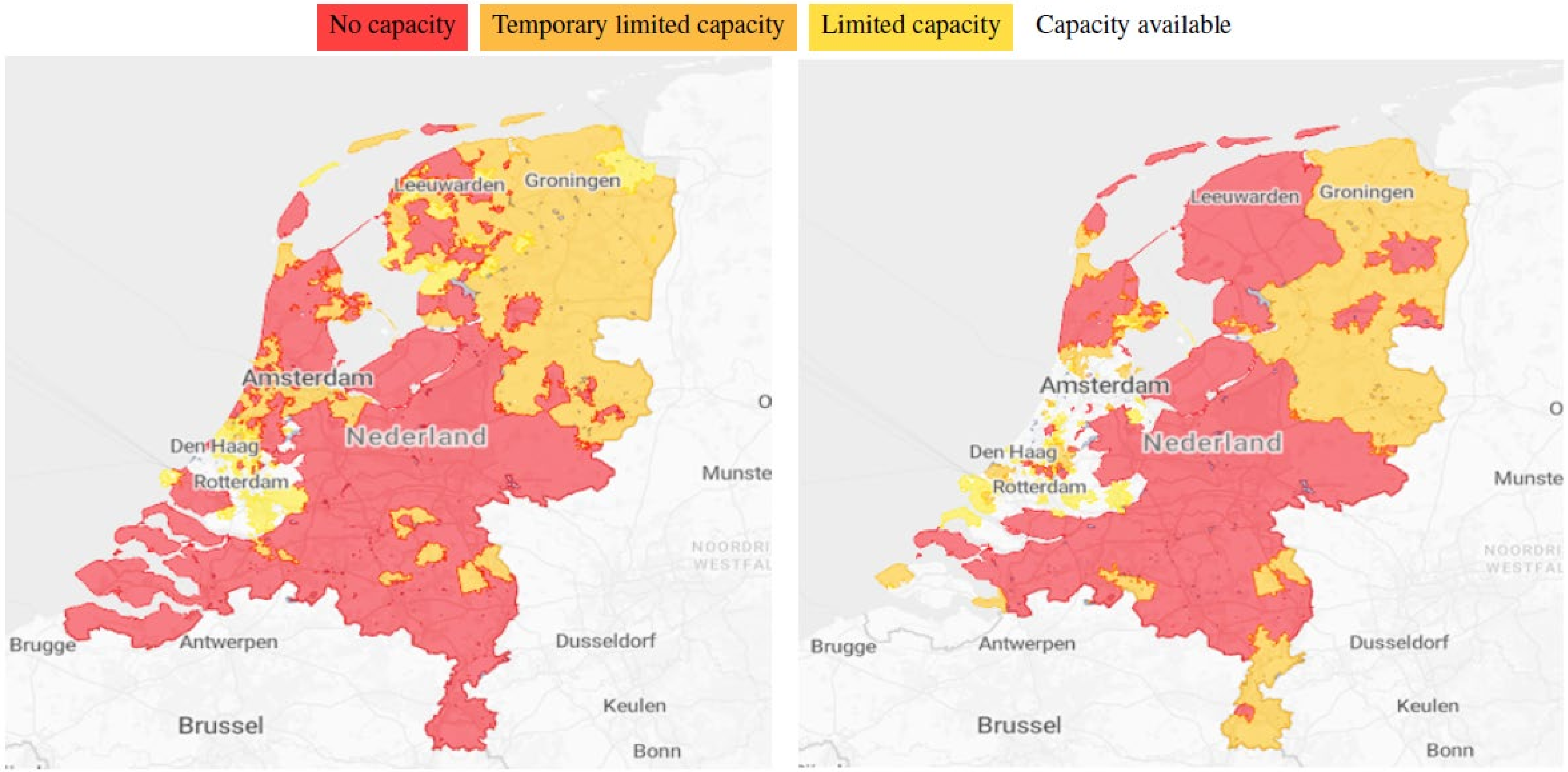
MW Charging System (MCS)
DC, Vmax: 1.25kV, Imax: 3 kA,
Pmax: 3.75 MW

@Cavotec



@ Heliox

GRID CONGESTION

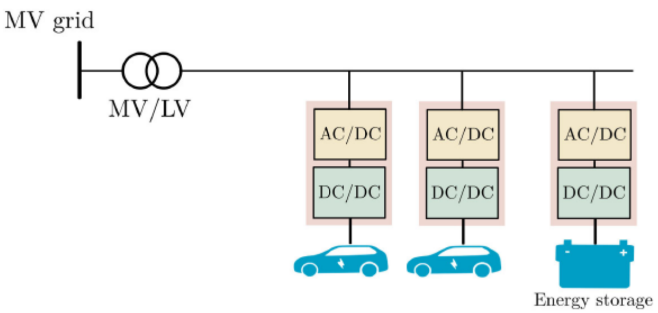


(a) Consumption contingency

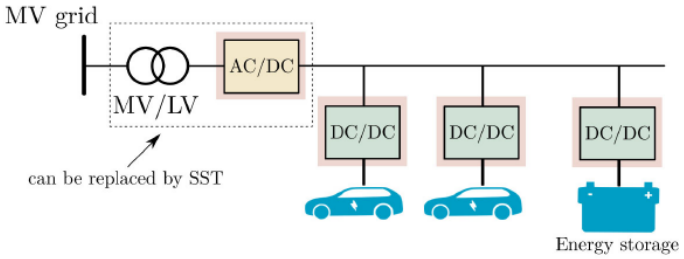
(b) Generation contingency

Source: CFP Green Buildings, Grid congestion: what is it and how can you avoid it?

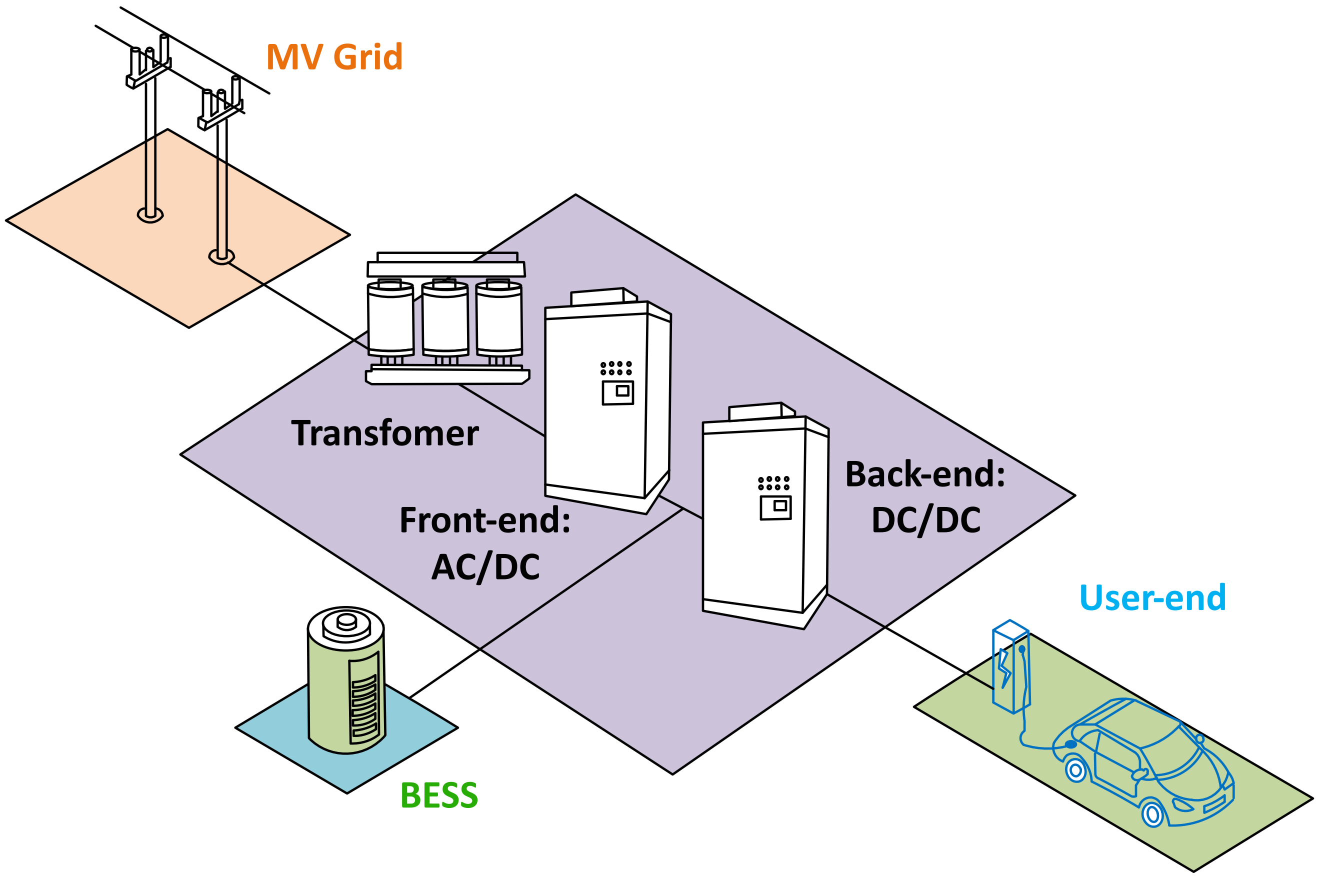
LAYOUT OF THE FAST CHARGING STATION



- Integration of BESS reduces the grid connection capacity and thereby CAPEX

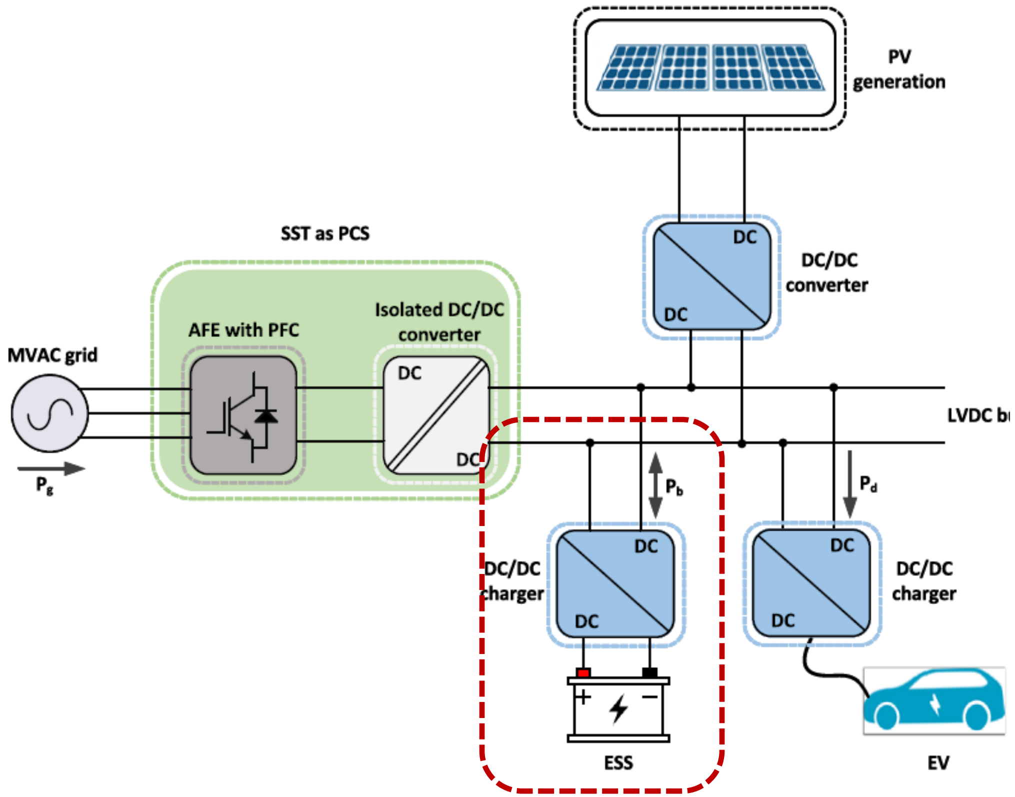


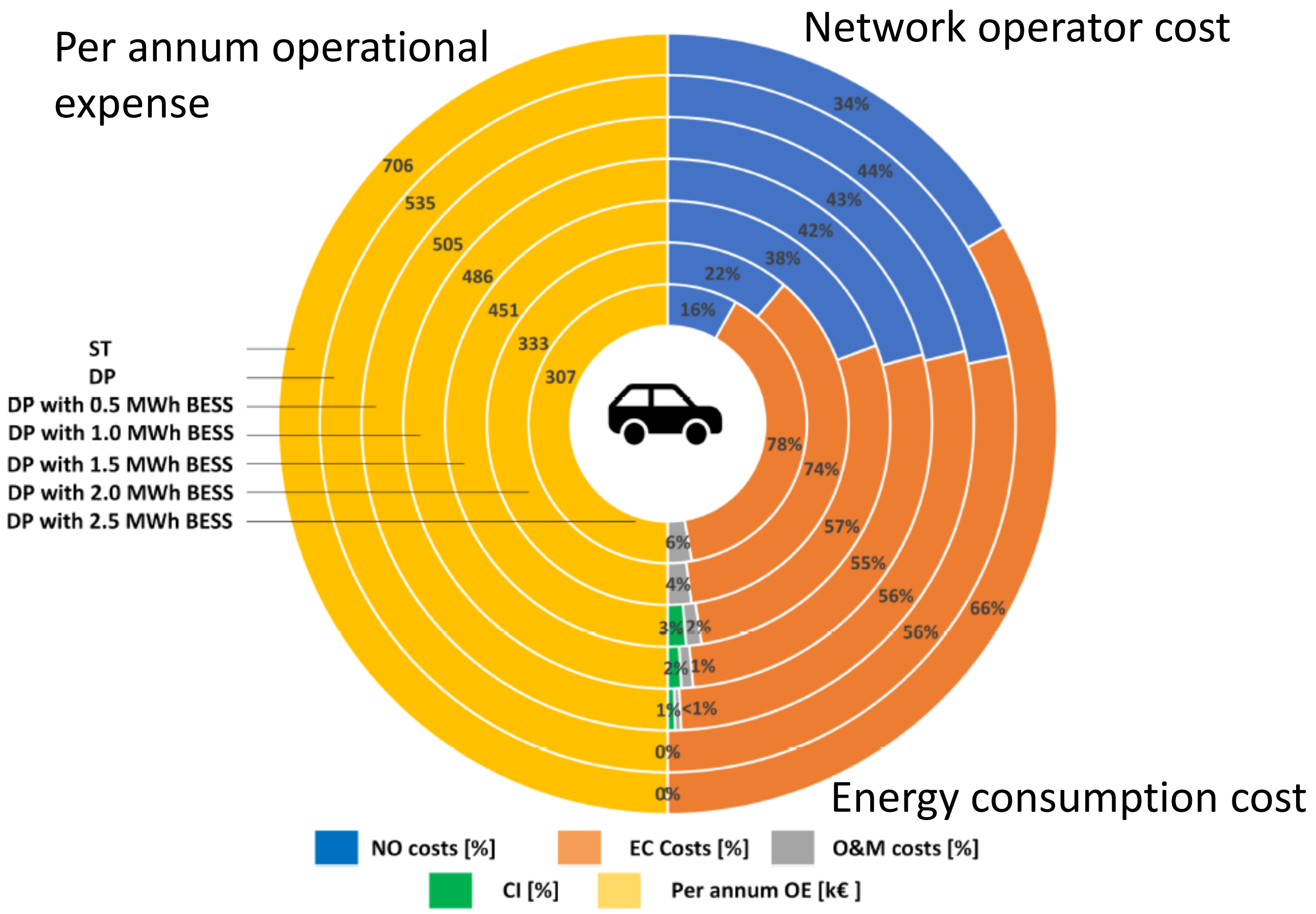
- Less power conversion stages between ESS and vehicles, higher efficiency



Note: if the BESS is integrated, the bidirectional front-end AC/DC is preferred to enable grid ancillary service to maximize the benefit

ENERGY STORAGE INTEGRATION



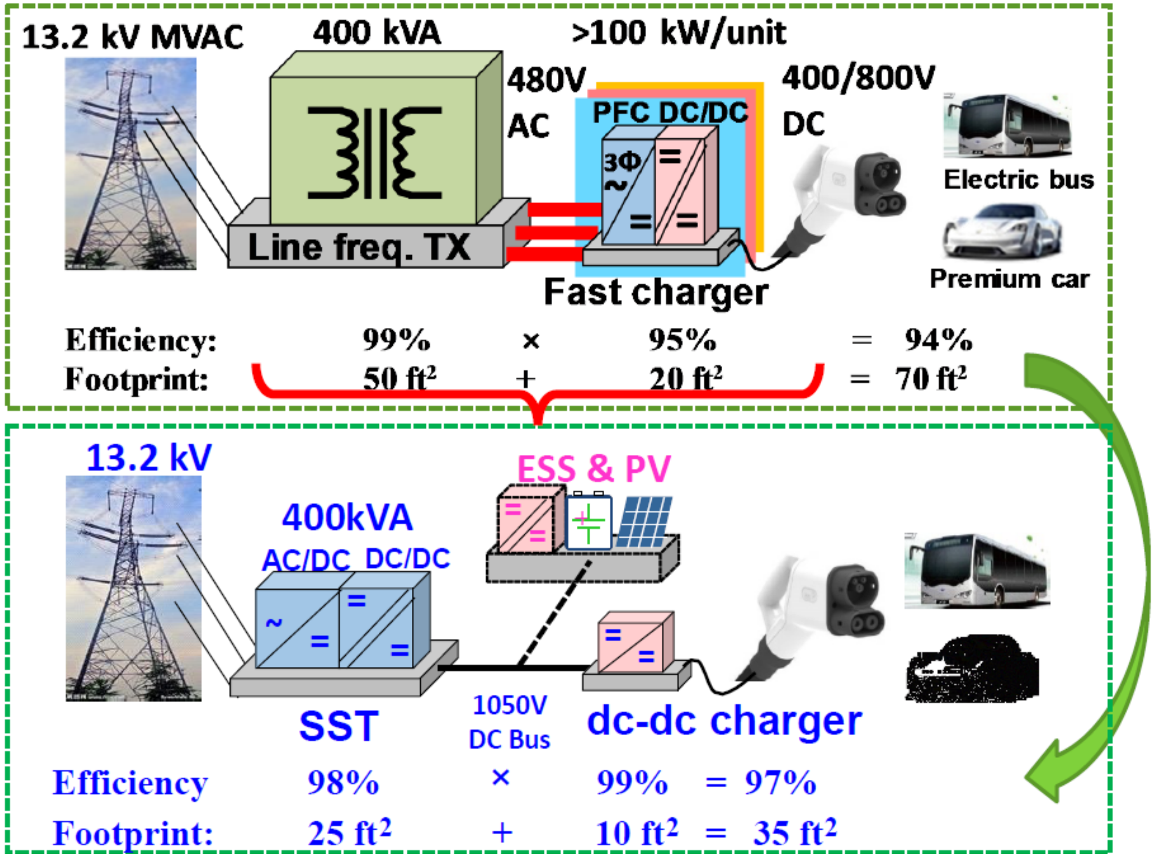


SST BASED MV MW CHARGER

Line Freq. Transformer

SST

Line Frequency Transformer vs SST



3% Eff. Improved

Up to 50% Space Saving

@DELTA

Wrap up

- The offboard charger is increasing in power to reduce the charging time. The battery voltage is increasing to 800 V to adapt to higher charging power. Chargers have to cover from 200~1000 V to have a better market
- In heavy-duty e-transportation, the charger is typically connected to a medium voltage grid and rated at MWs
- For MV MW chargers, SST becomes an interesting for the MVAC/LVDC power conversion
- Grid congestion is becoming more significant. Integration of batteries is promising and necessary to reduce the overall cost of energy, by reducing the grid fee

Thank you!

Contact: z.qin-2@tudelft.nl