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FORUM ELEKTROMOBILITÄT SCHLESWIG-HOLSTEIN

Effizienz als Leitprinzip für Konzepte, Fahrzeuge und Infrastruktur

MULTIFUNCTIONAL AND UNIVERSAL CHARGING STATION

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CHARGING STATION OVERVIEW

CHARGING STATION OVERVIEW

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The electrification of transportation sector needs charging stations in very different contexts

- **Green Airport** - in this case, EV Charging Stations could be placed strategically to supply the local electrical fleet.
- **Logistic Centers** (e.g DHL facilities) and **Public Transport Companies**
- **Urban Parking solutions** in general as commercial parking garages, shopping centers and Airports.
- **Charging Points** alongside the Highway ("truck stop")
- **Industrial Applications** due to the available MVAC connection, MVDC distribution could be applied to supply directly DC Loads and still provides EV Stations.

Megawatt Charging Stations capable to **supply several EVs**, include local **PV** generation, guarantee **V2G** services, and implement energy storage (**BESS**) are starting to become a trending topic at the commercial level.

ATLANTE PROJECT

- **2025:** 1500 CS, with 5000 V2G chargers integrated with BESS and PV.
- **2030**: 9000 CS, with 35000 V2G chargers integrated with BESS and PV.
- **Charging power:** 200 kW or 2x 100 kW
- **BESS:** at least 100 kWh per each charger

[ref] https://nhoa.energy/ev-infrastructure/

Charging Stations with High Integration of ESS and Renewable Energy Sources

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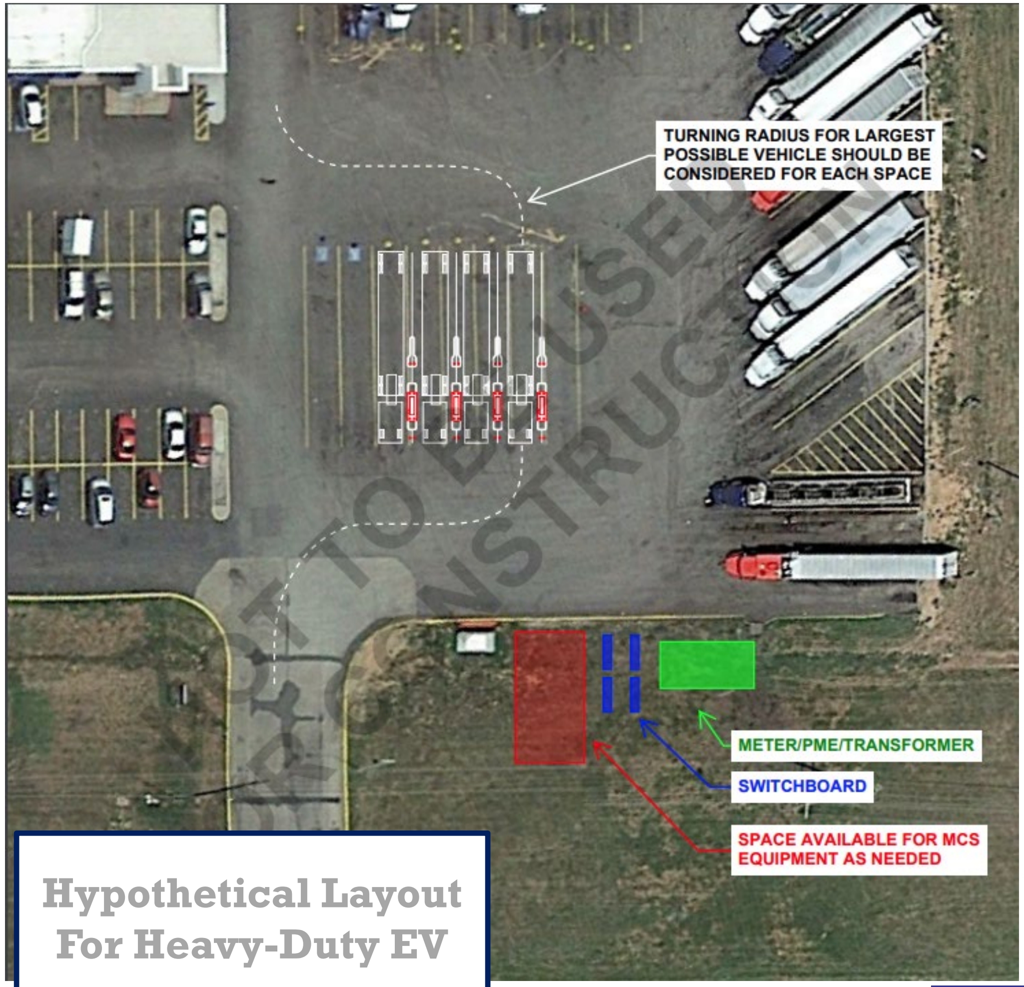
Additional considerations on HDEV Charging:

- New DC Fast-Charging Protocols are for **Heavy Duty Trucks (500 kWh)** are under study.
- At the current stage, CharIN task force is proposing a single connector **bidirectional** protocol capable to reach **4.5 MW** at **1500 V** and **3000 A**.
- Truck are expected to have battery packs of about **500 kWh** but in the future might reach **1 MWh**.
- A truck driver must stop for **45 min** every 4.5 h of driving.
- No more than **10 h of driving a day**.



Hypothetical Layout For Heavy-Duty EV

CharIN - Megawatt Charging System

Charging Stations along the Highway

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Some number about a Highway Service Station:

- **160 car** parking spots over a surface of about **2150 m²**
- **75 truck** parking spots over a surface of about **4900 m²**
- Petrol station with a maximum throughput of about **60 vehicles/h** and **4 truck/h**
- Car average stop time: **30 min**

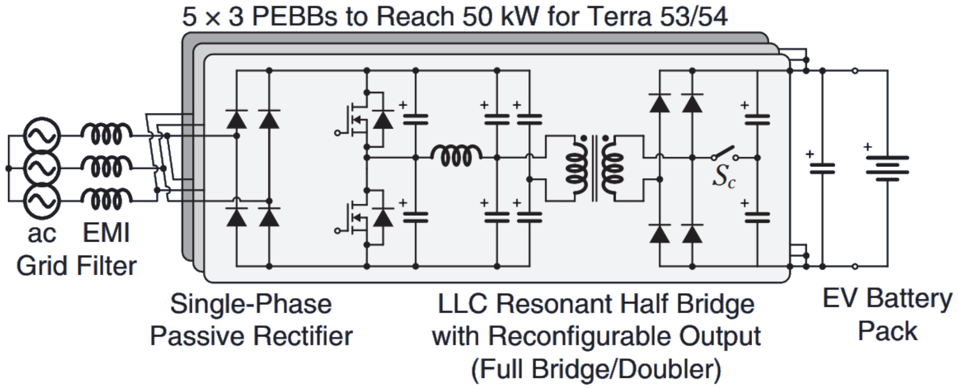
Tank & Rast Raststätte Holmmoor West
BAB7, A7, 25451 Quickborn

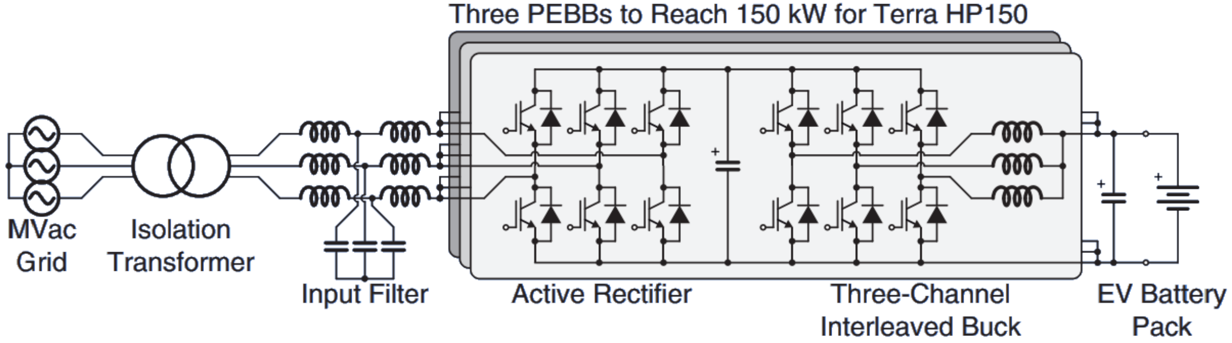
Additional considerations on V2G:

A virtual power plant can provide service to the grid if the **AC** power is at least **1 MW**. In order to generate revenues even when no EV is connected to the EVSE a **BESS** coupled with a DC/DC of at least **1 MW** should be implemented.

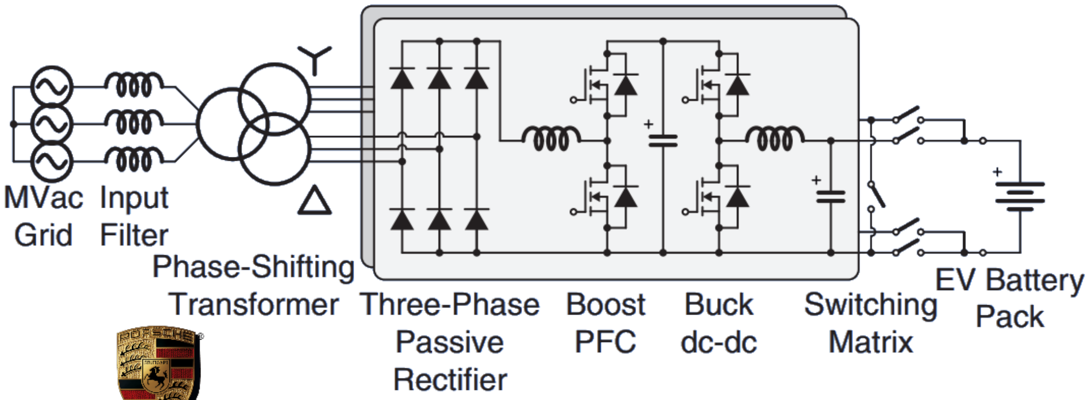
▶ DC Charging Station Overview - Electrical Specifications

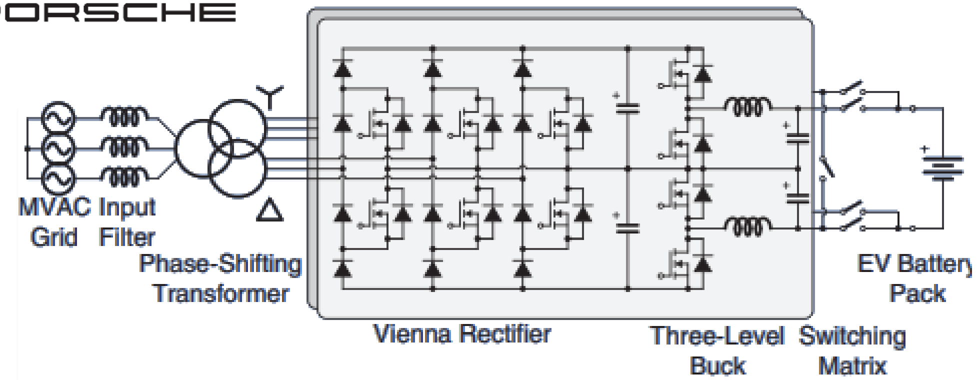
ABB





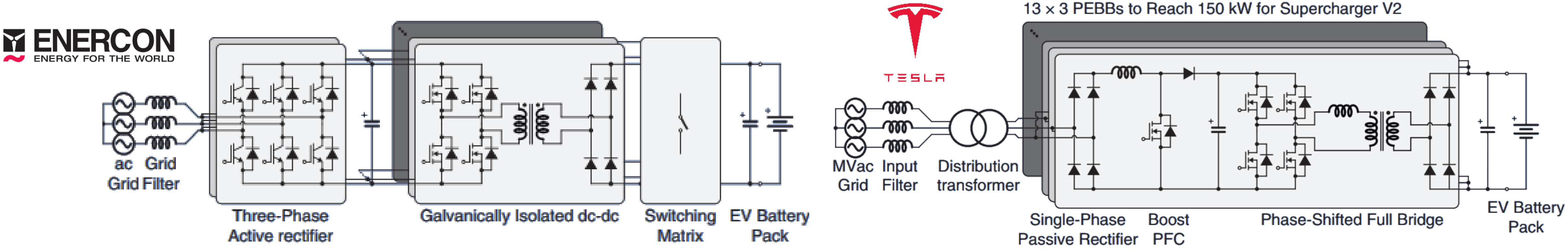
PORSCHE





S. Rivera, S. Kouro, S. Vazquez, S. M. Goetz, R. Lizana and E. Romero-Cadaval, "**Electric Vehicle Charging Infrastructure: From Grid to Battery**," in IEEE Industrial Electronics Magazine, vol. 15, no. 2, pp. 37-51, June 2021, doi: 10.1109/MIE.2020.3039039.

▶ DC Charging Station Overview - Electrical Specifications



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▶ DC Charging Station Overview - Electrical Specifications

The Charging Specifications of some commercially available EVs.

Tesla SuperCharger

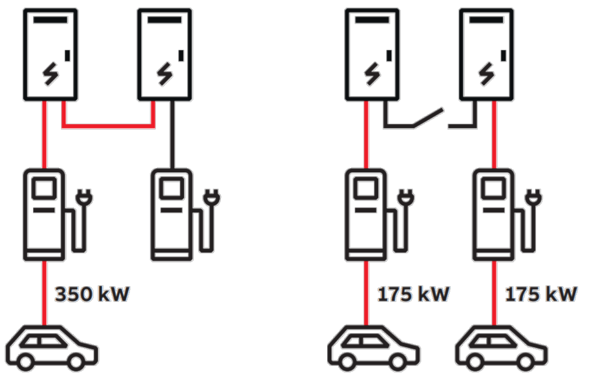
MODEL	MANUFACTURER	BATTERY VOLTAGE	RATED ENERGY (USABLE)	ONBOARD CHARGING POWER (TIME)*	MAXIMUM CHARGING POWER (TIME)*	DRIVING RANGE‡
eCitaro (bus)	Mercedes-Benz	400 V	182 kWh	N/A	300 kW (OPP†) (29 min)	N/A
7900 Electric (bus)	Volvo	600 V	150 kWh	11 kW (10.9 h)	300 kW (OPP†) (24 min)	N/A
Model S, long range	Tesla	400 V	100 kWh (95 kWh)	11.5 kW (10.25 h)	250 kW (38 min)	624 km
E-tron 55 Quattro	Audi	396 V	95 kWh (86.5 Wh)	11 kW (9.25 h)	150 kW (26 min)	436 km
EQC 400 4Matic	Mercedes-Benz	405 V	85 kWh (80 kWh)	7.4 kW (10.5 h)	150 kW (31 min)	417 km
Taycan 4S	Porsche	800 V	79.2 kWh (71 kWh)	11 kW (9 h); 9.6 kW (9.5 h) United States	270 kW (21 min)	407 km
Model 3, long range	Tesla	360 V	75 kWh (72.5 Wh)	11.5 kW (7.75 h)	250 kW (22 min)	560 km
Polestar 2	Polestar (Volvo)	450 V	75 kWh (72.5 Wh)	11 kW (7.75 h)	150 kW (31 min)	470 km
Bolt	Chevrolet	350 V	62.2 kWh (58 kWh)	7.4 kW (8.3 h)	50 kW (66 min)	423 km
Leaf e+	Nissan	360 V	62 kWh (56 kWh)	6.6 kW (11.5 h)	100 kW (35 min)	385 km
Zoe ZE50	Renault	400 V	54.7 kWh (52 kWh)	22 kW (3 h)	50 kW (56 min)	395 km
Ioniq	Hyundai	320 V	40.4 kWh (38.3 kWh)	7.2 kW (6.25 h)	100 kW (20.6 min)	294 km
Leaf	Nissan	360 V	40 kWh (36 kWh)	6.6 kW (6.5 h)	50 kW (40 min)	270 km

S. Rivera, S. Kouro, S. Vazquez, S. M. Goetz, R. Lizana and E. Romero-Cadaval, "**Electric Vehicle Charging Infrastructure: From Grid to Battery**," in IEEE Industrial Electronics Magazine, vol. 15, no. 2, pp. 37-51, June 2021, doi: 10.1109/MIE.2020.3039039.

▶ DC Charging Station Overview - Electrical Specifications

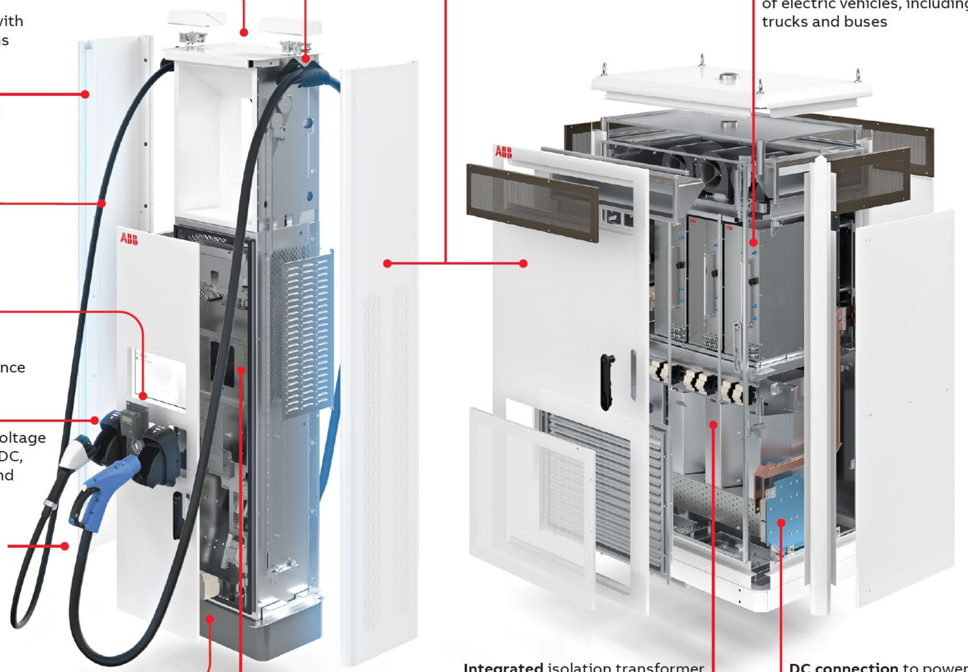
ABB's Terra HP generation III charge post is a **175 to 350 kW** high power charger ideally suited for highway corridor and EV fleet applications.

Dynamic DC power sharing illustrated



High power charging at up to 350 kW and 500 A at either charge post.

Simultaneous charging at up to 175 kW and 375 A at both charge posts.



SPECIFICATIONS

MAX CHARGING POWER
CCS: 500 A – 350 kW
CHAdeMO: 200 A

MAX CHARGING VOLTAGE
CCS: 920 V DC
CHAdeMO: 500 V DC

POWER EFFICIENCY
94% at full load

DIMENSIONS & WEIGHT

Charge Post
Height 245.8 cm / 96.8 in
Width 59 cm / 23.2 in
Depth 42.5 cm / 16.7 in

250 kg / 551 lbs

Power Cabinet
Height 203 cm / 79.9 in
Width 117 cm / 46.1 in
Depth 77 cm / 30.3 in

1340 kg / 2954 lbs

ABB

Charging Station Architectures

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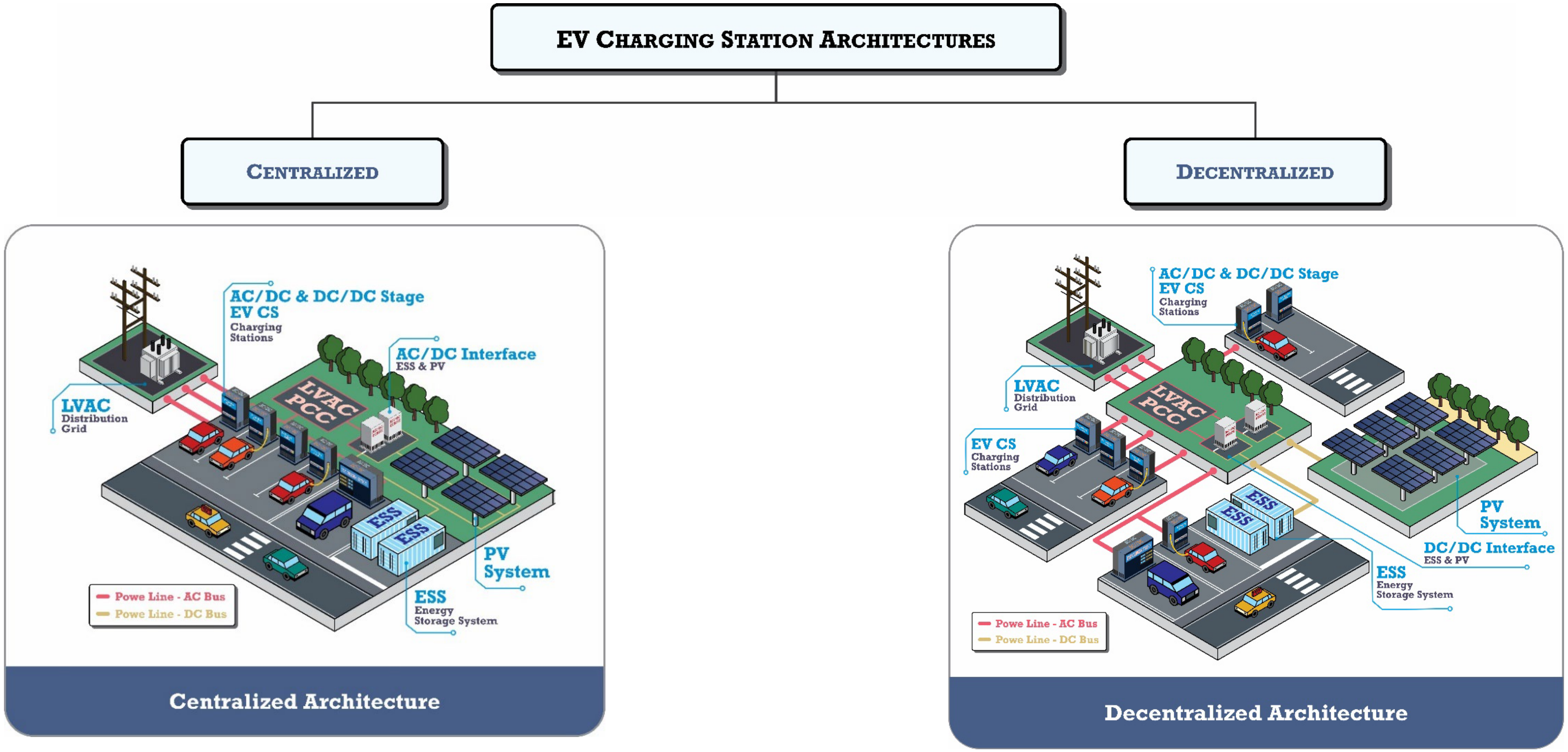
▶ State-of-the-Art – EV Charging Station Architecture - Classification

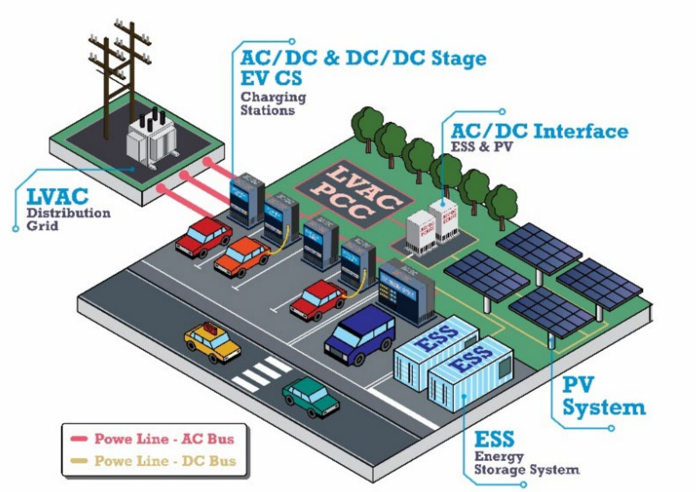


Charging Station Architectures

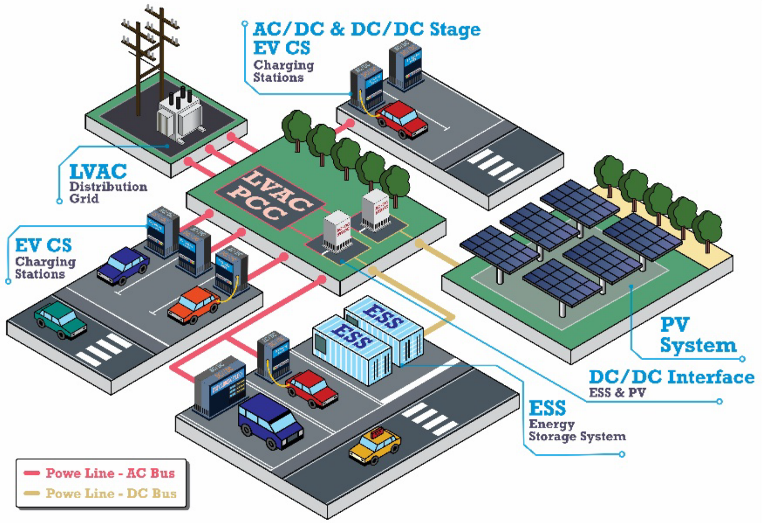
▶ State-of-the-Art – EV Charging Station Architecture - Classification

EV CHARGING STATION ARCHITECTURES

- **CENTRALIZED** — e.g. Rest stops (Raststätten)
- **DECENTRALIZED** — e.g. Logistic Centers



Centralized Architecture

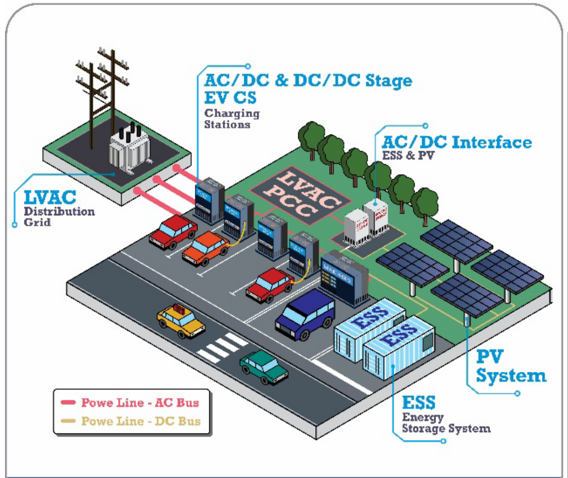


Decentralized Architecture

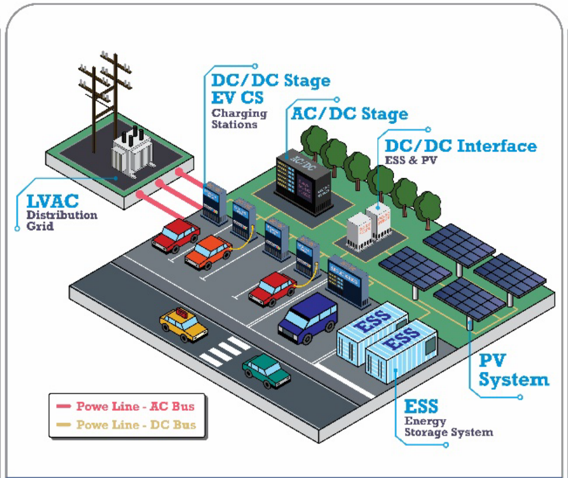
▶ State-of-the-Art – EV Charging Station Architecture - Classification

EV CHARGING STATION ARCHITECTURES

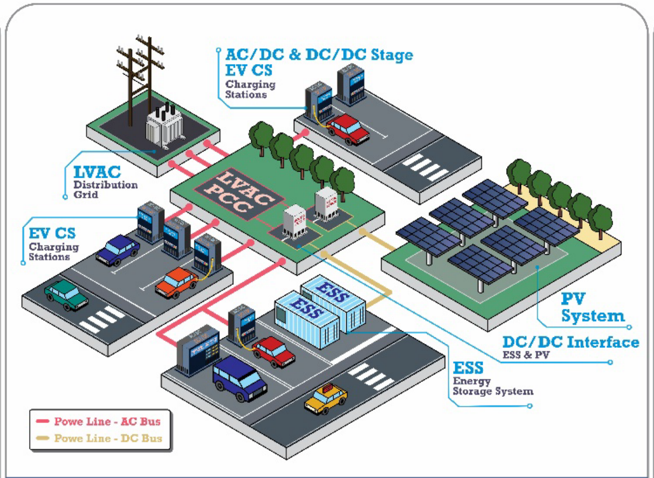
- **CENTRALIZED**
  - AC Distribution
  - DC Distribution
- **DECENTRALIZED**
  - AC Distribution
  - DC Distribution



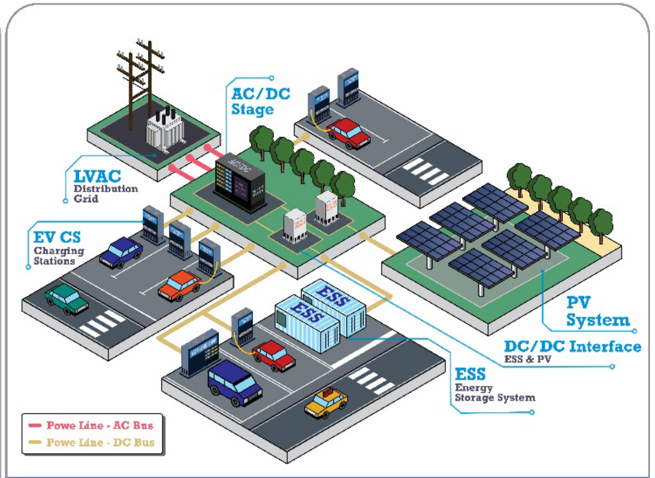
Centralized Architecture
AC Distribution



Centralized Architecture
DC Distribution

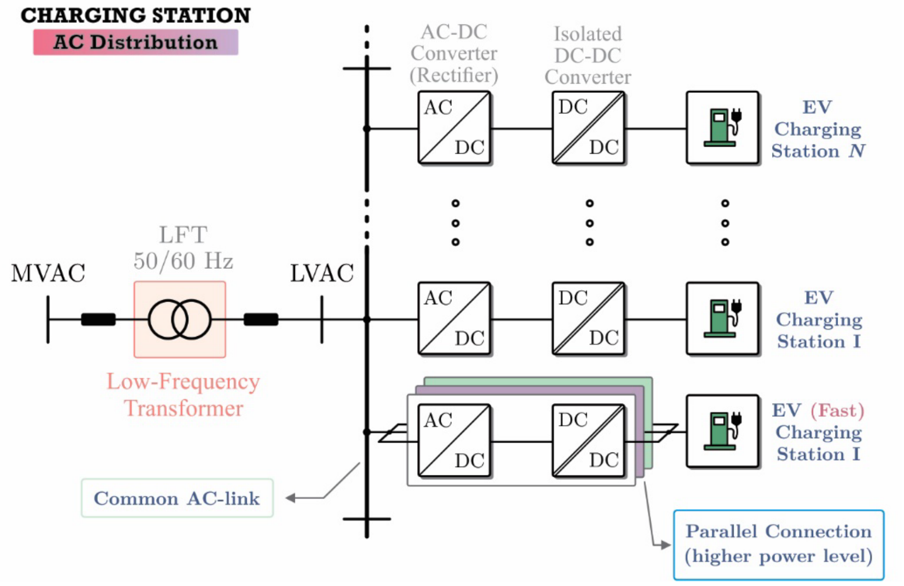


Decentralized Architecture
AC Distribution



Decentralized Architecture
DC Distribution

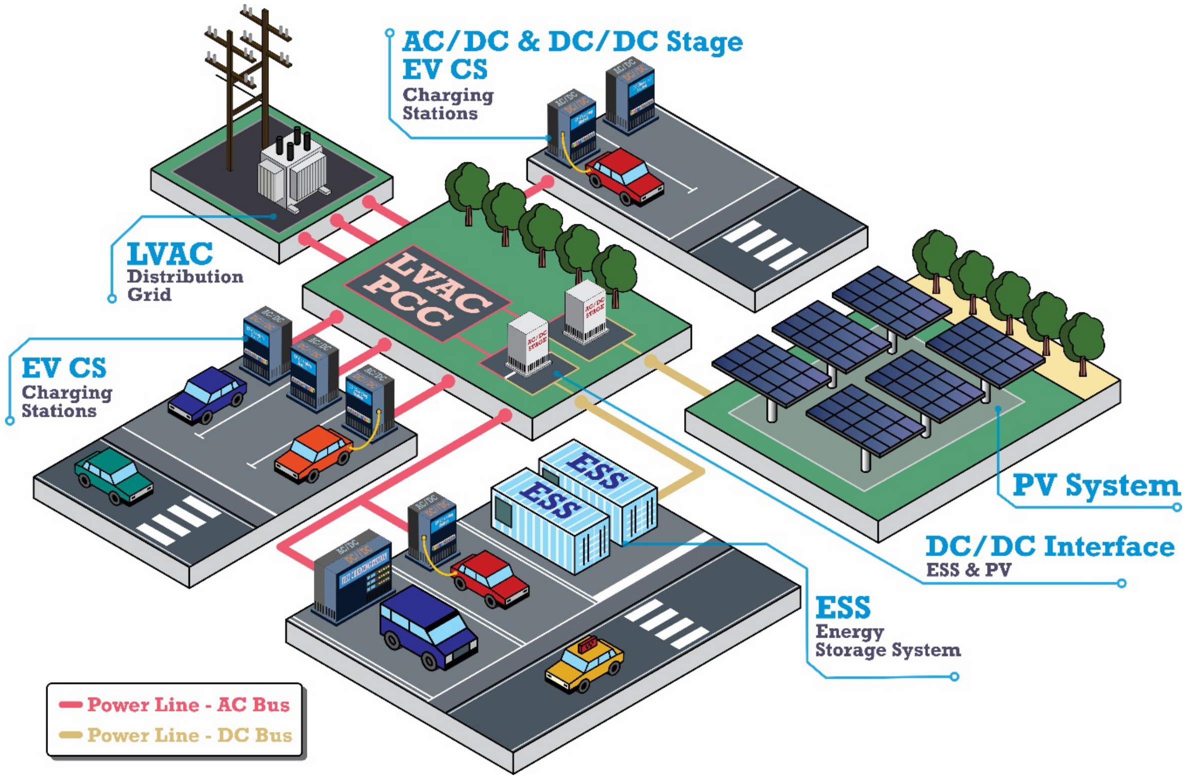
▶ State-of-the-Art – EV Charging Station Architecture - Classification



Architecture Description

- Common AC-link (LVAC)
- Several rectifier associated to the multiples DC-links
- Multiple AC/DC and DC/DC Converters
- Suitable for Decentralized Architecture (AC distribution)

AC Distribution – Decentralized Architecture



Charging Station Architectures

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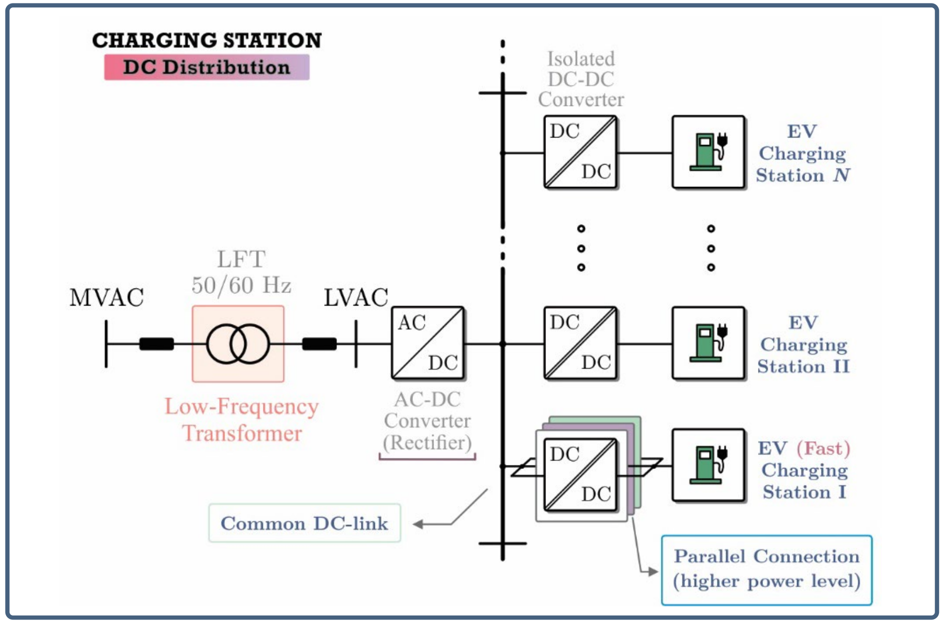
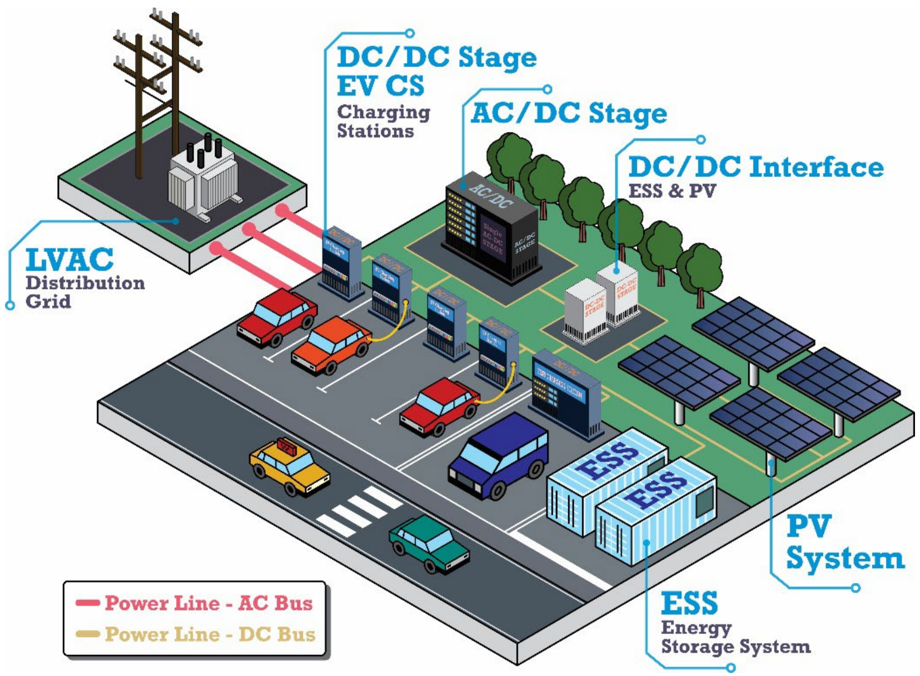
▶ State-of-the-Art – EV Charging Station Architecture - Classification



Architecture Description

- Common DC-link (LVDC)
- Centralized rectifier and Multiple Isolated DC/DC Converters
- Suitable for centralized architecture (DC distribution)
- Potential for MTB dc-dc converter

DC Distribution – Centralized Architecture



Charging Station Architectures

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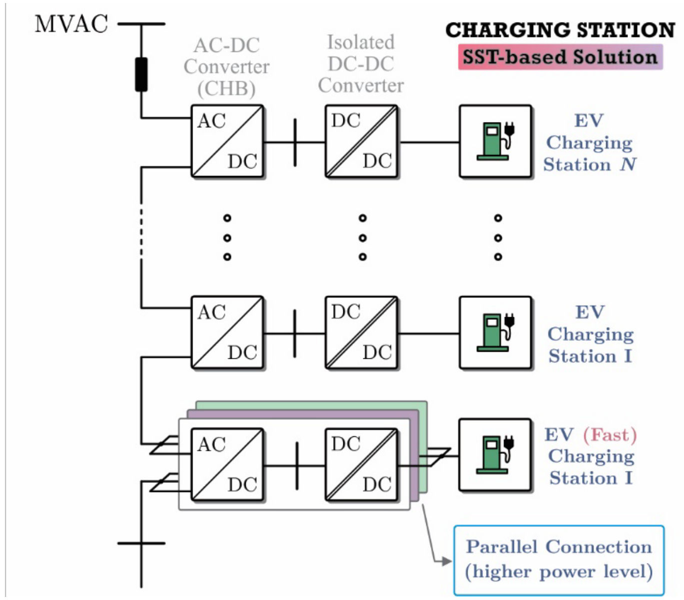
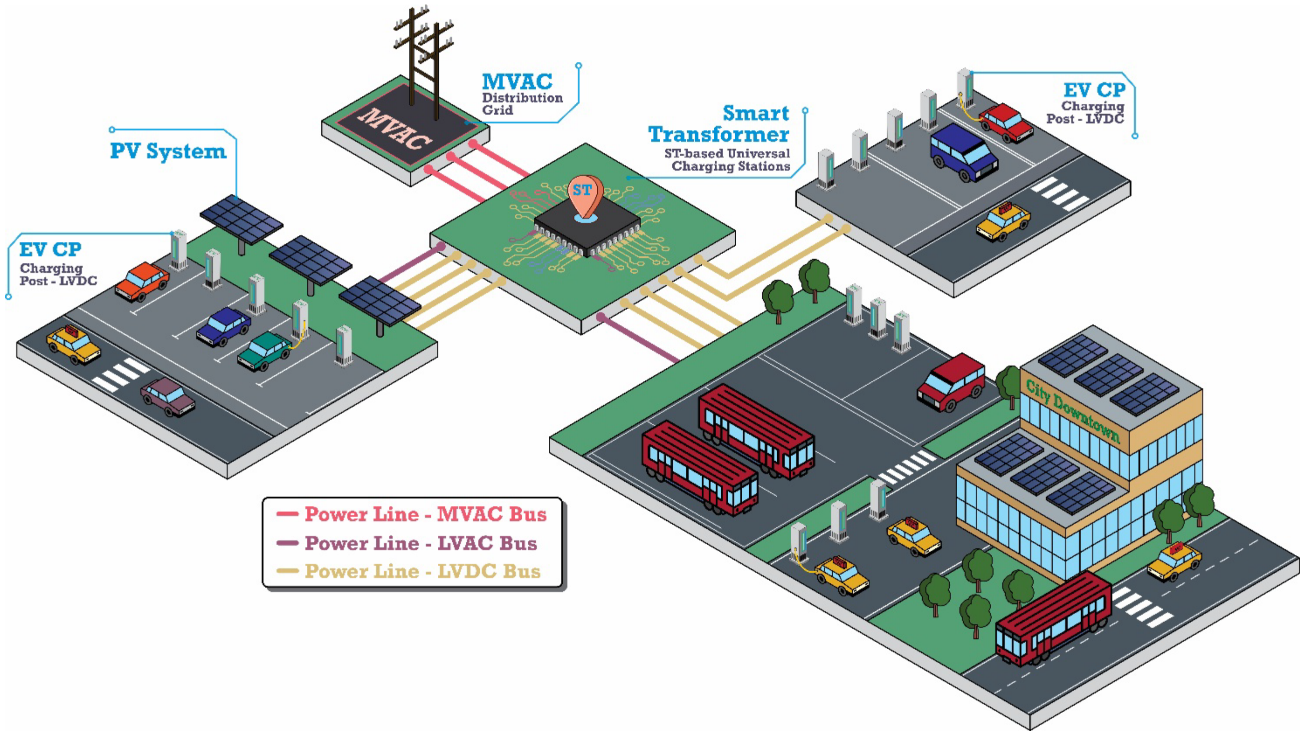
▶ State-of-the-Art – EV Charging Station Architecture - Classification



ST-based MV (FAST) Charging Stations

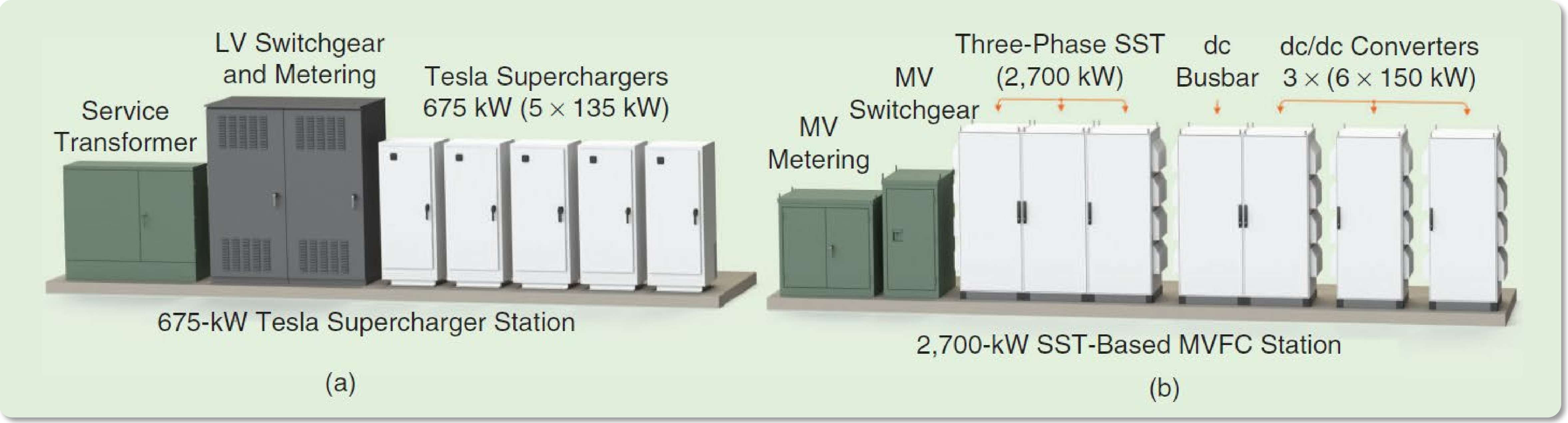


Architecture Description

- Direct Connection to the MVAC
- Solution for High Power Charging Station
- Multiple Isolated DC/DC Converters – High ESS Integration
- Suitable for Centralized Architecture (DC)

Charging Station Architectures

► **State-of-the-Art – EV Charging Station Architecture - Benchmark**



(a) state-of-the-art 675 kW Tesla Supercharger Station (with an estimated efficiency of 92 %)

(b) ST-based 2.7 MW MV Fast Charging Station Solution with the same footprint.

S. Srdic and S. Lukic, "Toward Extreme Fast Charging: Challenges and Opportunities in Directly Connecting to Medium-Voltage Line," in IEEE Electrification Magazine, vol. 7, no. 1, pp. 22-31, March 2019, doi: 10.1109/MELE.2018.2889547.

ESS Integration & Grid Support by Fast Charging Stations

ESS Integration & Grid Support by Fast Charging Stations

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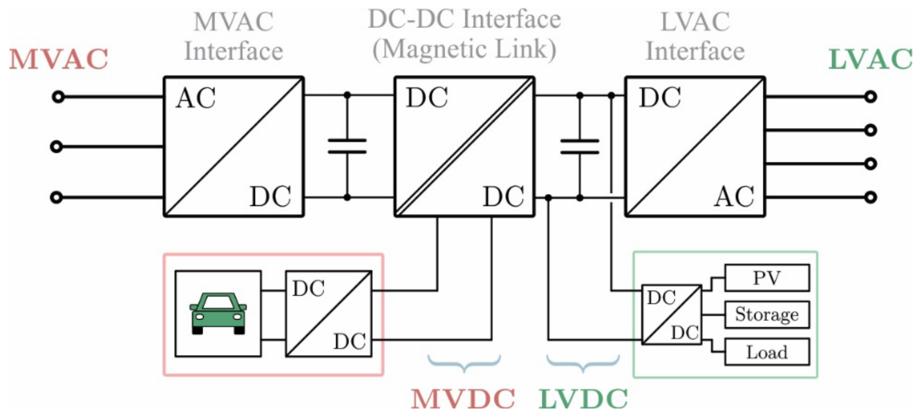
▶ ST-Based MV Architecture – Ancillary Services by Fast-Charging Stations

- ❑ Methods for using **ESS inside the stations to reduce the power consumption** of fast-charging stations are required.

- ❑ There are two types of approaches for the ESS Integration:
  - The first approach aims **at minimizing the total capital investments** in the ESS.
  - The idea is to install **ESS to avoid high power requirements** for the charging stations and the grid.
  - The second approach is to **use an ESS that can store more energy** than needed for charging.



- ❑ The **extra stationary storage may help** the system in the following ways.
  - It can help **supply the station's loads during peak hours**, avoiding the need for additional grid capacity and reducing voltage problems.
  - It can supply **active or reactive power control** when needed, thus helping in maintaining the voltage at the local level.
  - Aggregators can use it for **load balancing** and for controlling the system frequency.

Improved charging performance	Additional grid services
Reduction of peak loads on the grid by buffering from the battery[2]	Arbitrage trading by charging during low-price hours
Supply of higher charging power than the available grid connection again by buffering from the battery[3]	Continued supply during power cuts and in islanding operation[4]
Utilization of locally generated energy such as a PV plant[5]	Balancing services such as Primary or Secondary Control Reserve[6]

S. Brueske, M. Langwasser, J. Goetze, X. Gao and M. Liserre, "Potential of EV Charging Stations for MV Grid Voltage Support," NEIS 2020; Conference on Sustainable Energy Supply and Energy Storage Systems, 2020, pp. 1-6.

ESS Integration & Grid Support by Fast Charging Stations

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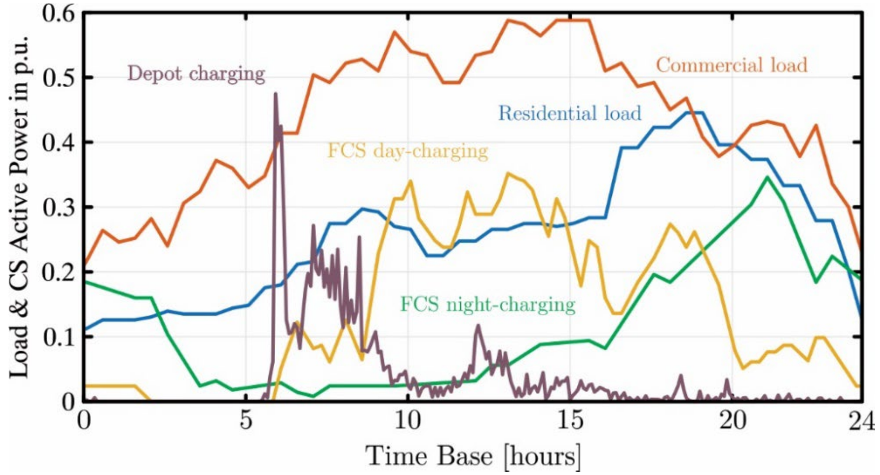
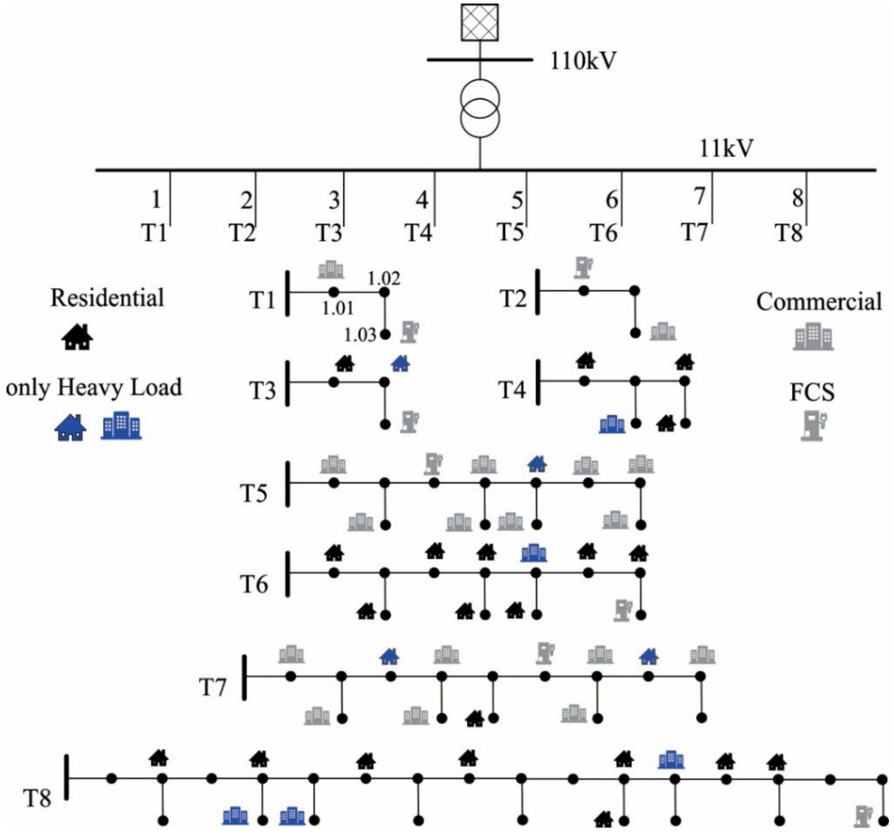
▶ ST-Based MV Architecture – Grid Support by Fast-Charging Stations

KielFlex

- ❑ Adapted UK Benchmark Grid
- ❑ **Load Conditions:** Light Load and Heavy Load.
- ❑ **Charging Profile:**
  - Day-Charging
  - Night-Charging
  - Measured Industrial Depot-Charging

24 h Profiles for Load and FCS.





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▶ ST-Based MV Architecture – Grid Support by Fast-Charging Stations – Light Load

Light-Load Condition in MVAC Grid

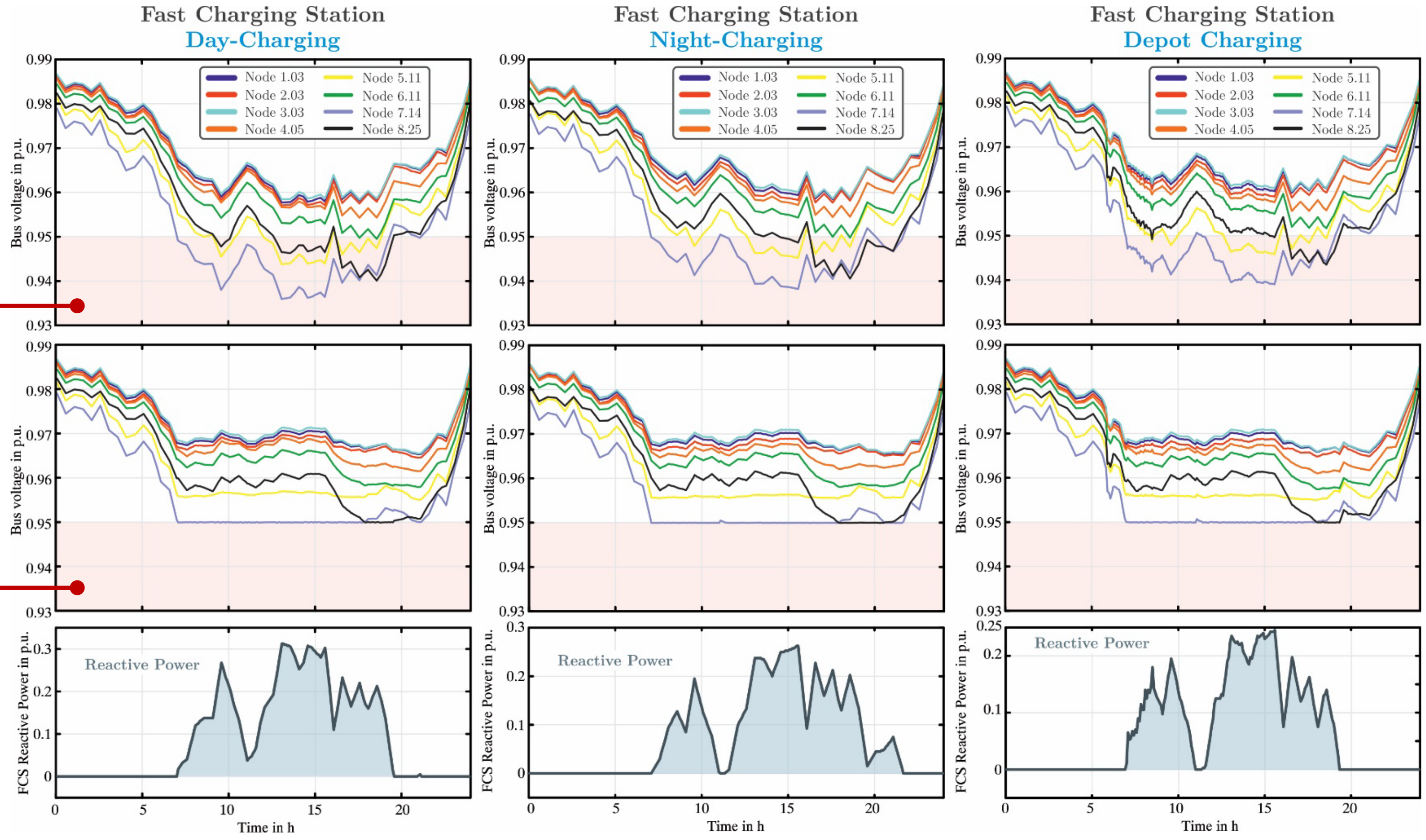
Voltage profile without FCS Support

Grid Voltage Violation

Voltage profile with FCS Reactive Power Support and No Active Power Curtailment

Grid Voltage Violation

Reactive Power Injection



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ESS Integration & Grid Support by Fast Charging Stations

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▶ ST-Based MV Architecture – Grid Support by Fast-Charging Stations – Heavy Load

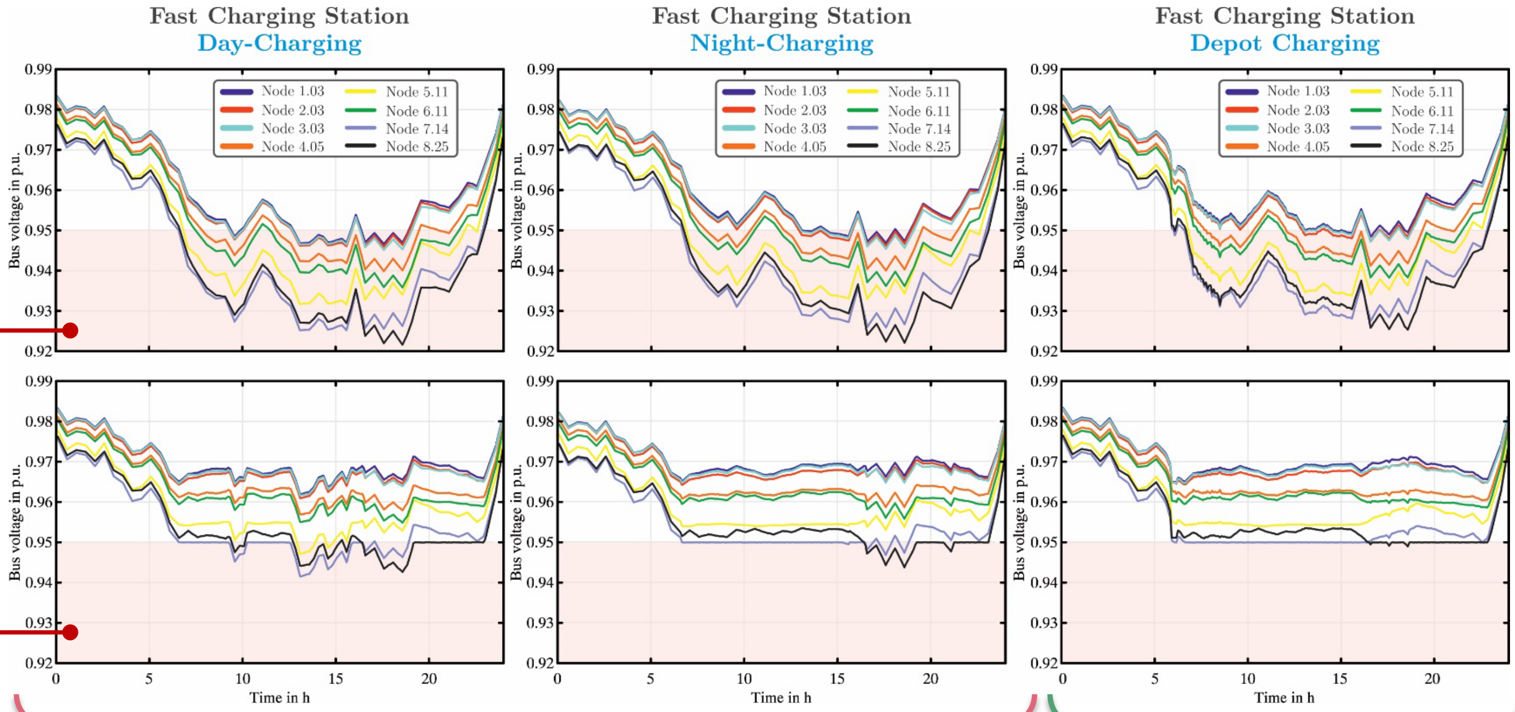
Heavy-Load Condition in MVAC Grid

Voltage profile without FCS Support

Grid Voltage Violation

Voltage profile with FCS Reactive Power Support and No Active Power Curtailment

Grid Voltage Violation



Reactive Power Injection

However, it is not sufficient to support the voltage, being restricted by the FCS apparent power capacity of 0.5 MVA.

Reactive Power Injection

S. Brueske, M. Langwasser, J. Goetze, X. Gao and M. Liserre, "Potential of EV Charging Stations for MV Grid Voltage Support," NEIS 2020; Conference on Sustainable Energy Supply and Energy Storage Systems, 2020, pp. 1-6.

► ST-Based MV Architecture – Grid Support by Fast-Charging Stations – Heavy Load

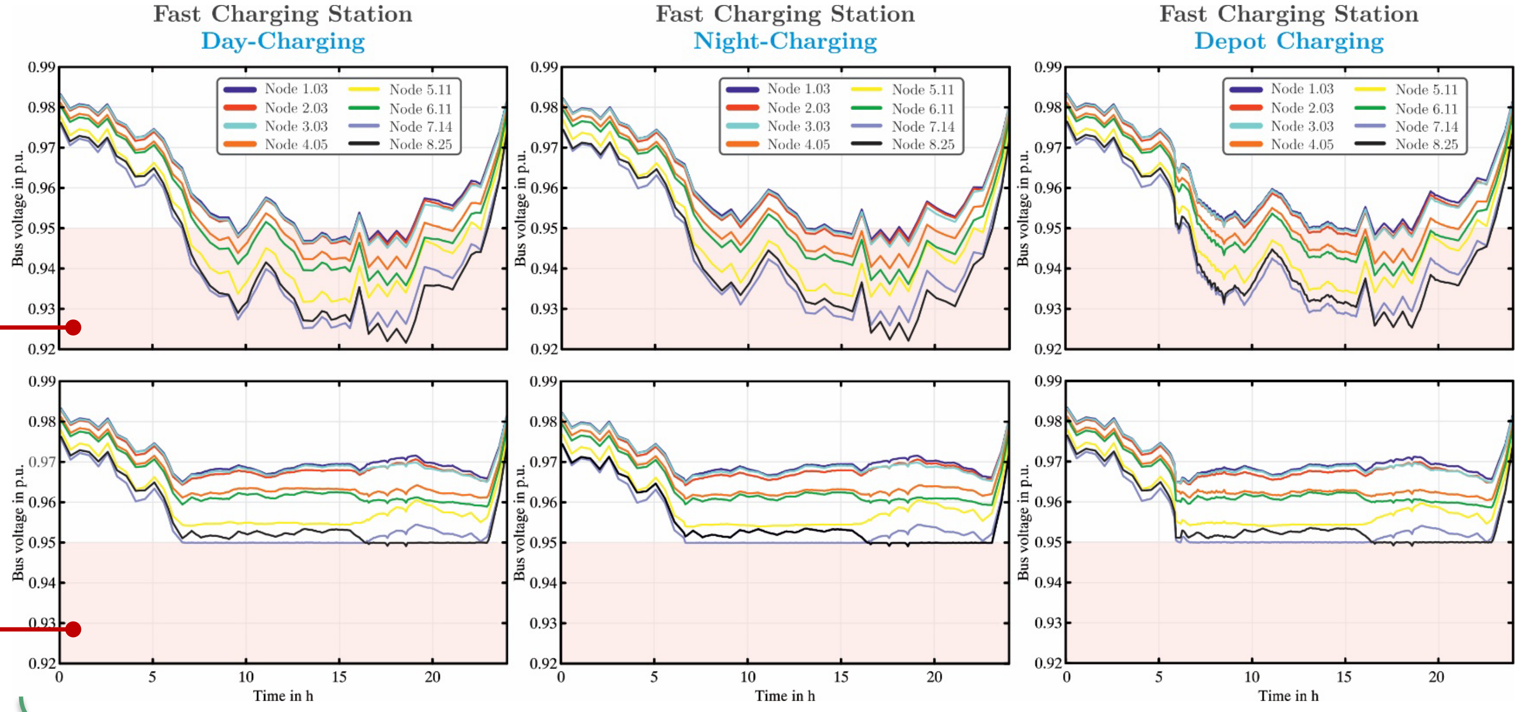
Heavy-Load Condition in MVAC Grid

Voltage profile without FCS Support

Grid Voltage Violation

Voltage profile with FCS Reactive Power Support and Active Power Curtailment

Grid Voltage Violation



Smart charging enables the possibility to curtail the active power of the FCS to provide higher capacity for reactive power support and hence keep the voltage within allowed boundaries.

S. Brueske, M. Langwasser, J. Goetze, X. Gao and M. Liserre, "Potential of EV Charging Stations for MV Grid Voltage Support," NEIS 2020; Conference on Sustainable Energy Supply and Energy Storage Systems, 2020, pp. 1-6.

ESS Integration & Grid Support by Fast Charging Stations

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► ST-Based MV Architecture – Grid Support by Fast-Charging Stations – Heavy Load

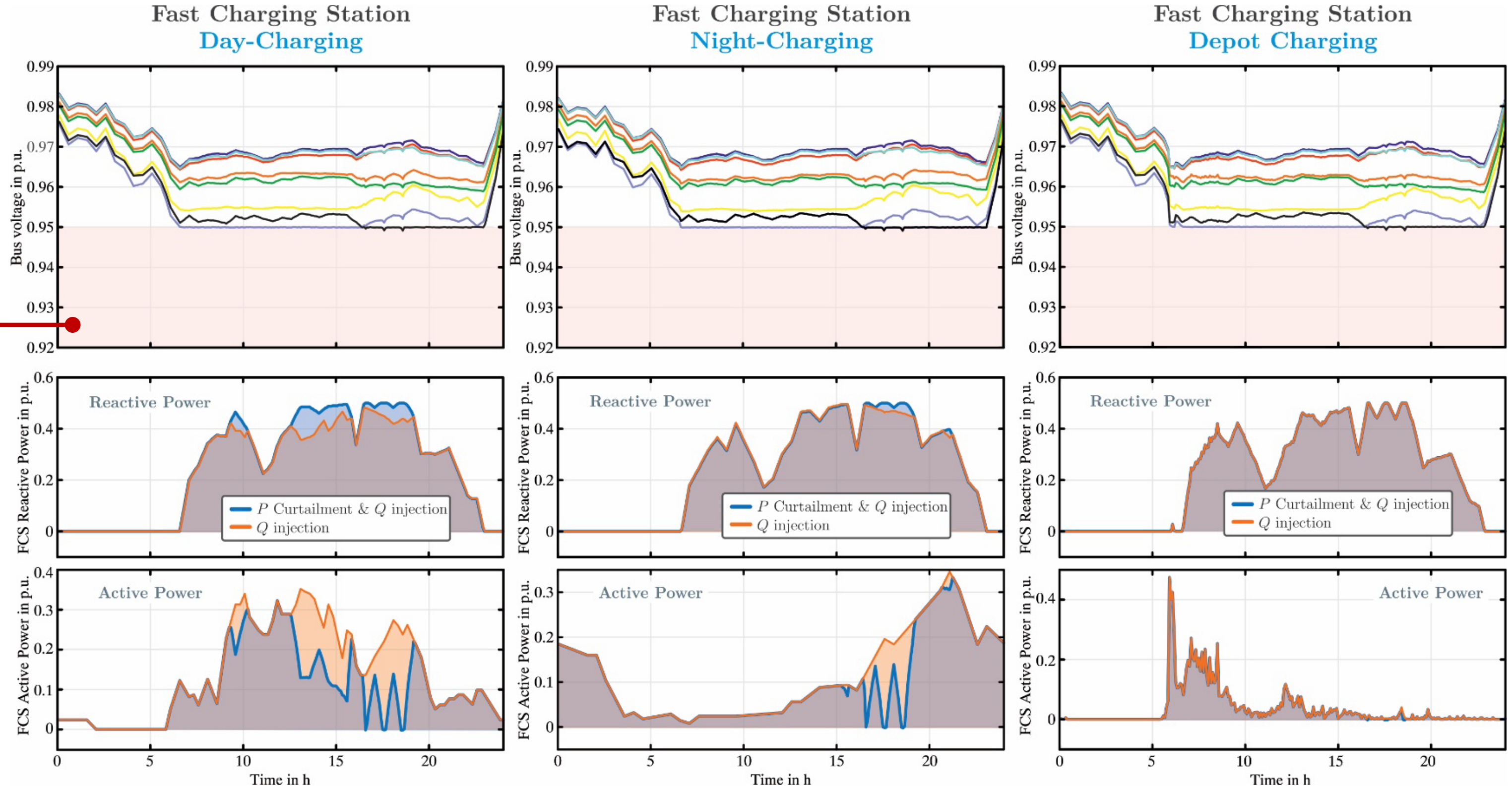
Heavy-Load Condition in MVAC Grid

Voltage profile with FCS Reactive Power Support and Active Power Curtailment

Grid Voltage Violation

Reactive Power Support

Active Power Support



Grid Support considering the Active Power Reduction and the respective results

S. Brueske, M. Langwasser, J. Goetze, X. Gao and M. Liserre, "Potential of EV Charging Stations for MV Grid Voltage Support," NEIS 2020; Conference on Sustainable Energy Supply and Energy Storage Systems, 2020, pp. 1-6.

UNIVERSAL FAST CHARGING STATIONS

CAU
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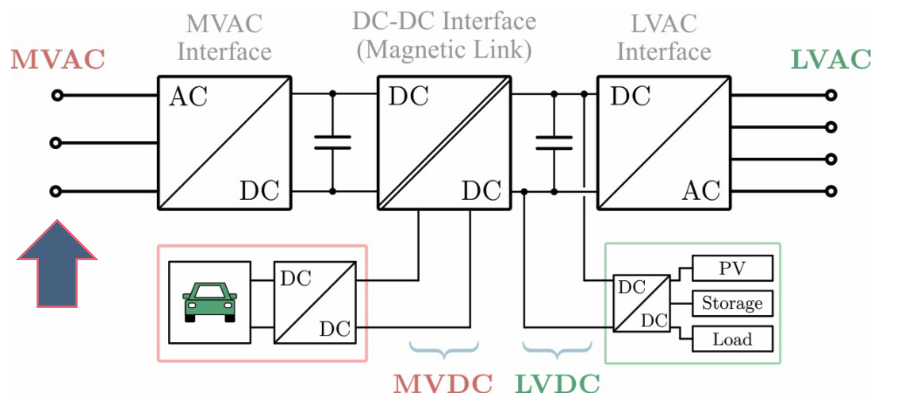
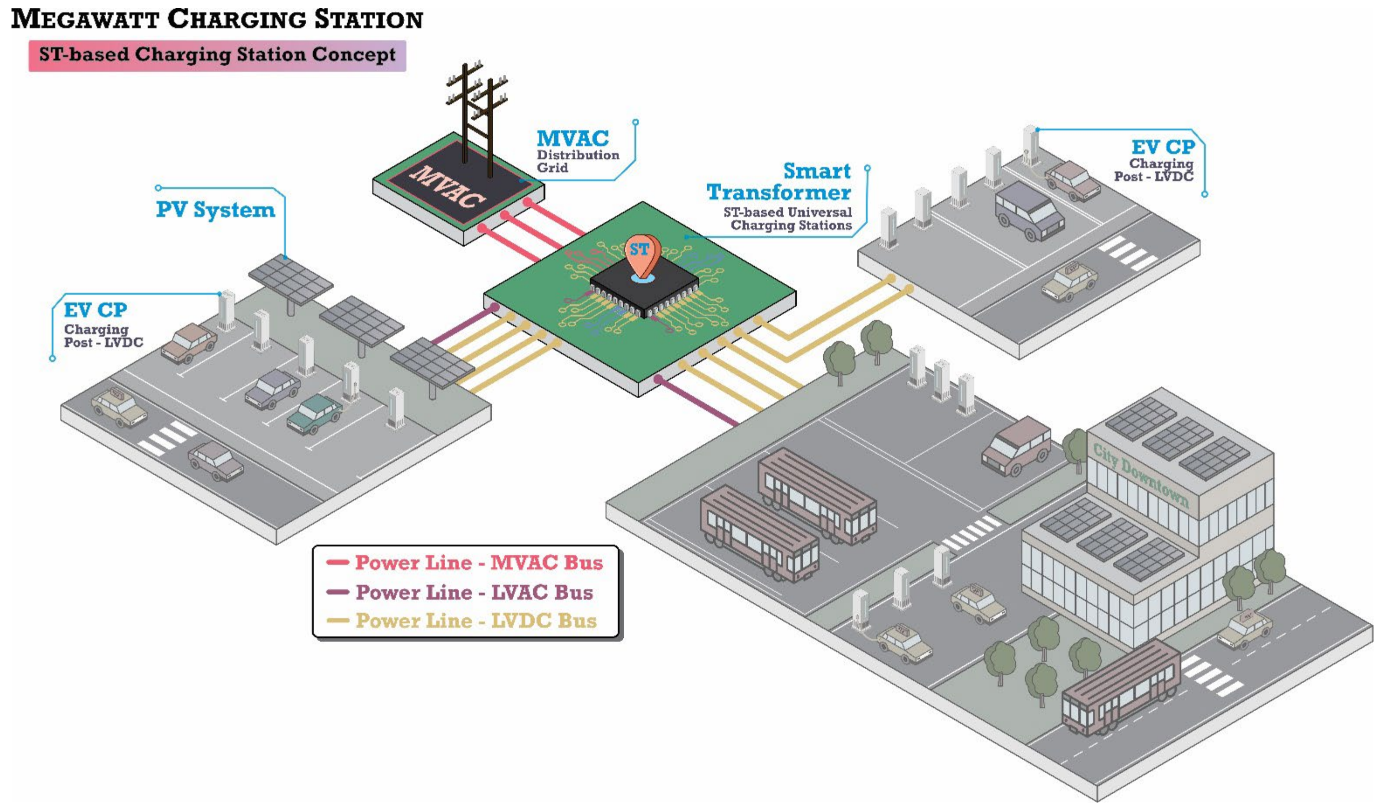
▶ ST-Based MV Architecture – Main Concept



- ❑ **Direct Connection to the MVAC Grid side.**
- ❑ Elimination of the Low-Frequency Transformer by an **MV-based AC-DC Converter (i.e. CHB converter or MMC).**
- ❑ The **MVAC connection** leads to the possibility to scale up the MV systems, in terms of power rating (i.e. number of the charging stations).



Voltage Transformer, by L. F. Costa and M. Liserre. (2021, March 18). World International Patent (WIPO) WO2021/048327A1 [Online]. Available: https://bit.ly/30Yd6DS.

Universal Charging Station Architectures

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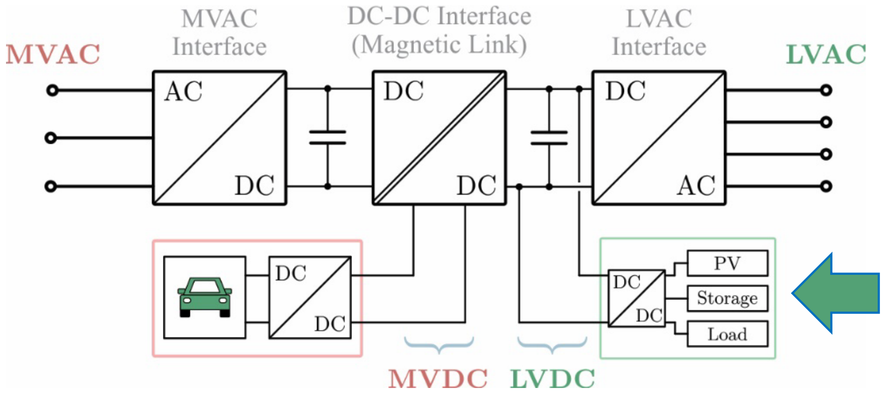
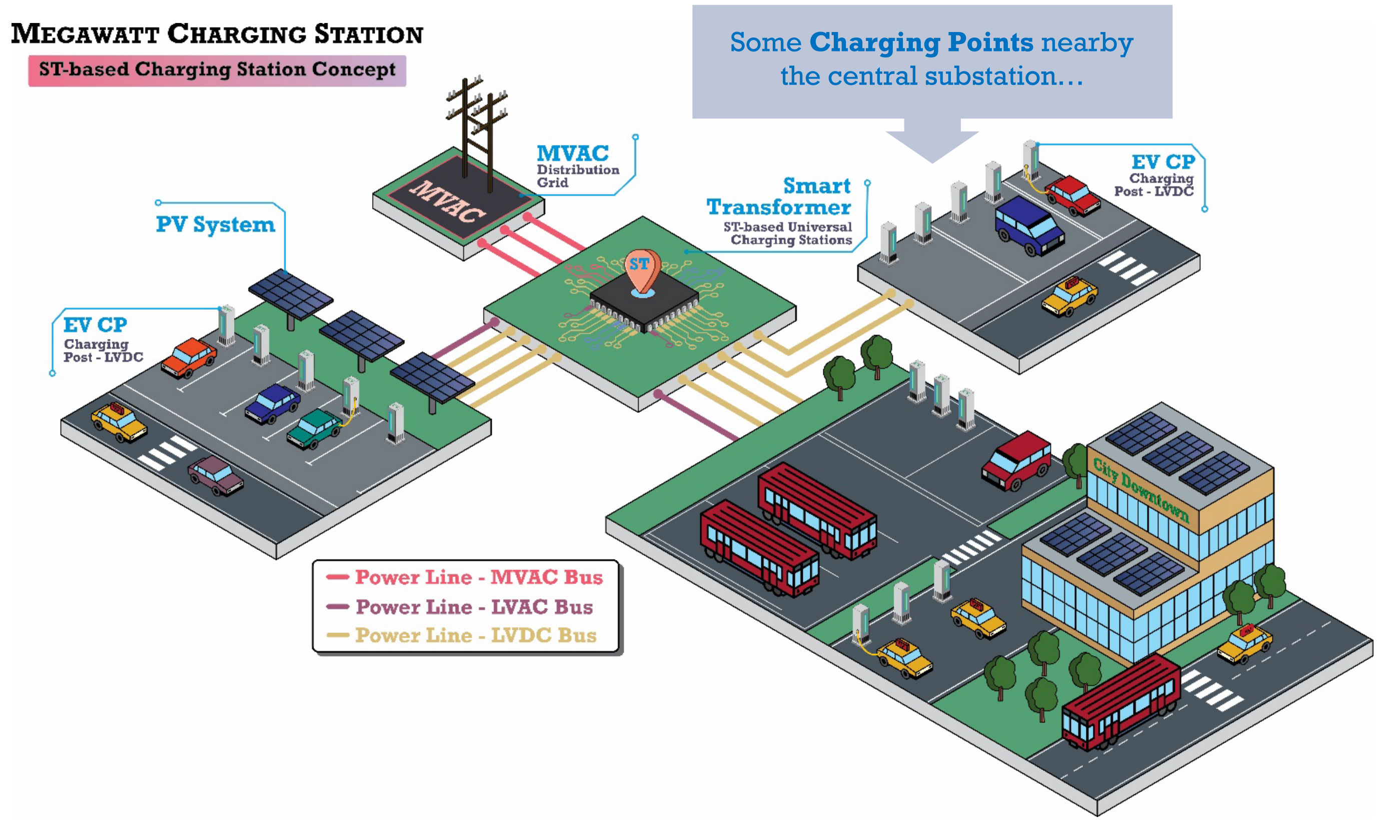
▶ ST-Based MV Architecture – Main Concept





- **ST-based solution** present an optimal solution for offering LVAC, LVDC, and MVDC buses.
- **MVDC distribution** to supply several charging points (either centralized or decentralized placement).
- **Single or Multiple MVDC Links** of different Voltage and Power Levels (which depends on the number of cell).

Universal Charging Station Architectures

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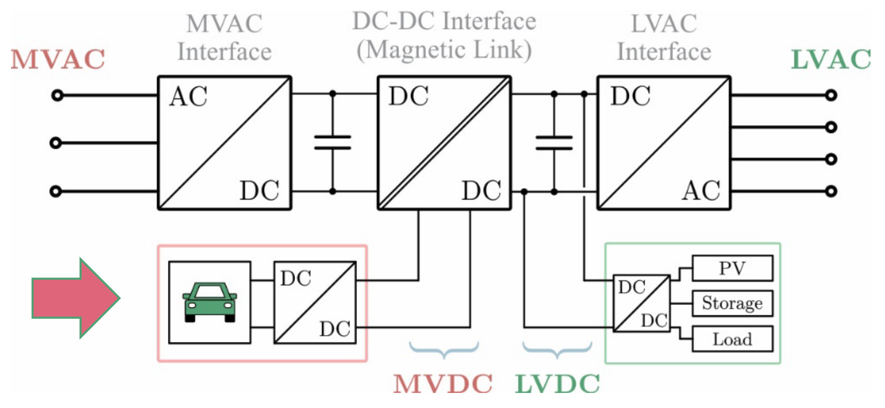
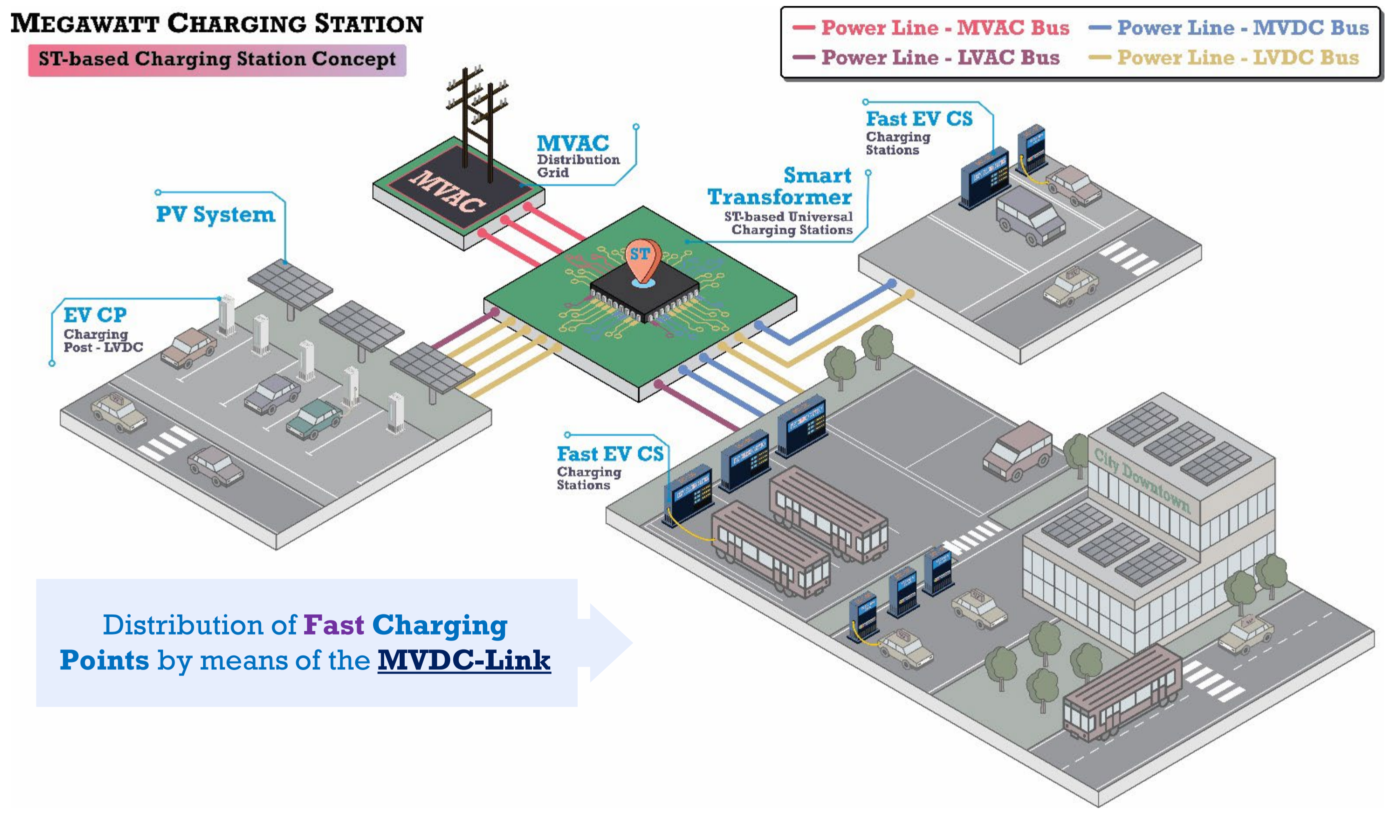
▶ ST-Based MV Architecture – Main Concept



- **Single or Multiple MVDC Buses** of different Voltage and Power Levels, depending on the number of cells and specifications.
- **MVDC Distribution** enables the placement of multiple Fast-Charging Stations (FCS).
- **MVDC buses** arises as a solution to increase the Charging Power and to reduce the Charging Time.



Distribution of **Fast Charging Points** by means of the **MVDC-Link**

MULTIFUNCTIONAL & UNIVERSAL FAST CHARGING STATIONS

Multifunctional & Universal Charging Station Architectures

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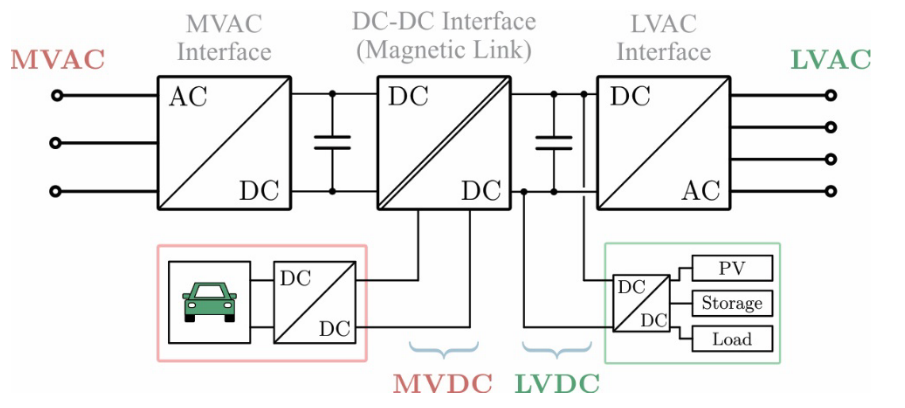
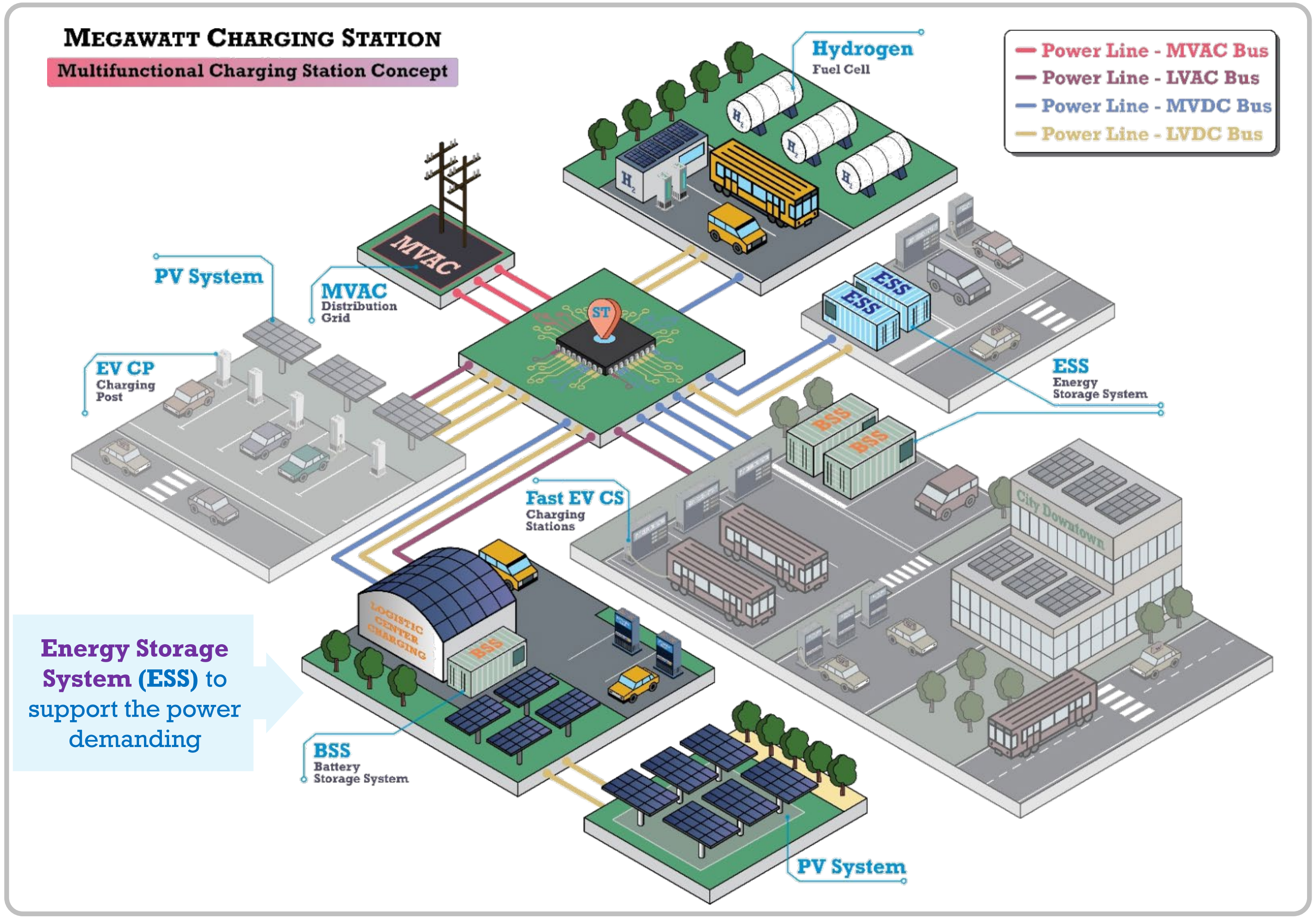


- Enhanced Integration of multiple **Energy Storage Systems (ESS)**, as for example Fuel Cell, Super Capacitors, and battery storage systems (BESS).
- Enhanced Integration of **Renewable Energy Source (RES)**, as for example PV Systems.
- **Support to the MVAC and LVAC** by means of ancillary services.
- **ESS and RES to support** the power demanding.



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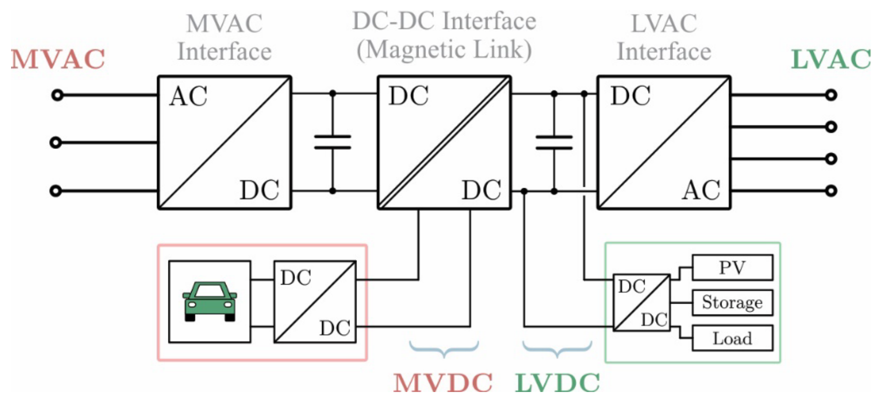

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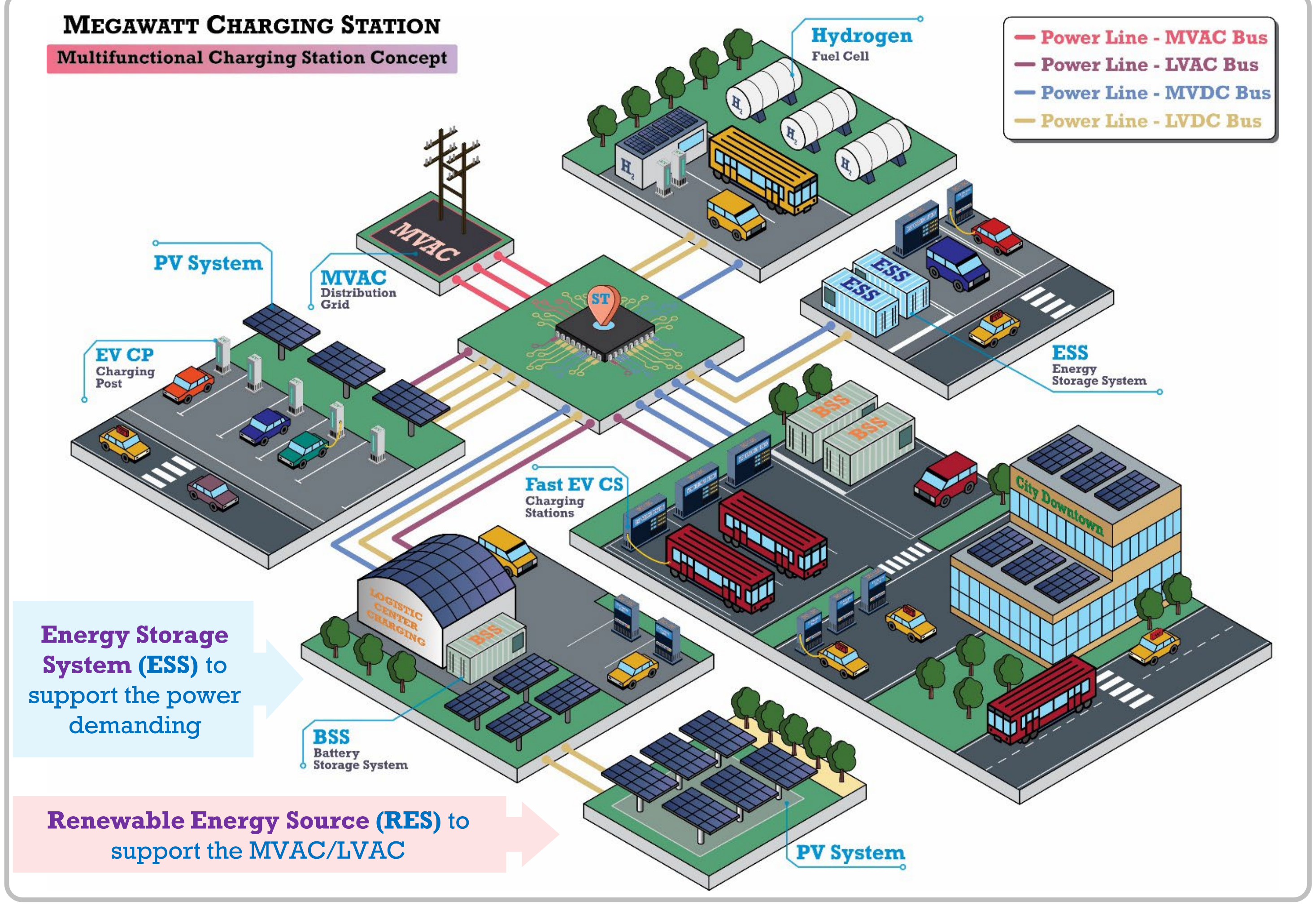

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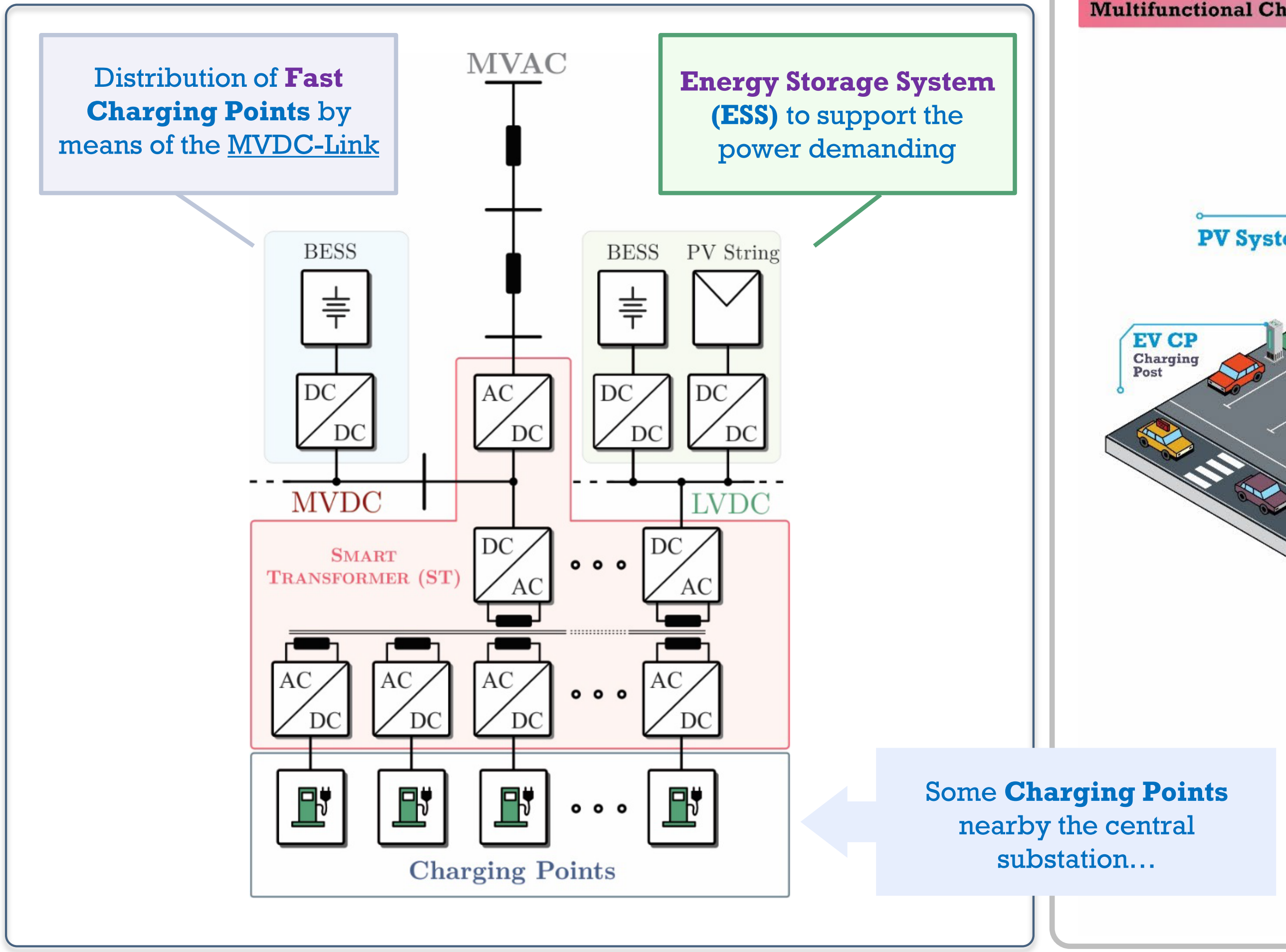

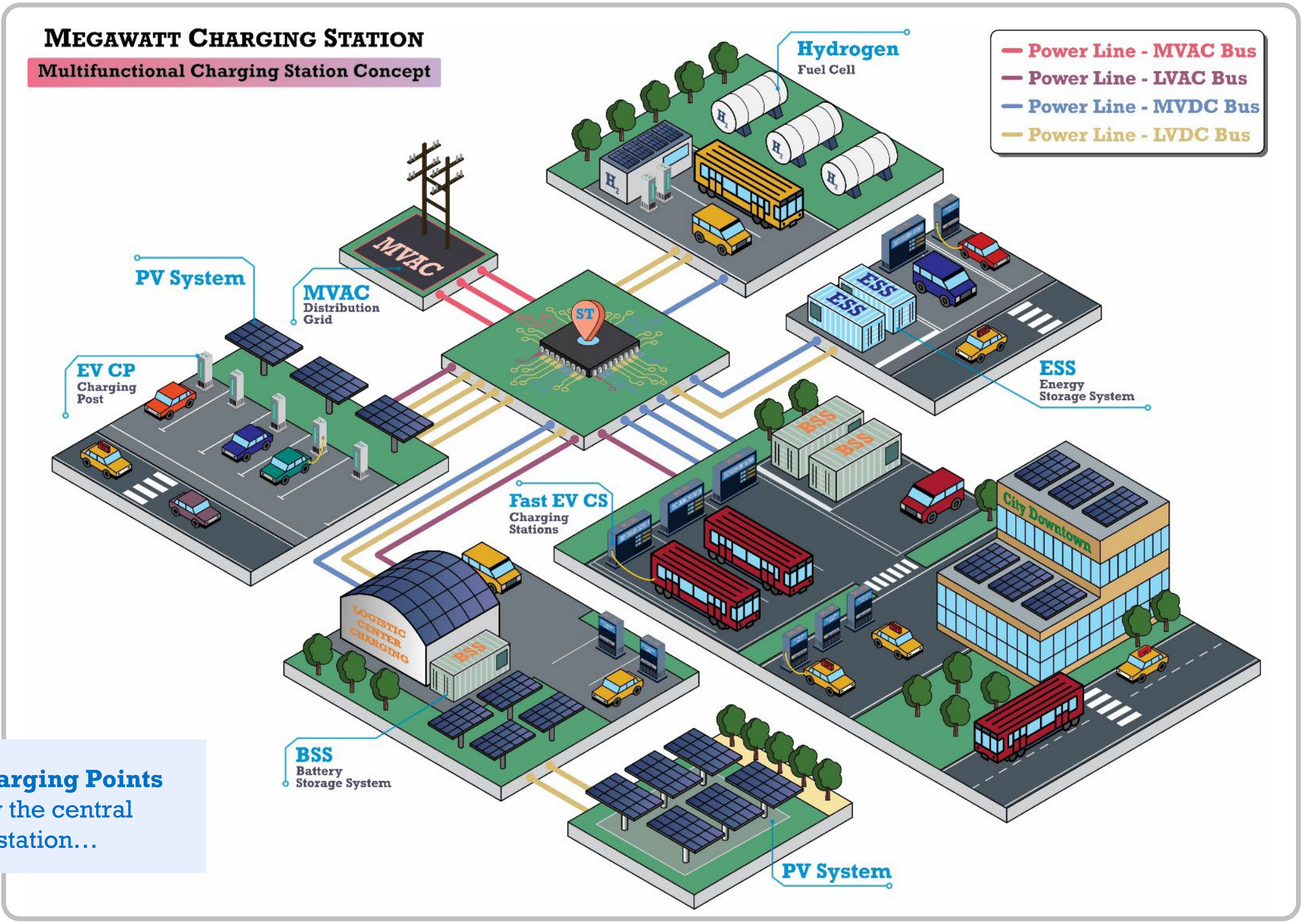

Multifunctional & Universal Charging Station Architectures

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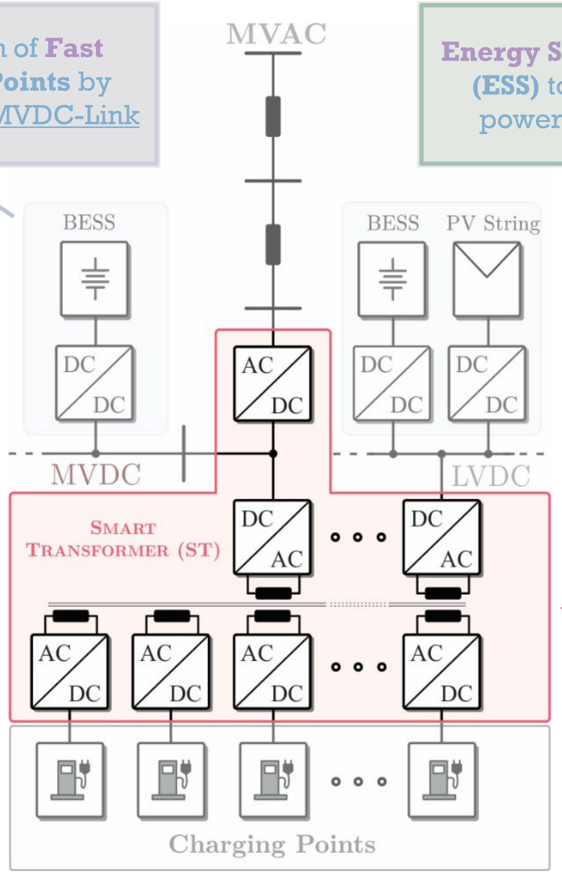
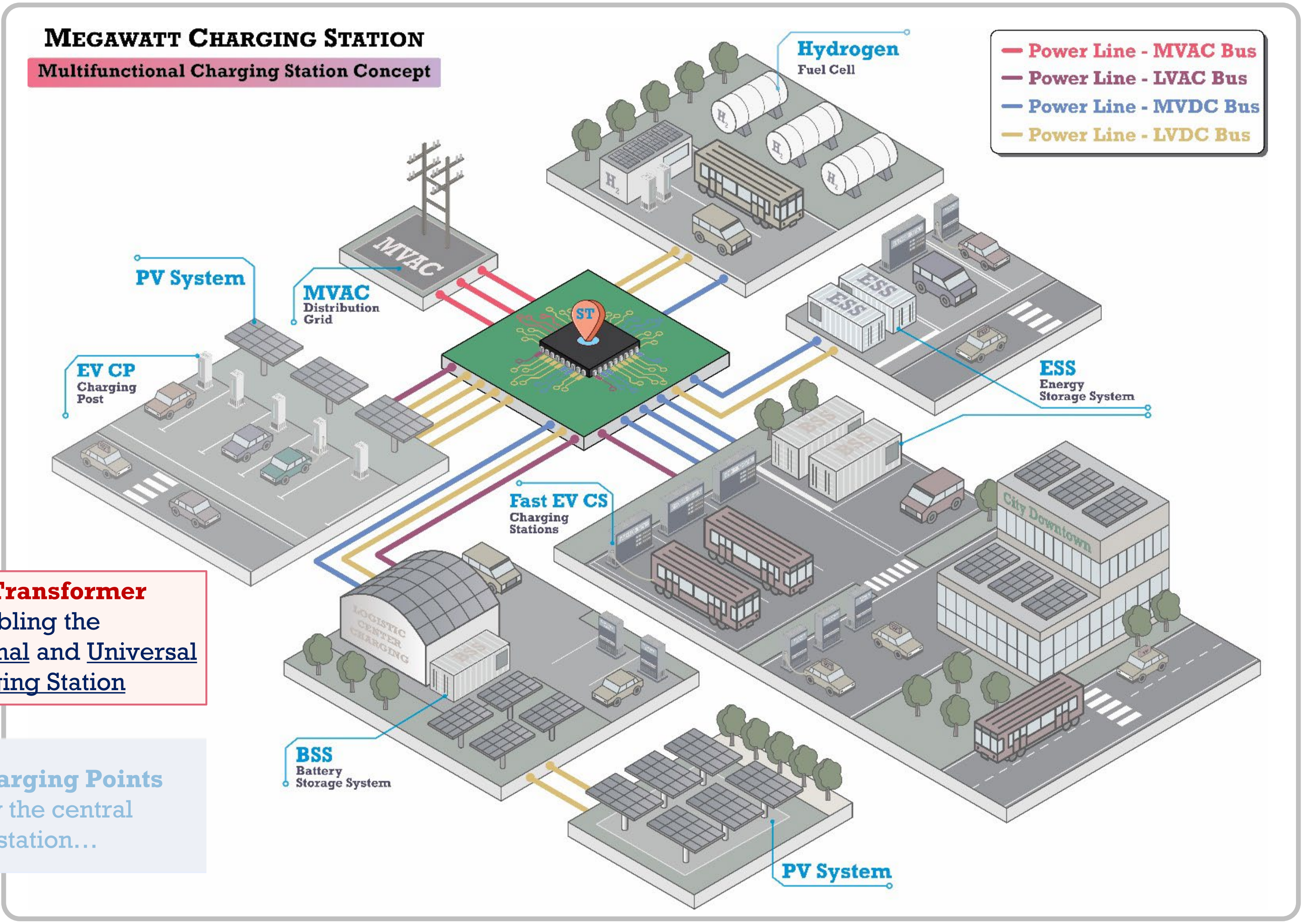


Smart Transformer enabling the Multifunctional and Universal Charging Station

Some Charging Points nearby the central substation…



MTB DC/DC Converter

Key Component

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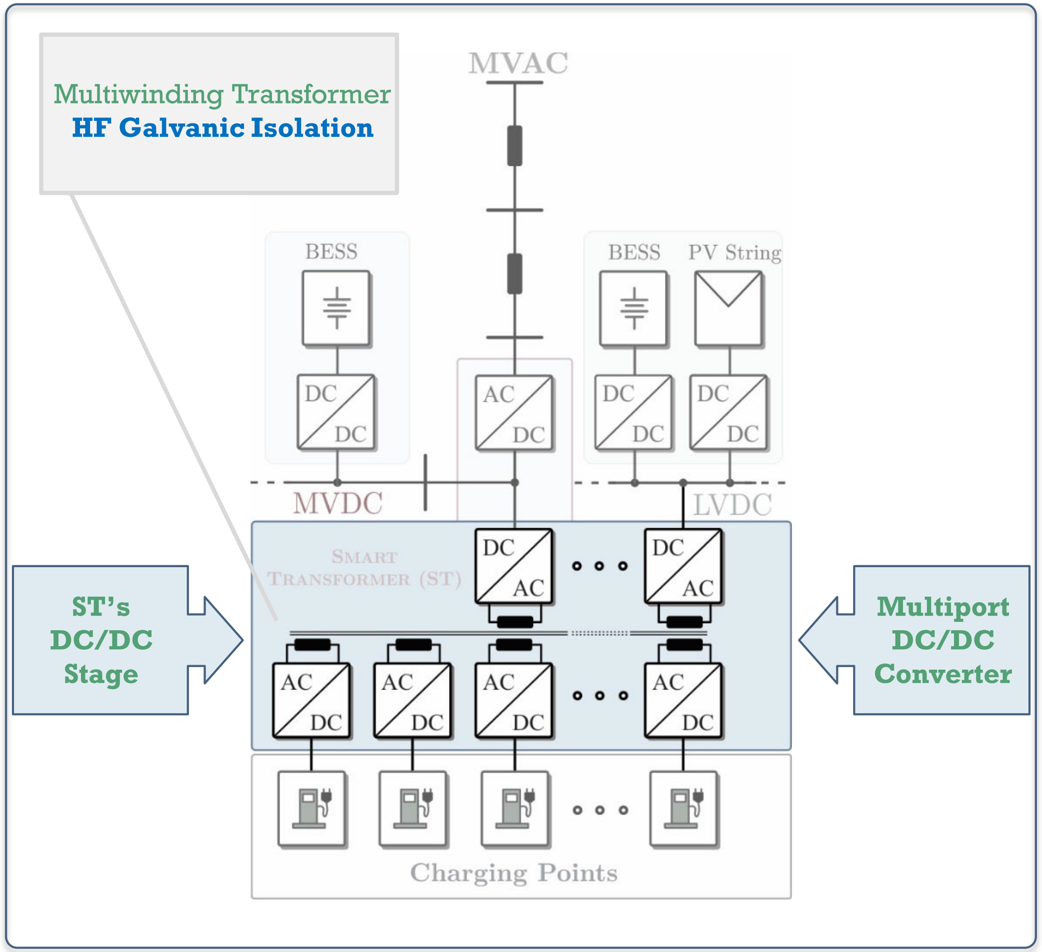
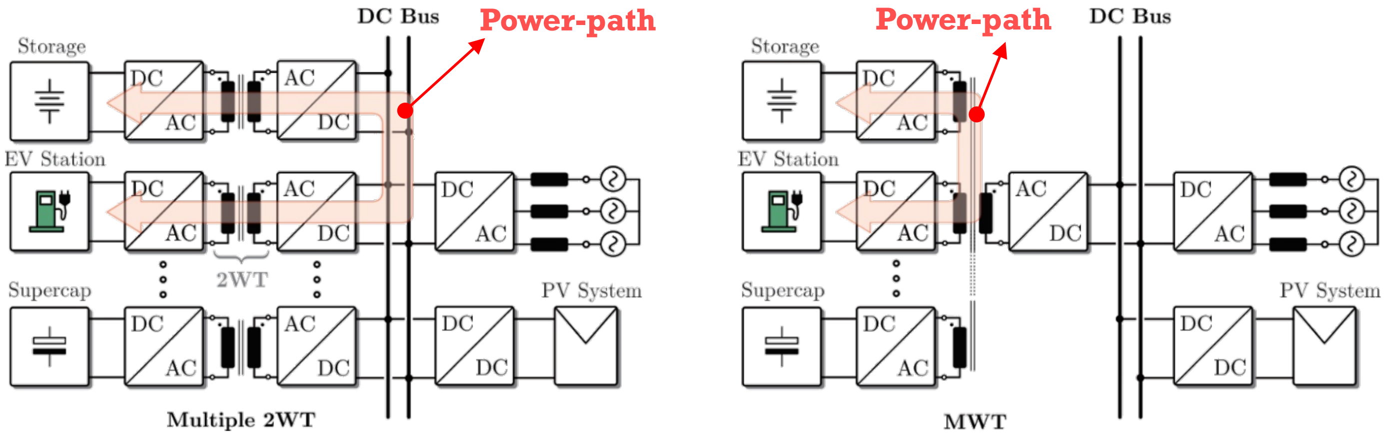
▶ ST-Based MV Architecture – DC/DC Stage



Potential of the Multiwinding Transformer-based DC/DC Converter – Key Component

- MTB dc/dc Converter enables:
  - **Multiterminal feature** (MVDC and LVDC buses)
  - High **Interconnection Capability** (Magnetic Link)
  - Fault-tolerance capability (High Availability)
  - High Power Density and Cost-Benefit
  - HF Galvanic Isolation.



- The **power-paths** can be shortened when the Multiwinding Transformer (MWT) is adopted, due to its inherent magnetic link.
- As a result, since the structure uses less cells, the **power density** of the MTB topologies can be **increased in 30 %** when the MWT is adopted.
- Thanks to the **core material** and **number of cells reduction**, the MTB topologies might be more advantageous in terms of **cost (around 15 %)**.

M. Liserre, F. Hoffman and T. Pereira, **"Multiwinding-Transformer-Based dc-dc Converter Solutions for Charging Stations [Technology Leaders],"** in *IEEE Electrification Magazine*, vol. 9, no. 2, pp. 5-9, June 2021.

Charging Station Architectures

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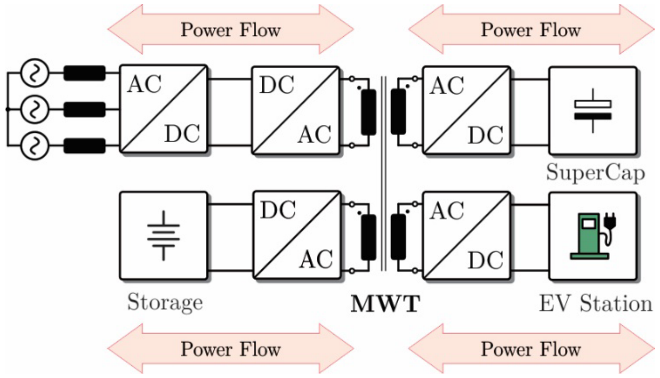
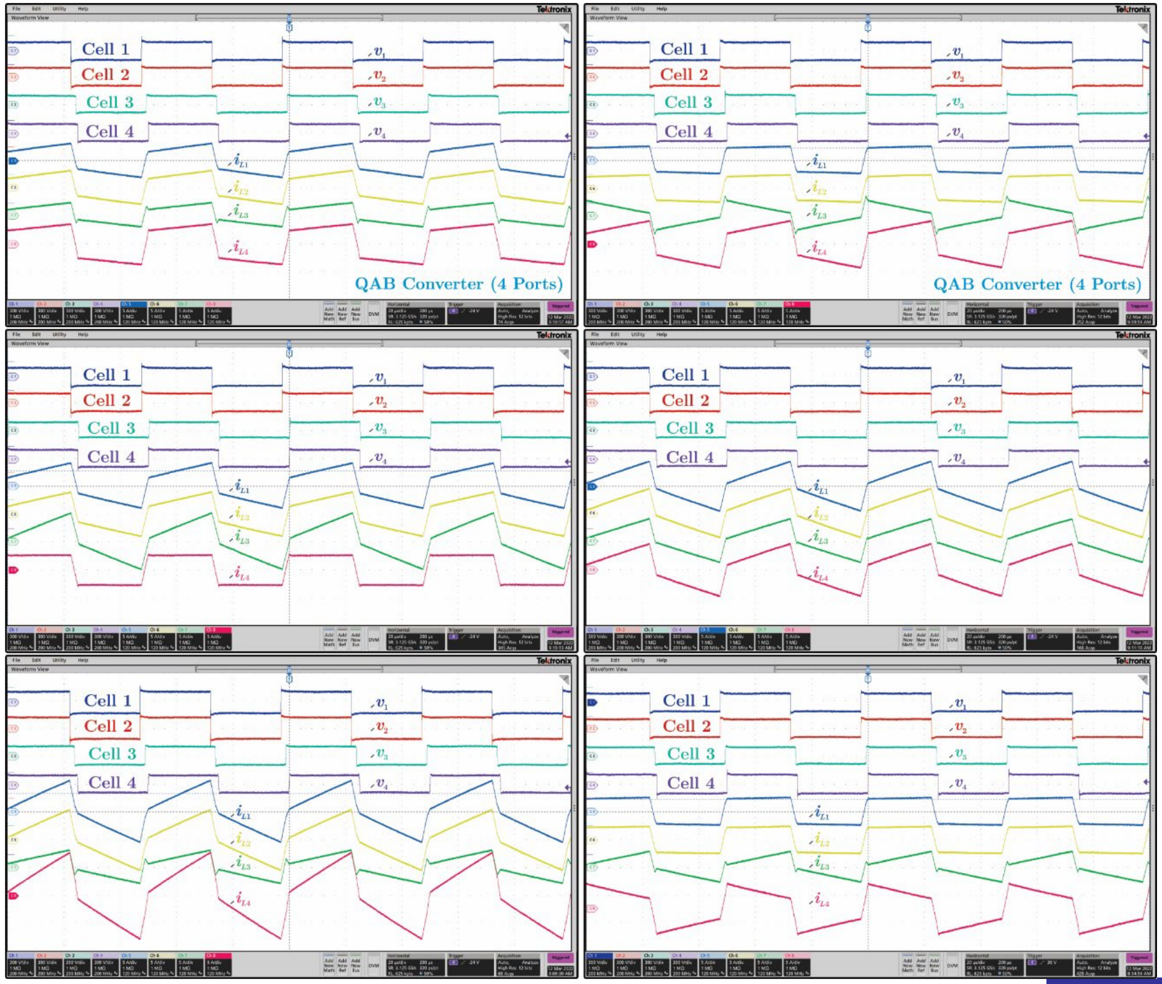
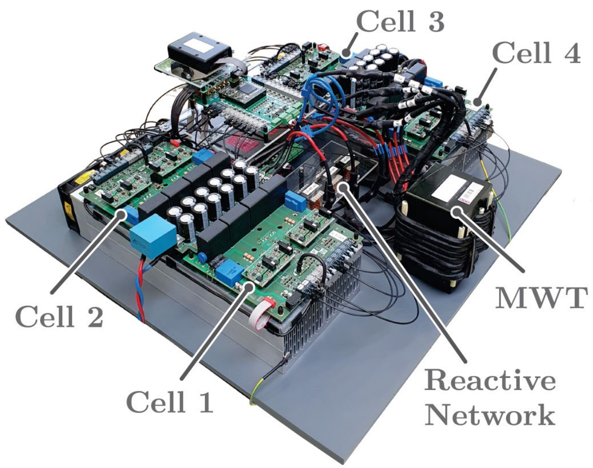
▶ **Potential of the MTB DC/DC Topologies in EV Charging Stations Applications – Key Component**

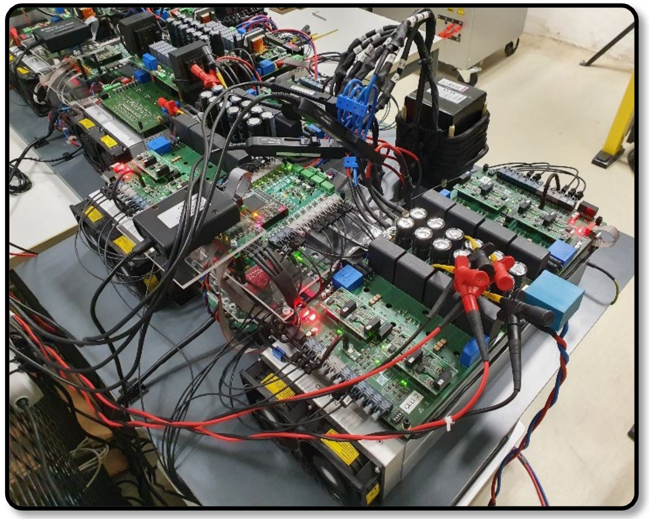


Experimental Results

Considering the Integration among different Sources and Power Levels







FINAL CONSIDERATIONS & FURTHER DISCUSSION

Final Consideration & Further Discussion

- ✓ **Modularity** is the key for different charging stations needs (different vehicles, different charging times, different configurations)
- ✓ **Grid Support** will be mandatory. In a **Heavily loaded grid**, the reactive power supply utilizing the free power capacity of charging stations can be insufficient, and coordination with smart charging will be needed.
- ✓ **Multifunctional and Universal Charging Station** offers multiple buses with different voltage and power levels as well as the Integration of storage
- ✓ **Special DC/DC topologies** allow **Multifunctional and Universal Charging Station with lower costs and footprint**.

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THANK YOU!

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FORUM ELEKTROMOBILITÄT SCHLESWIG-HOLSTEIN
Effizienz als Leitprinzip für Konzepte, Fahrzeuge und Infrastruktur

MULTIFUNCTIONAL AND UNIVERSAL CHARGING STATION

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