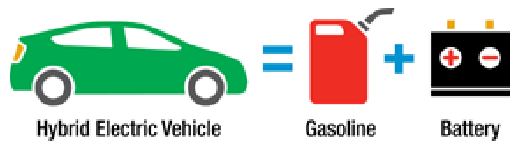
ELECTRIC VEHICLE CHARGER

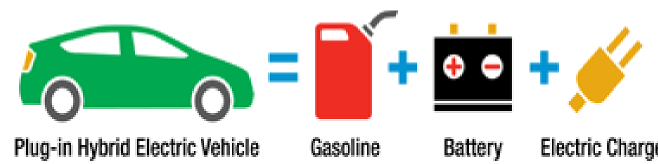
METU EE7566 Electric Drives in Electric and Hybrid Electric Vehicles

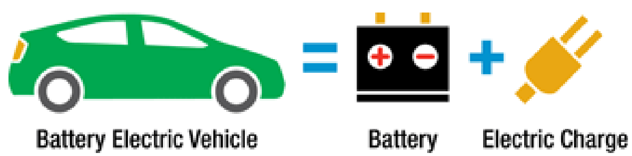
Instructor: Dr. Emine BOSTANCI

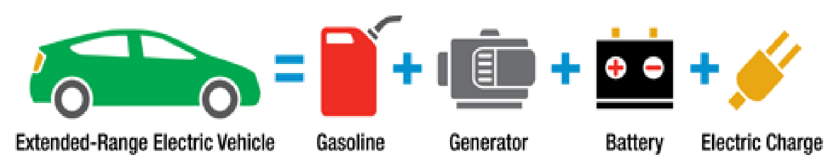
Prepared by Serhat ÖZKÜÇÜK

EV Types

- Hybrid EV (HEV) 

- Plug-In Hybrid EV (PHEV) 

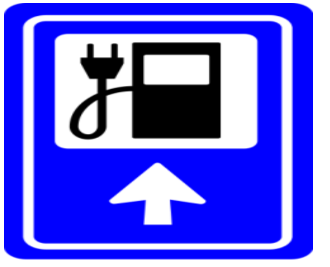
- Battery EV (BEV) 

- Extended Range EV (ER-EVs) 

EVSE : Electric Vehicle Supply Equipment

- EVSE is a device that can communicate with electrical vehicles within the standards (IEC,ISO) and transmit the electrical energy to electric vehicles in a controlled way.

USA

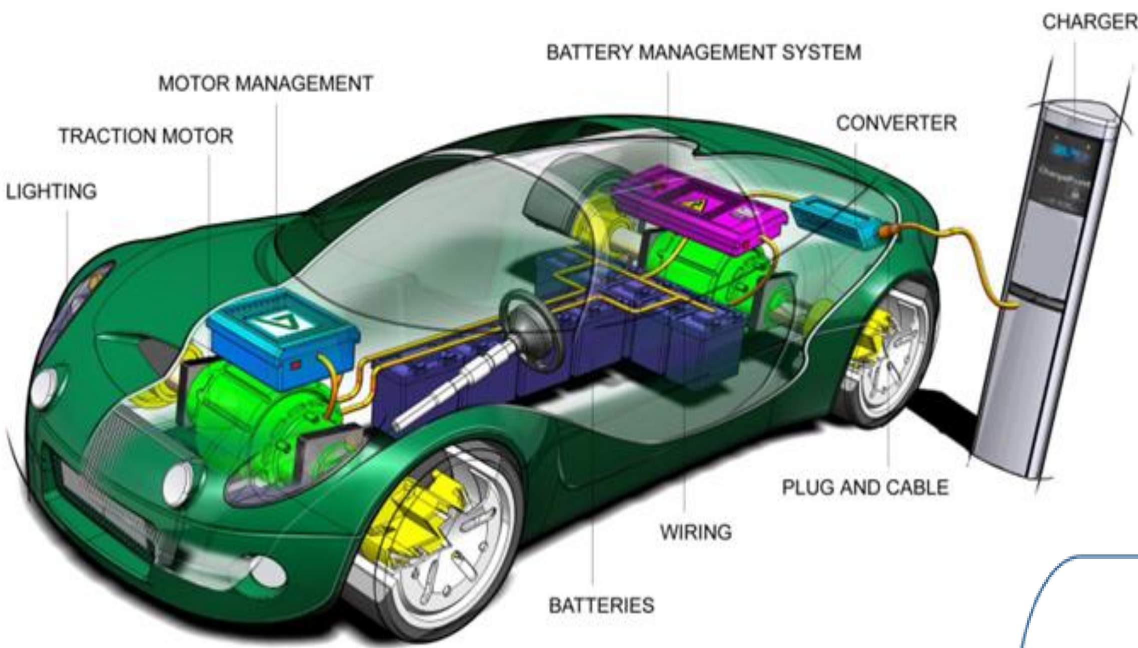


EUROPE

Charge Types

- AC
- DC
- INDUCTIVE

EV – Charger Structure



DC Charging :

-Infrastructure investment is shared
among hundreds of users

-Large Power Rating

-Fast Charging

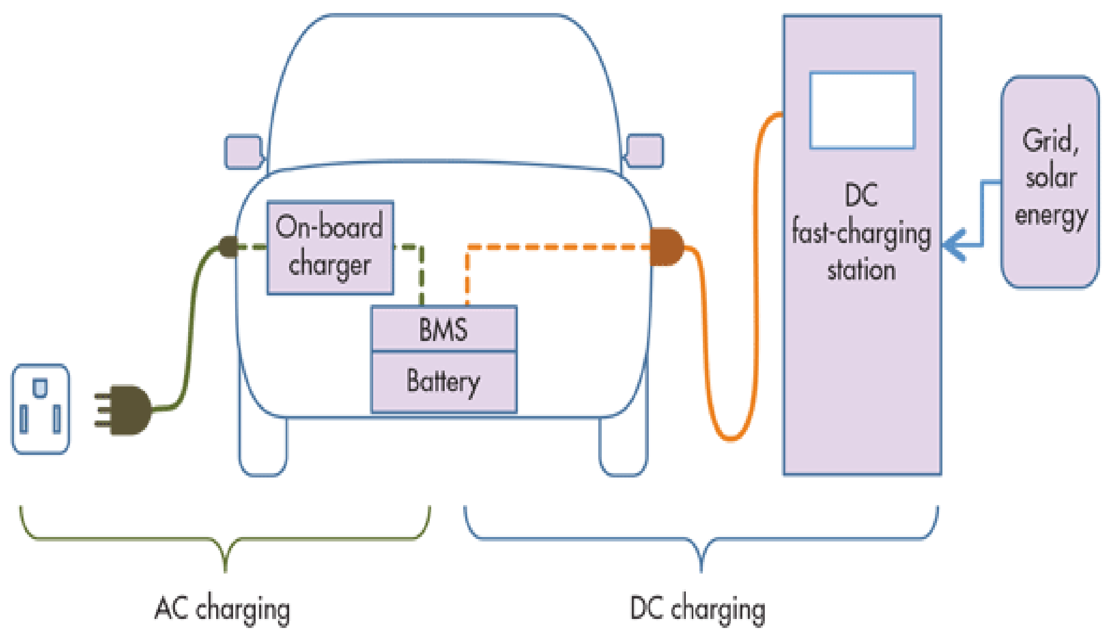
-Capable of integration with renewable resources

AC Charging :

-On-Board Charger

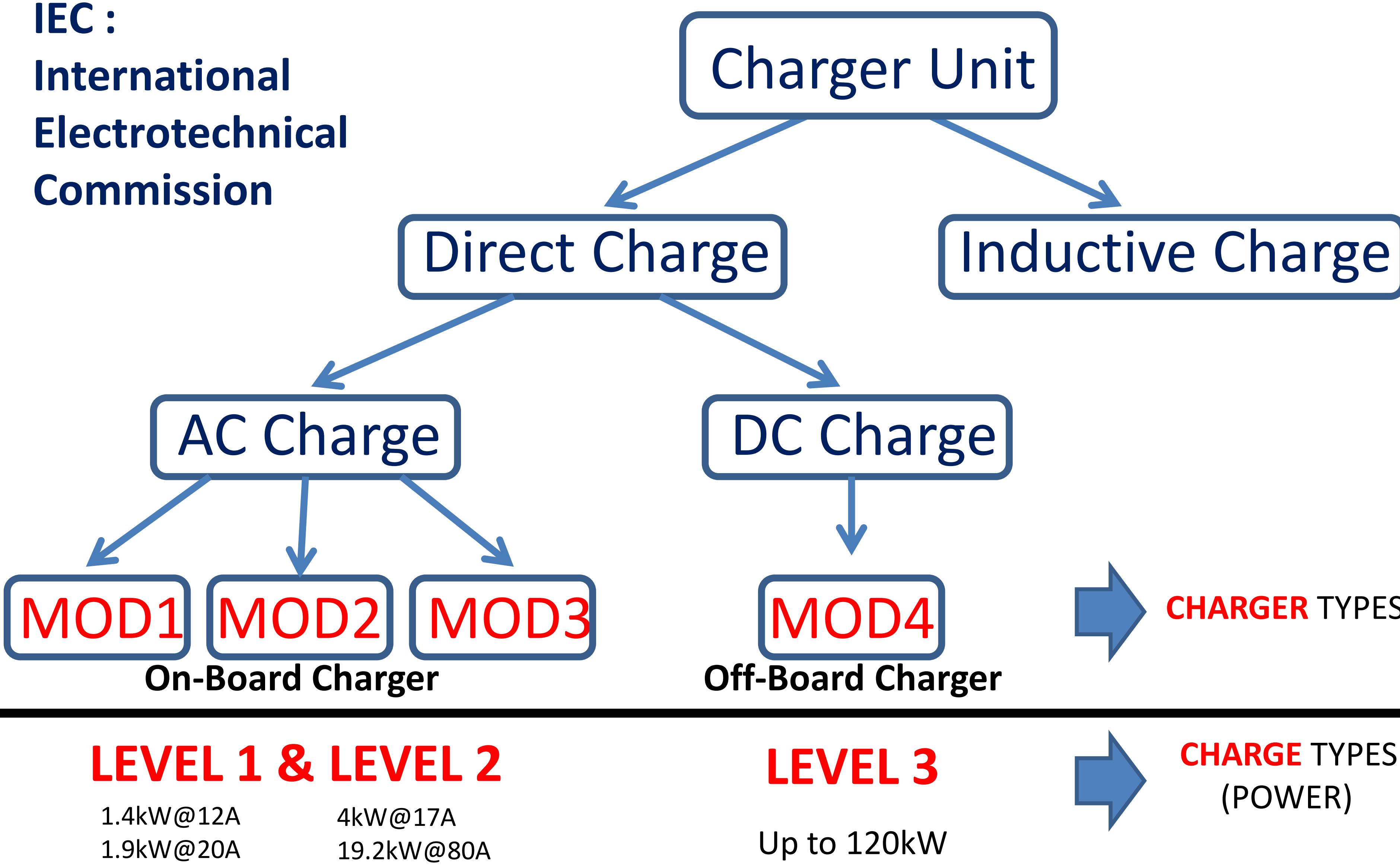
-Limited Power

-Slow Charging



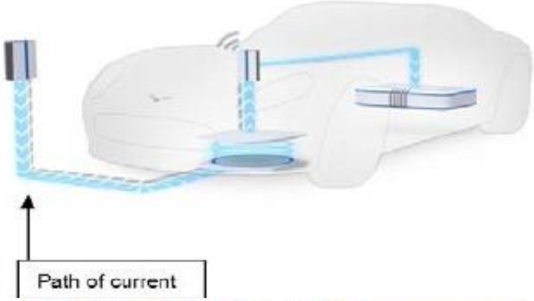
EVSE Types

IEC :
International
Electrotechnical
Commission

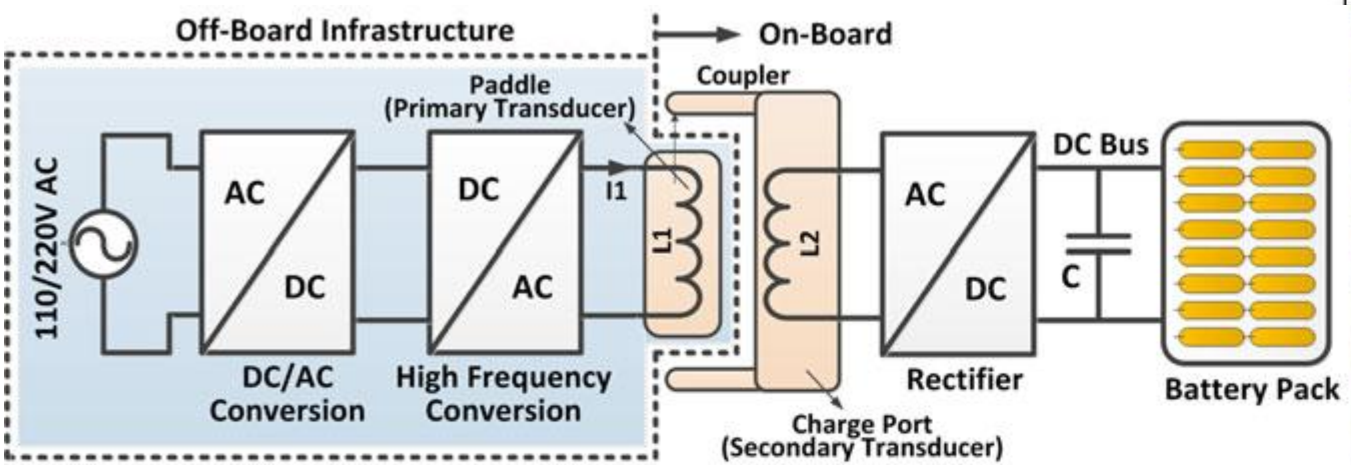


Inductive Charge

- It is based on the transfer of energy through magnetic coupling.
- The electromagnet in the station constitutes half of a transformer and the other electromagnet under the vehicle the other half of the transformer.
- When the exact match between the electromagnets is achieved, the energy transfer starts.



- OAK RIDGE National Laboratory surges forward with 20-kilowatt wireless charging for EVs: https://www.youtube.com/watch?v=NP-SACM3jtQ

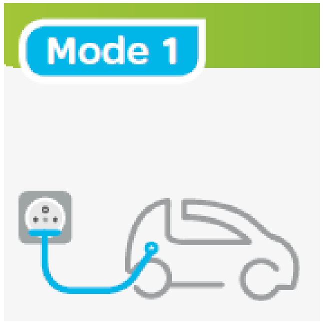


Typical inductively coupling stationary EV battery charging and GM EV1 system.

Direct Charge (AC) – MOD1

- Charged using standard household cables and socket outlets.
- Grounding is provided using the PE connection on the mains socket.
- It is the most preferred method of charging, but its use is prohibited in America, Canada, Israel and the UK (Safety Problems).
- Portable structure

MOD 1	1 PHASE	3 PHASE
MAX. CURRENT	16A	16A
VOLTAGE	230V	400V
MAX. POWER	3.7kW	11kW



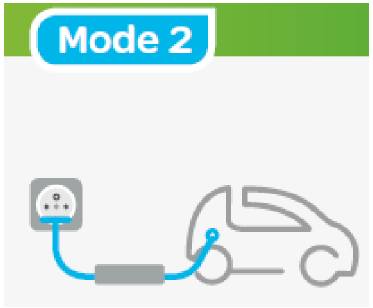
Direct Charge (AC) – MOD2

- It is based on charging the vehicle using standard household cables and socket outlets. In addition to MOD 1, the cable is equipped with a protection device (type A RCD).

- The ground connection is provided using the PE connection on the mains socket and the charging device and the charging compatibility communication with the protection device are provided by CP(Control Pilot) and PP(Proximity Pilot).

- Portable structure

MOD 2	1 PHASE	3 PHASE
MAX. CURRENT	32A	32A
VOLTAGE	230V	400V
MAX. POWER	7.4kW	22kW



Direct Charge (AC) – MOD3

- The charger is permanently connected to the mains.
- Communication between the EV and EVSE is provided by CP(Control Pilot) and PP(Proximity Pilot) signals.
- It is widely used in street or parking areas.

MOD 3	1 PHASE (Current/Voltage/Power)	3 PHASE (Current/Voltae/Power)
Normal Charge	16A/230V/3.7kW	16A/400V/11kW
Semi-Fast Charge	32A/230V/7.4kW	32A/400V/22kW
Fast Charge	70A/230V/16.1kW	63A/400V/44kW

Direct Charge (DC) – MOD4

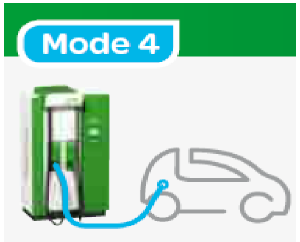
- The charger is permanently connected to the mains. AC form of energy is isolated and converted to DC and supplied in the DC form to the Electric Vehicle.

- The power conversion required to feed the batteries has been made at DC charging stations and has been a solution to the reliability problems of electric vehicles.

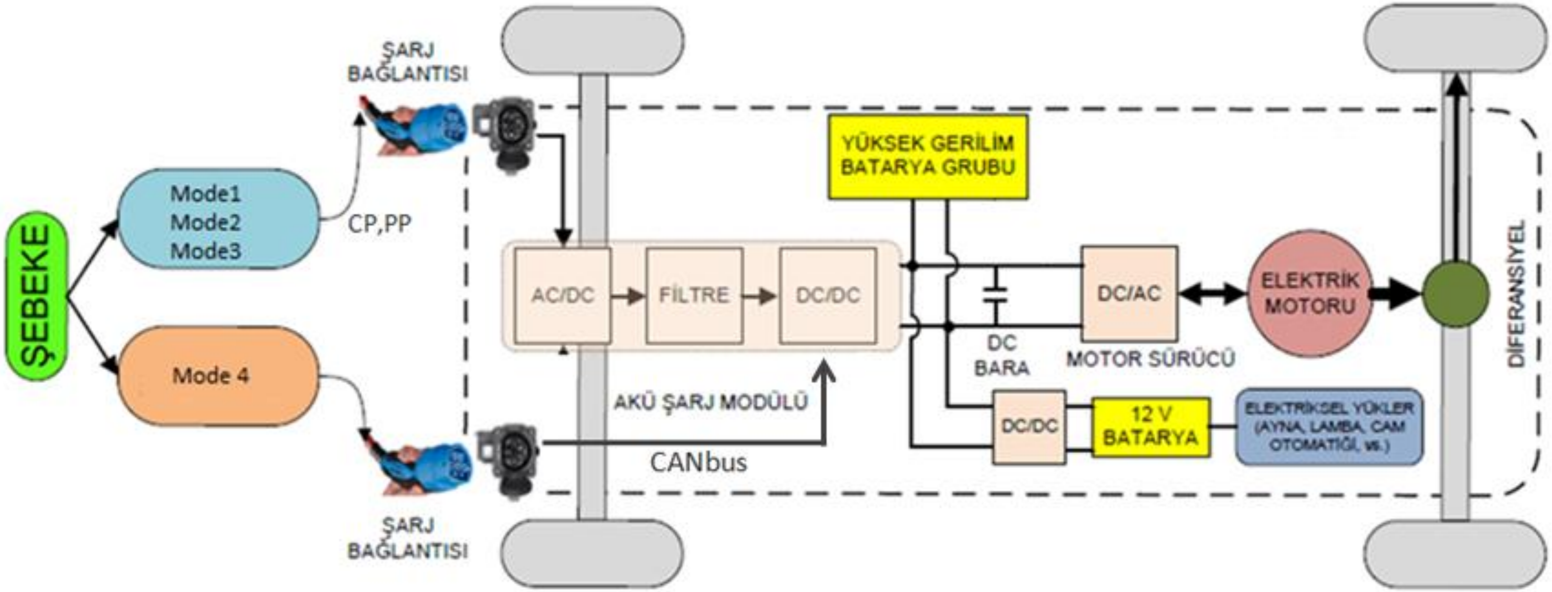
- Wall and stationary types are common.

- The output voltage range depends on the station. Generally, electric vehicles have a nominal voltage of 400V.

- Communication with Electric Vehicles is provided by PLC or CAN.
- Modular structures are preferred for power conversion.



Direct Charge Modes and Times

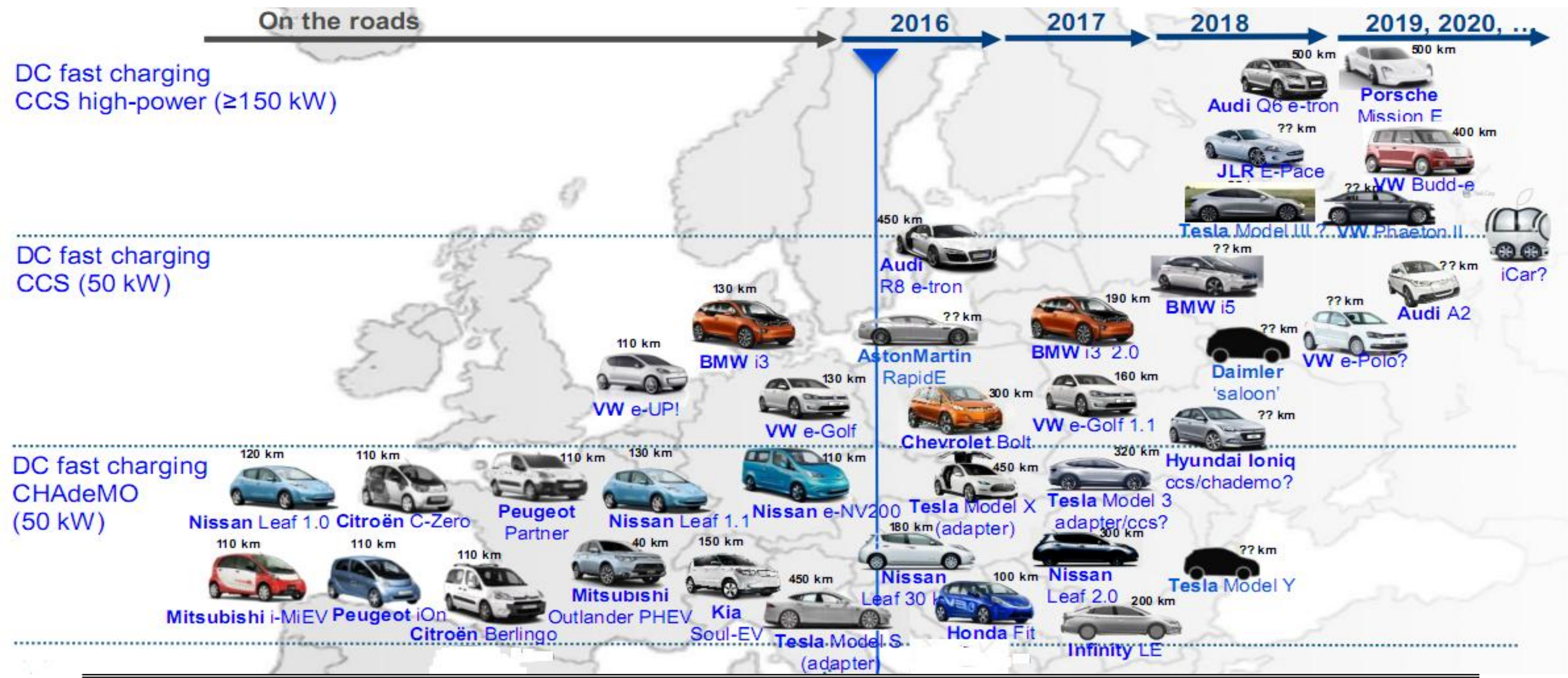


Different charge modes and charge times

	Charging time for 100 km of BEV range	Power supply	Power	Voltage	Max. current
AC	6–8 hours	Single phase	3.3 kW	230 V AC	16 A
AC	3–4 hours	Single phase	7.4 kW	230 V AC	32 A
AC	2–3 hours	Three phase	10 kW	400 V AC	16 A
AC	1–2 hours	Three phase	22 kW	400 V AC	32 A
AC	20–30 minutes	Three phase	43 kW	400 V AC	63 A
DC	20–30 minutes	Direct current	50 kW	400–500 V DC	100–125 A
DC	10 minutes	Direct current	120 kW	300–500 V DC	300–350 A

Charge Levels

Power Level	Description	Power Level
Level 1	Opportunity charger (any available outlet)	1.4kW (12A) 1.9kW (20A)
Level 2	Primary dedicated charger	4kW (17A) 19.2kW (80A)
Level 3	Commercial fast charger	Up to 100kW



	Battery Type and Energy	All-Electric Range	Connector Type	Level 1 Charging		Level 2 Charging		DC Fast Charging	
				Demand	Charge Time	Demand	Charge Time	Demand	Charge Time
Toyota Prius PHEV(2012)	Li-Ion 4.4kWh	14 miles	SAE J1772	1.4kW (120V)	3 hours	3.8kW (240V)	2.5 hours	N/A	N/A
Chevrolet Volt PHEV	Li-Ion 16kWh	40 miles	SAE J1772	0.96–1.4 kW	5–8 hours	3.8kW	2–3 hours	N/A	N/A
Mitsubishi i-MiEV EV	Li-Ion 16kWh	96 miles	SAE J1772 JARI/TEPCO	1.5kW	7 hours	3kW	14 hours	50kW	30 minutes
Nissan Leaf EV	Li-Ion 24kWh	100 miles	SAE J1772 JARI/TEPCO	1.8kW	12–16 hours	3.3kW	6–8 hours	50 + kW	15-30 minutes
Tesla Roadster EV	Li-Ion 53kWh	245 miles	SAE J1772	1.8kW	30 + hours	9.6–16.8 kW	4–12 hours	N/A	N/A

Charge Socket Types

CHAdeMO DC
(Japan)

DC COMBO
(Europe)

EV and EVSE Communication

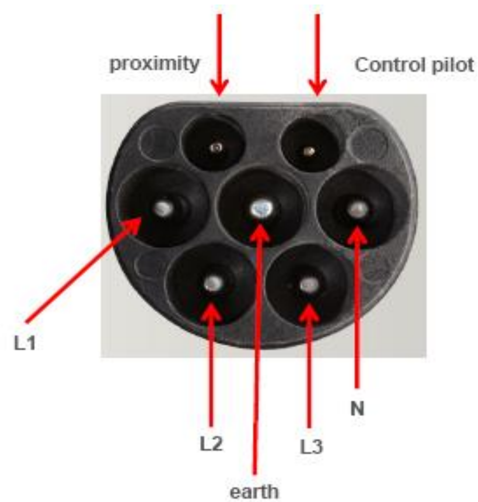
Proximity Plot (PP) (IEC Stds.)

- The main task is to check the cable is connected. Activates the installed charger in the vehicle.
- Provides information about the maximum current that the cable can carry. The current is determined by the resistance value between PP and PE in the socket.

Control Pilot (CP) (IEC Stds.)

- It carries the information of the vehicle case.
- Used for MOD2, MOD3, MOD4.
- The maximum current for charging is reported (duty cycle) to the vehicle within this signal.

Resistance	Max. Current
1.5kohm	13A
680ohm	20A
220ohm	32A
100ohm	63A



Chargers (Converters)

Light weight, High efficiency, Small volume,
Low electromagnetic interference,
Low current ripple drawn from the Fuel Cell or the battery

Unidirectional Chargers

Single - Phase

Three - Phase

Non-Isolated

Diode Bridge + Buck
+ Boost
+ Buck-Boost

Isolated

Diode Bridge +Flyback(<100W)
+Forward(50-200W)
+Pushpull(100-500W)
+Half-bridge(200-500W)
+Full-bridge(>500W)
+SEPIC(>500W)
+CUK(>500W)
+Multilevel

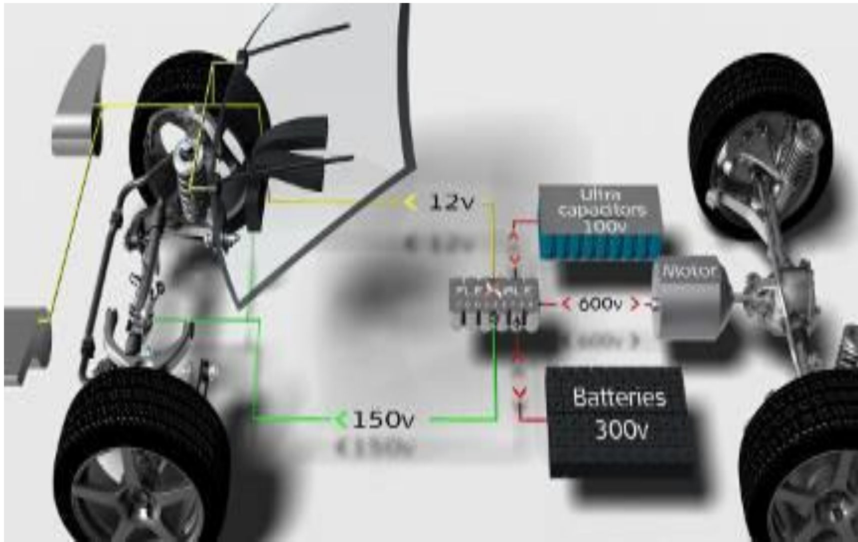
Low Power
Slow Charging

High Power
Fast Charging

Bidirectional Chargers

Non-Isolated or Isolated

Pushpull
Half-bridge
Full-bridge (VSI - CSI)
Multilevel (VSI - CSI)
Matrix Converters



<table>
<tr><th></th><th colspan="2">Configurations</th><th>Properties and Comparison</th><th>Methods for Improving Performance</th><th>Control Algorithms</th></tr>
<tr><td rowspan="2">Unidirectional Chargers</td><td>Single-phase Non-isolated or Isolated (Low power-slow charging)</td><td rowspan="2">-Diode Bridge + Buck
-Diode Bridge + Boost
-Diode Bridge + Buck/Boost
-Diode Bridge + Isolated Con.
- Flyback
- Forward
- Pushpull
- Half-Bridge
- Full-Bridge
- SEPIC
- CUK
- Multilevel</td><td rowspan="2">**Buck is** the simplest converter if you require an output voltage that is lower than the input, as it requires only a small number of components. It wastes very little energy. **Boost** converts a lower input voltage to a higher output. It contains at least a pair of diodes and transistors and at least one capacitor or any energy storage element. Output voltage can be either higher or lower than input in **Buck-Boost**; also, a negative-polarity output is obtained with respect to the common terminal of the input current. The main advantage is the small number of devices. Disadvantages are the high input voltage ripple and high electrical stresses.
Flyback is widely used in applications where an isolated conversion is required, for low-power ranges. High output voltages can be quite easily obtained, because there is no inductor in the output section. It is simple and inexpensive, but has high voltage stress and low efficiency due to leakage inductor. **Forward** can be considered a direct derivative of the **Push-Pull** converter, where one of the switches is replaced by a diode. The cost is usually lower, which makes this topology very common.
Similar to the buck-boost, the **CUK** provides a negative-polarity regulated output voltage with respect to the common terminal of the input. Advantages are a continuous current at the input (and at the output) and reduced input and output current. Disadvantages are a high number of passive components, large inductors and high electrical stresses. **SEPIC** contains two large inductors and output capacitor; output current is discontinuous. It has a non-inverting buck-boost characteristic. It also exhibits (like the Cuk) the desirable feature that the switch control terminal is connected to ground; this simplifies the construction of the gate drive circuitry. Voltage stresses in the capacitor are lower than in the Cuk. It exhibits non-pulsating input current. Transfer capacitor is rated only to input voltage. Cuk and SEPIC/**Luo** can convert power bi-directionally by using two active switches. The current stress for active switches and diodes in the Cuk and SEPIC/Luo are larger than that in the half bridge under the same input/output voltage and power conditions. Therefore, the half-bridge is expected to be more efficient. It also has fewer inductors and capacitors.</td><td rowspan="4">**-PFC**
-Bridgless boost PFC
-Interleaved: Reduced battery charging current, inductor size and stress on output capacitor, but limited power level
-Bridgless Interleaved: High power level
-Multicell
-Resonant Circuit: Reduced switching stress and losses, high efficiency
-Soft/Hard switching
-Zero voltage and current switching (ZVS ZCS) : Reduced size and weight</td><td rowspan="4">-PI
-PID
-Sliding Mode
-Fuzzy Logic
-Adaptive
-Neural Network</td></tr>
<tr><td>Three-phase Non-isolated or Isolated (High power-fast charging)</td></tr>
<tr><td rowspan="2">Bidirectional Chargers</td><td>Single-phase Non-isolated or Isolated (Low power- slow charging)</td><td rowspan="2">-Push-pull
-Half-Bridge
-Full- Bridge (VSI –CSI)
-Multilevel (VSI – CSI)
-Matrix Converters</td><td rowspan="2">**Half-Bridge:** Fewer components, lower cost, control simplicity, but high component stress. It has the same number of active and passive components as the two-quadrant buck-boost. There is only one inductor instead of two (SEPIC – CUK). Higher efficiency than the SEPIC and CUK, because it has lower inductor conduction and switching losses. Drawback is its discontinuous output current when operating as boost.
Full-Bridge: More components and PWM inputs, control complexity, higher cost, but lower component stress. It has a high conversion ratio and power level.
Multilevel: Requires additional control circuitry. Additional components increase cost and complexity, but lower component stress and losses. It has high efficiency, reduced size and switching frequency. It includes EMI and a high frequency component and a small and inexpensive filter.
Matrix Converters: Provides sinusoidal input/output waveforms, with minimal higher order harmonics and no sub-harmonics .It has inherent bidirectional energy flow; the input power factor can be fully controlled. It has minimal energy storage requirements, which allows elimination of bulky and lifetime-limited energy-storing capacitors. But it has a maximum input/output voltage transfer ratio limited to 87% for sinusoidal input and output waveforms and requires more semiconductor devices than a conventional ac-ac indirect power frequency converter, since no monolithic bidirectional switches exist and, consequently, discrete unidirectional devices, variously arranged, have to be used for each bidirectional switch. It is particularly sensitive to disturbances of the input voltage system.</td></tr>
<tr><td>Three-phase Non-isolated or Isolated (High power-fast charging)</td></tr>
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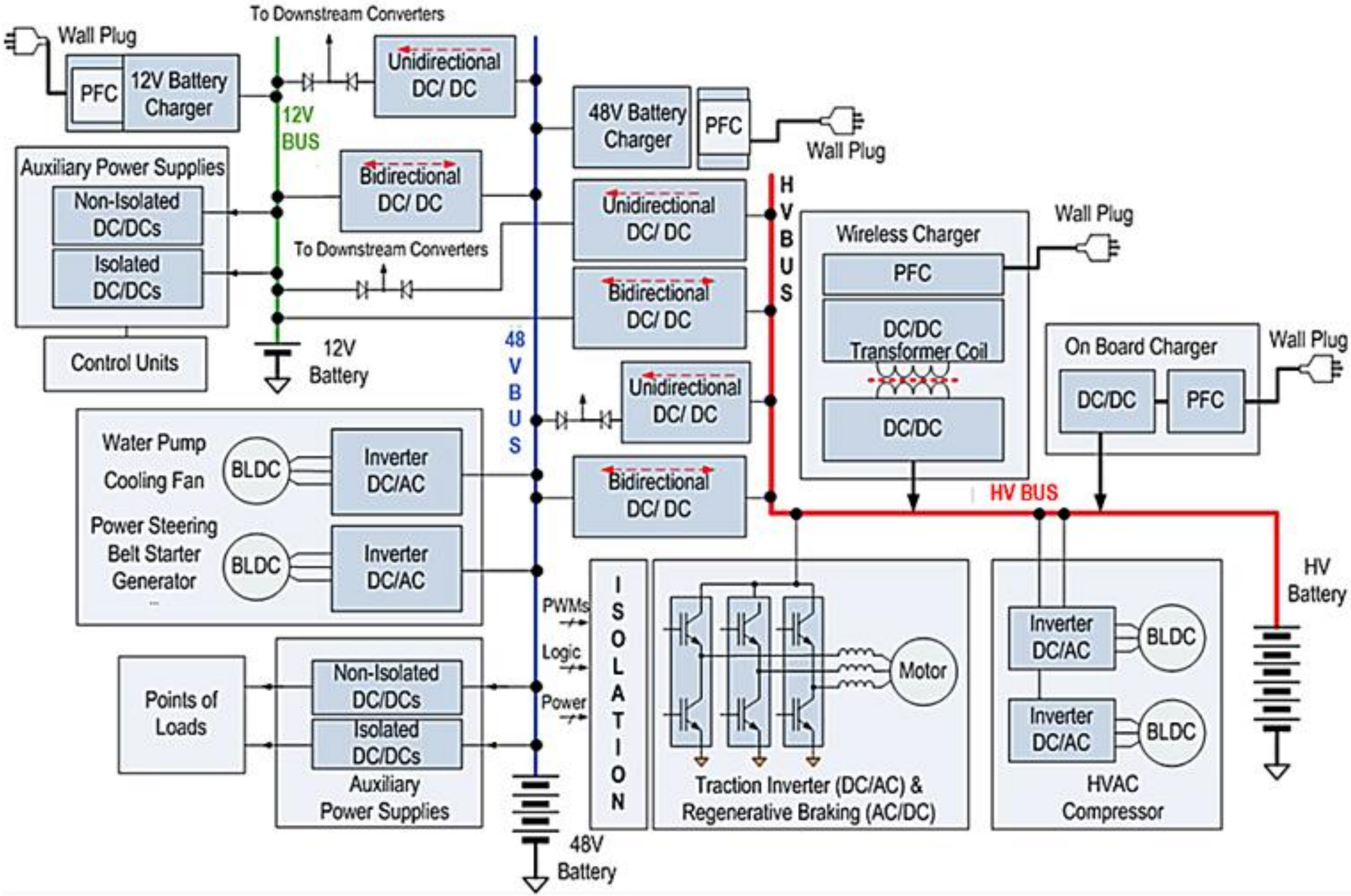
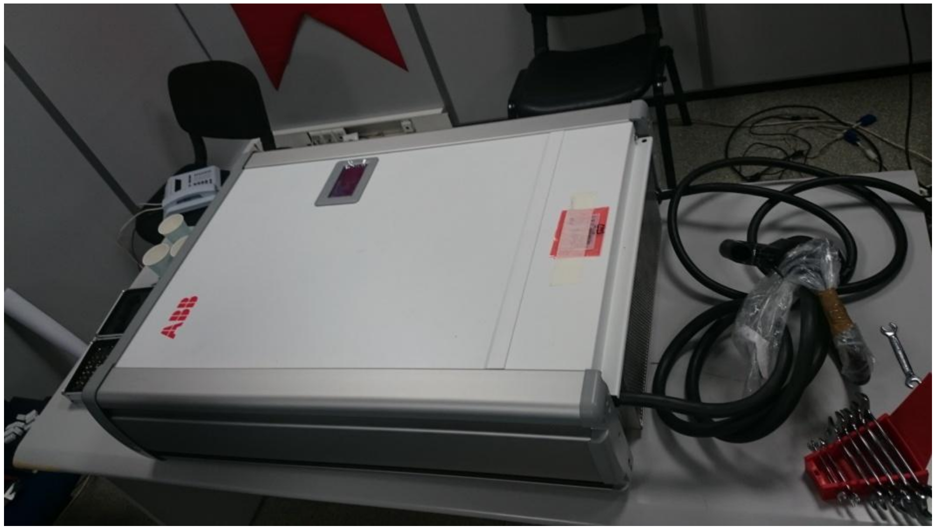
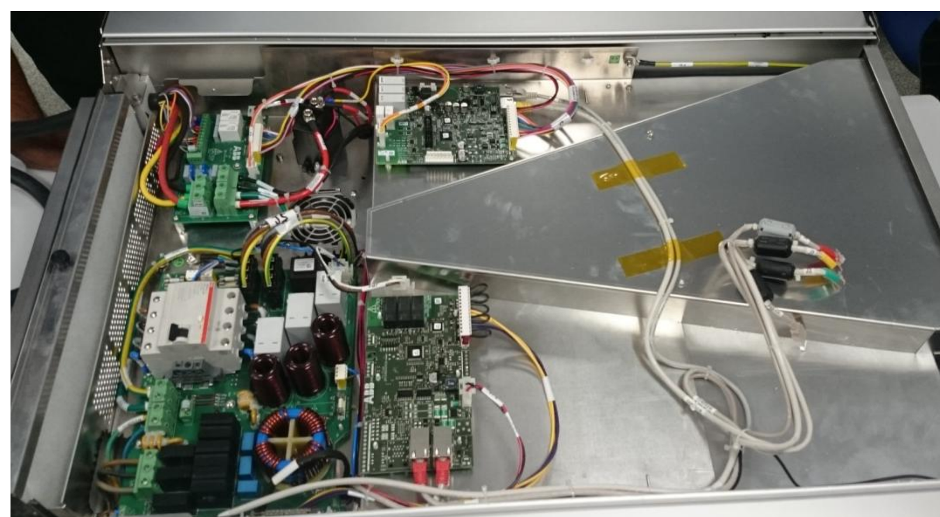


The HEV/EV requires numerous types of high-voltage converters, including unidirectional and bidirectional dc-dc topologies. (Source: [TI Training: "How to Design Multi-kW DC/DC Converters for Electric Vehicles (EVs) – EV System Overview" video](https://training.ti.com/how-design-multi-kw-dcdc-converters-electric-vehicles-evs-ev-system-overview?cu=1128387) : https://training.ti.com/how-design-multi-kw-dcdc-converters-electric-vehicles-evs-ev-system-overview?cu=1128387)

MOD4 DC Charger : ABB Wallbox 20kW





Internal Structure of ABB DC Charger

1 – Input Filter Block

2 – Display control,

Communication,

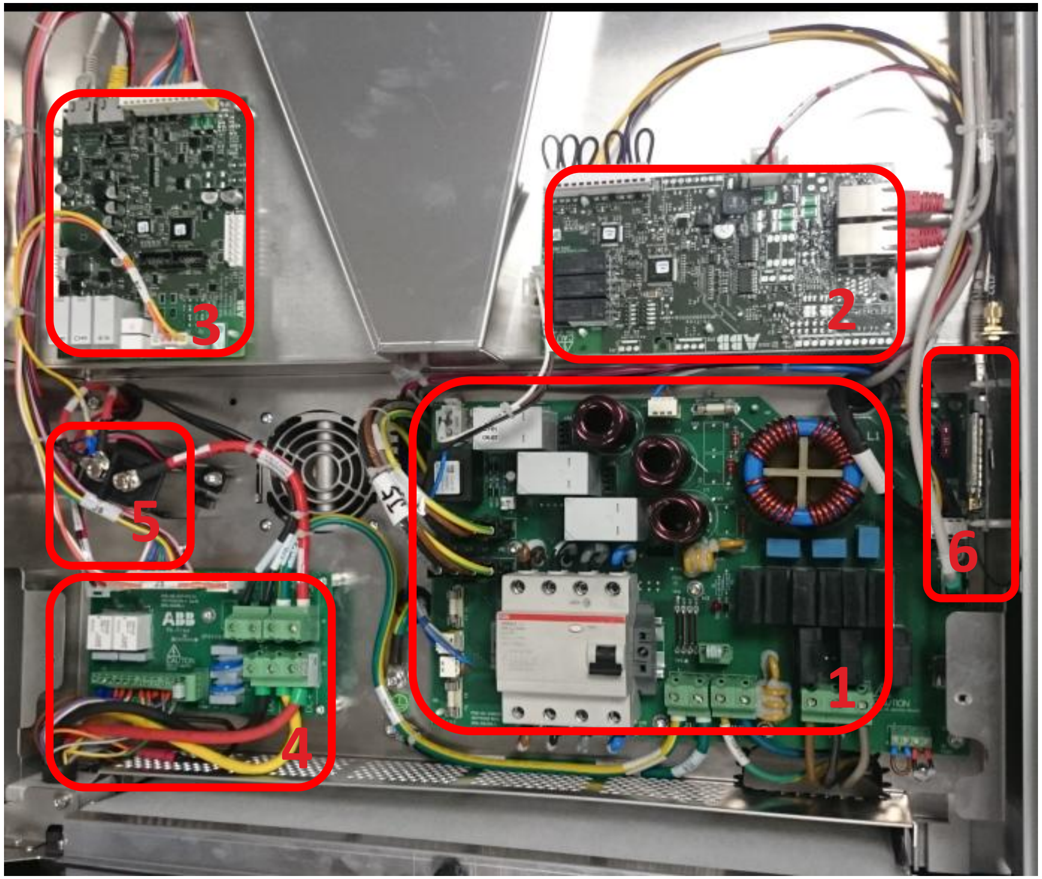
Main board

3 – EV Communication

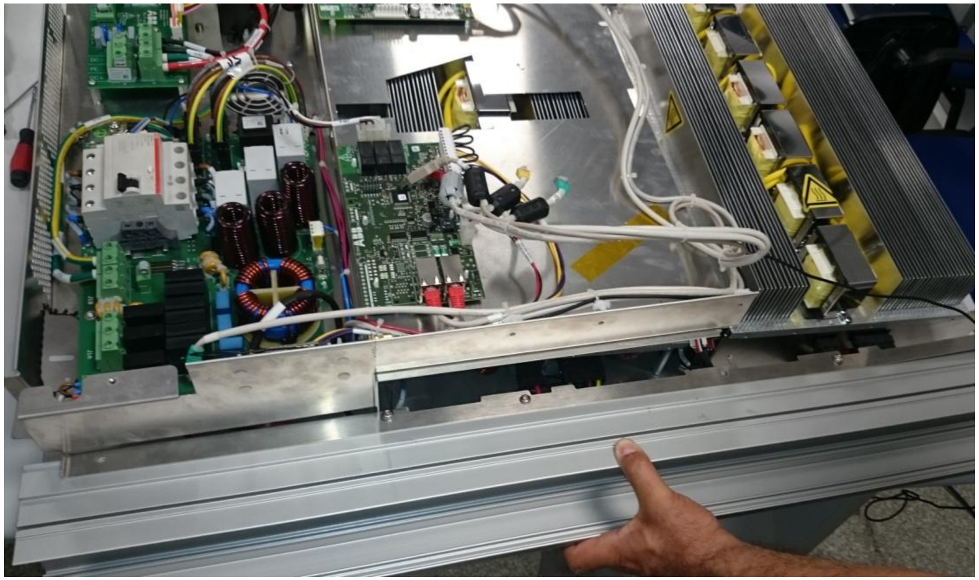
4 – Output

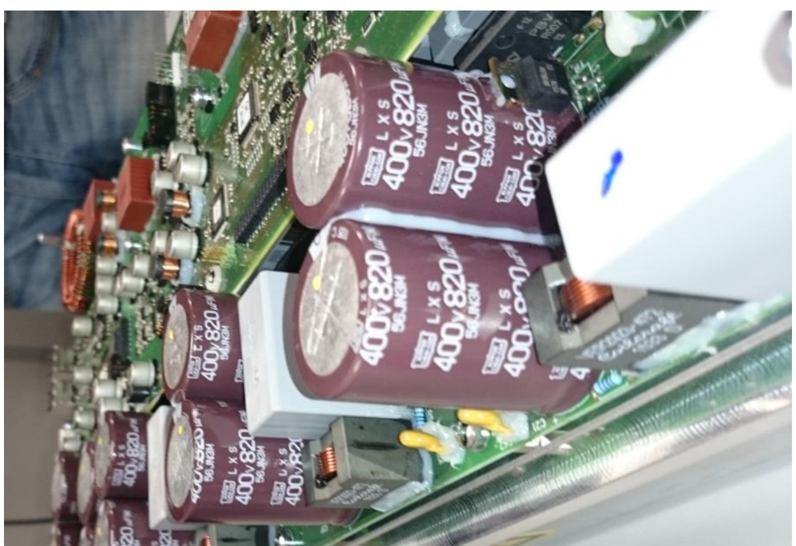
5 – DC Contactor

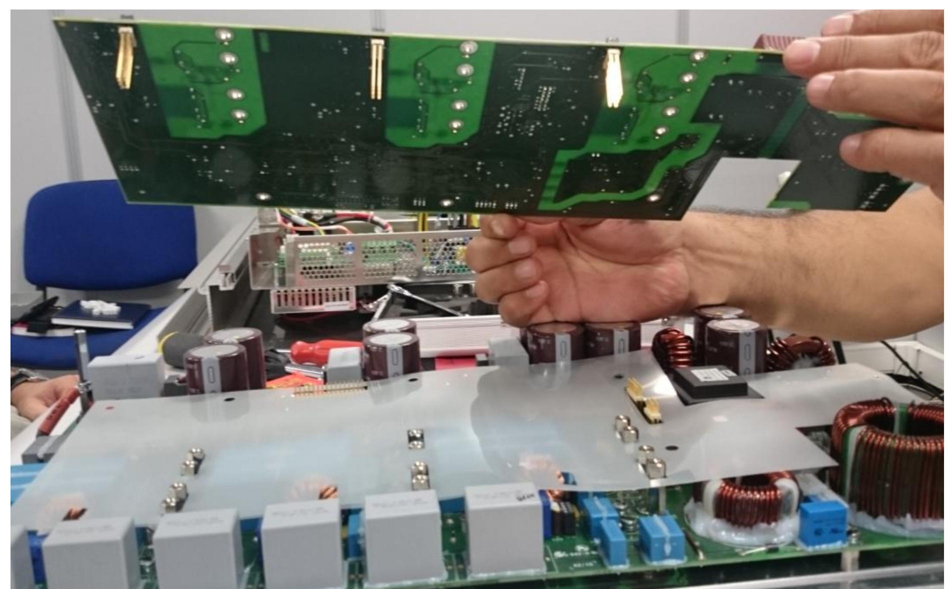
6 – GSM Module



Converter Board of ABB DC Charger







Converter Board of ABB DC Charger

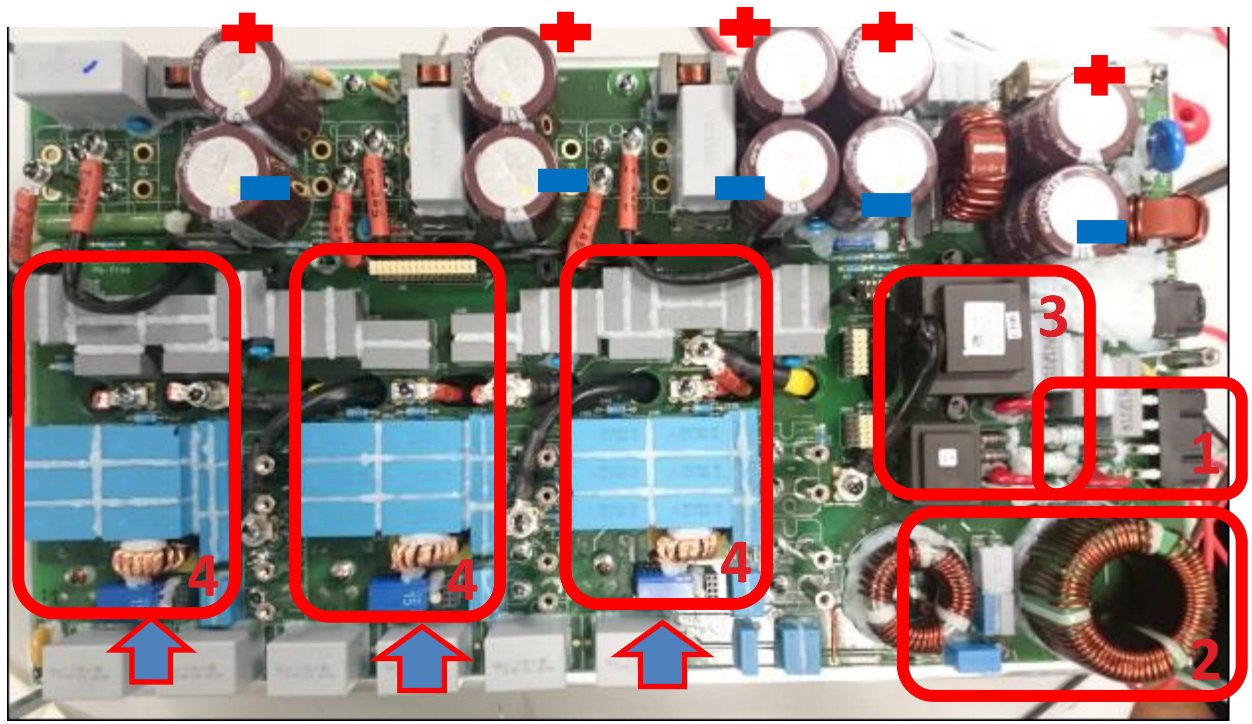
1 – AC Input

2 – Input Filtering

3 – Supplier Transformers

4 – AC/DC DC/DC Blocks

5 – DC Output



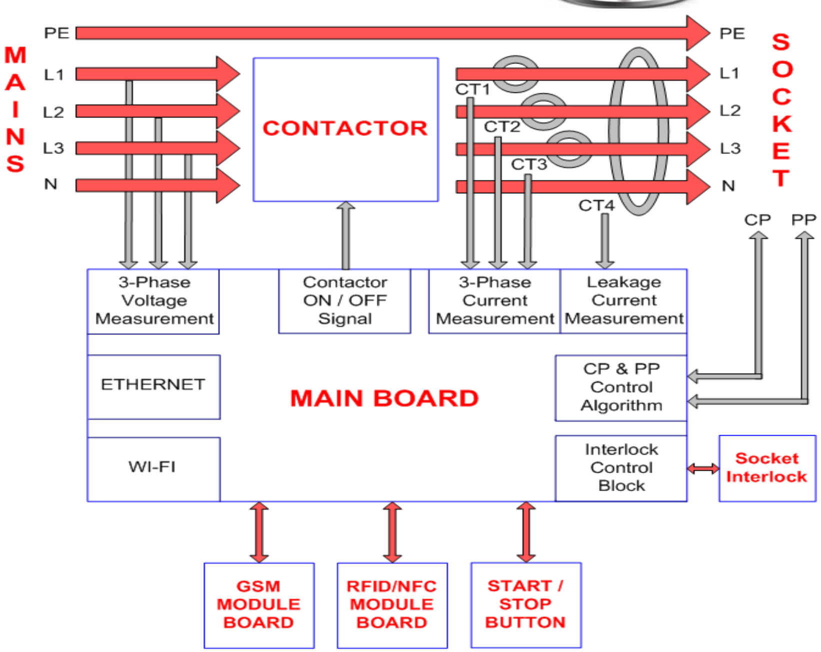
MOD3 AC Charger : VESTEL EV Charger

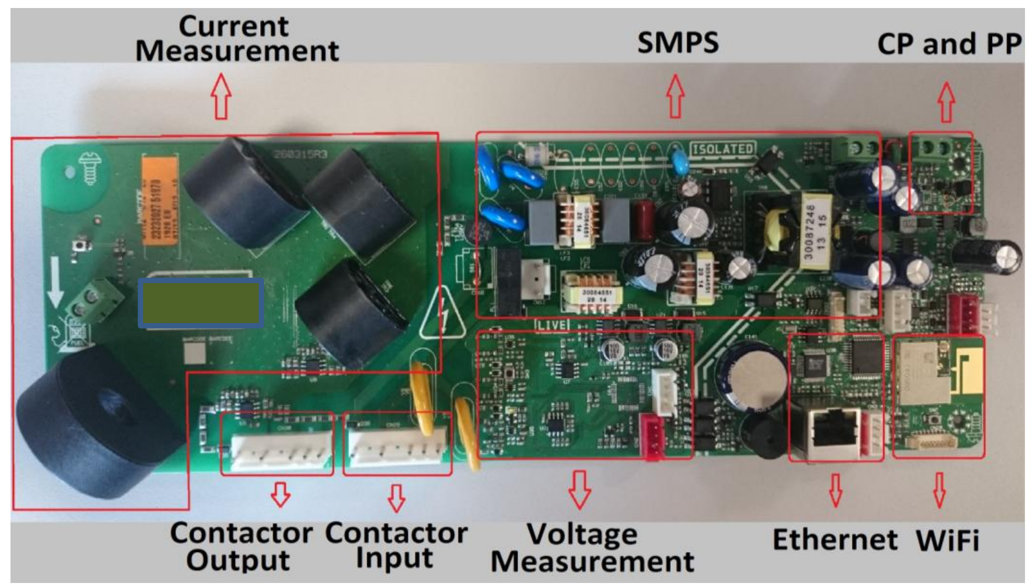
MOD3 (IEC)

– Wi-Fi , NFC/RFID , GSM

– LED Display(RB)

– Charge Start/Stop Button





DC WALLBOX BENCHMARK

- **Delta** DC Wallbox EV Charger (CCS: 200-500V, Chademo:50-500V, 60A, 25kW, 3phase)
- **IES** Keywatt DC Charger (CCS, Chademo, GB/T, 2output, 200-520V, 65A, 24kW, 3&1phase, IP54, IK07/09)
- **ABB** DC Wallbox EV Charger (CCS, Chademo, GB/T, 2output, 60A, 22.5kW, 3phase)

DC WALLBOX BENCHMARK

- **Designwerk** Mobile DC Charger (CCS, Chademo, 280-450V, 60A, 21kW, 3phase, IP54)

- **Efacec** DC Wallbox EV Charger (CCS: 260-425V, 60A, 24kW, 3&1phase, IP54, IK10)

DC TOTEM/SELF STANDING BENCHMARK

ABB 350kW

ABB

ABB

ABB

DC TOTEM/SELF STANDING BENCHMARK

EFACEC 150 kW

EFACEC

ENEL

References

- Review of Battery Charger Topologies, Charging Power Levels, and Infrastructure for Plug-In Electric and Hybrid Vehicles, Murat Yilmaz *and Philip T. Krein, 2013*
- Review of Integrated Charging Methods for Plug-In Electric and Hybrid Vehicles, Murat Yilmaz *and Philip T. Krein, 2012*
- https://training.ti.com/how-design-multi-kw-dcdc-converters-electric-vehicles-evs
- DC/DC Converters for Electric Vehicles, Monzer Al Sakka, Joeri Van Mierlo and Hamid Gualous, 2011
- https://www.electronicdesign.com/automotive/more-electrification-means-greater-automobile-efficiency
- Design and Analysis of 60 kW DC-DC Converter for Hybrid Electric Vehicle Applications, Muhammad Rafiq, Mohammed Fareed Ul Hasan, Prof. Torbjörn Thiringer.
- Powering The Future, Shenzhen Megmeet Electrical Co.,Ltd.
- Electric Vehicle Charger Stations, Garry H. Fox.