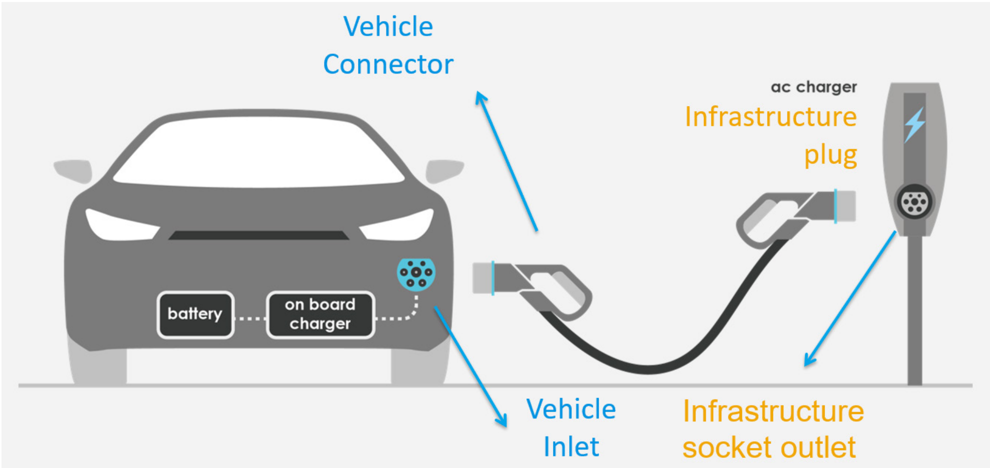
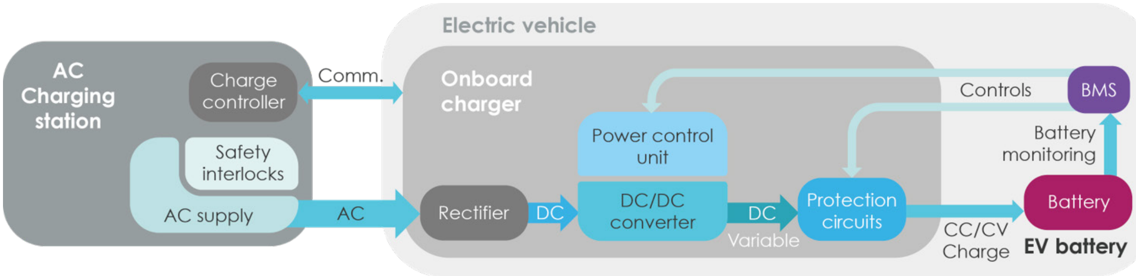
Electric cars: Technology
Lecture notes: Lecture 3.2

AC charging



AC charging allows EVs to be charged by using inexpensive AC charging stations which feed AC power directly from the grid to the car. The nature of AC, that is, single phase or three phase, voltage level and grid frequency may vary from country to country. AC charging uses an onboard charger to convert AC power from the conventional AC grid to direct current or DC power to charge the traction battery. Cars have a standardised vehicle inlet, and a charging cable is used for connecting the vehicle connector to the infrastructure socket of the AC charging station. The onboard charger needs to be light (typically less than 5 kg) and compact due to the limitation of allowable payload and space in the EV and the PHEV. The drawback of this charger is the limitation of the power output because of size and weight restrictions.

AC Charger: Operation



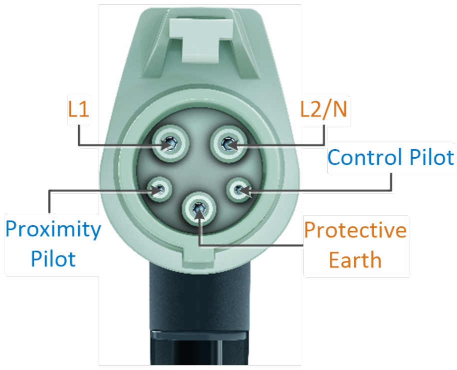
- When the charging station and the EV are first connected, the charge controller in the station communicates with the EV. Information regarding the connectivity, fault condition and current limits are exchanged between the charger and the EV.
- When the AC power is provided to the EV, the onboard charger has a rectifier that converts the AC power to DC power. Then, the power control unit appropriately adjusts the voltage and current of a DC/DC converter to control the charging power delivered to the battery.
- The power control unit, in turn, gets inputs from the Battery Management System or the BMS for controlling the battery charging.
- Apart from this, there is a protection circuit inside the onboard charger. The BMS triggers the protection circuits if the battery operating limits are exceeded, isolating the battery if needed.

AC Charging: types

The EV industry has not agreed on one specific AC connector, so depending on the car brand and country, the connector varies in shape, size and pin configuration. One of the main reasons is the difference in AC voltage and frequency. Generally, an AC connector has two or more larger pins to transmit power, and some smaller pins for communication. Four types of AC connectors are used worldwide, namely:

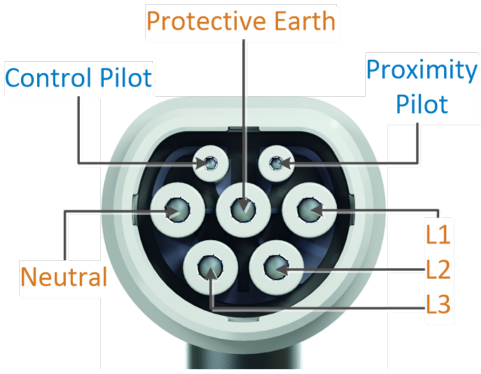
- The Type 1 connector, which is mostly used in USA & Japan.
- The Type 2 connector, which is mostly used in Europe, including those of Tesla cars.
- The Type 3 connector, used in Europe but is being increasingly phased out by Type 2 connectors.
- The proprietary connector used by Tesla for its cars in the USA.[9]
- China has its own standard for AC charging, which is similar to Type 2 connectors.

Type 1:



- **Brief History and Usage Information:**
  SAE International proposed a standardized coupling coupler (SAE J1772-2001) based on a design approved by the California Air Resources Board for charging stations of EVs. This rectangular plug was based on a design by Avcon. In 2009, a modification of this design with a round housing was published by Yazaki and the SAE J1772-2009 coupler specifications were included to the IEC 62196-2 standard as an implementation of the Type 1 connector for charging with single-phase AC. This connector is used for charging mostly in USA and Japan and it is popularly known as the Yazaki or J1772 connector.
- **Pin Configuration:**
  It is used specifically for charging with single-phase AC. It has a round housing consisting of five pins – 2 AC wires, earth wire and two signal pins. The two signal pins are the proximity detection pin used for ensuring connectivity between the EV and the charger, and the control pilot for control of charging.
- **Maximum voltage and current ratings:**
  Voltage 120V or 240V; Current up to 80A.

Type 2:

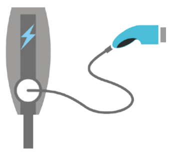
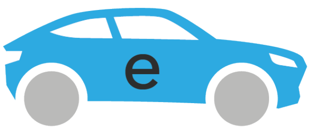


- **Brief History and Usage Information:**

  The type 2 connector was tested and standardized first by the German Association of the Automotive Industry (VDA) as VDE-AR-E 2623-2-2, and thereafter recommended for use by the European Automobile Manufacturers Association (ACEA) in 2011. The European Commission too recommended this charger for use across the whole of Europe in early 2013. The connector is circular in shape, with a flat top edge. It has been ergonomically designed such that it can be operated with one hand. Cars have a standardized male inlet while the female outlet is fitted to the charging station. The Chinese AC charger is similar to the type 2 connector. Tesla uses the Type 2 connector in Europe for both AC and DC charging.

- **Pin Configuration:**

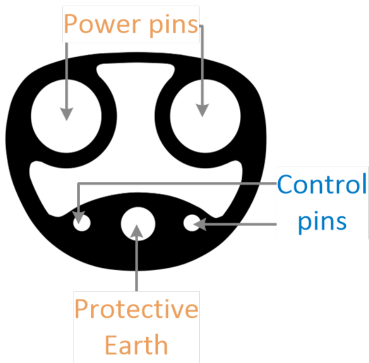
  The connector consists of two small signal pins for control and proximity pilot and five big pins, which combine both AC and DC charging in one single connector. The five power pins are used for Neutral (N) and line phases (L1, L2, and L3) and Protective earth (PE). The connector can hence be used for both single and three phase AC charging.

- Maximum voltage and current ratings:

  1 phase 230V, up to 80A; 3 phase 400V, up to 63A

Tesla US connector:



- **Brief History and Usage Information:**

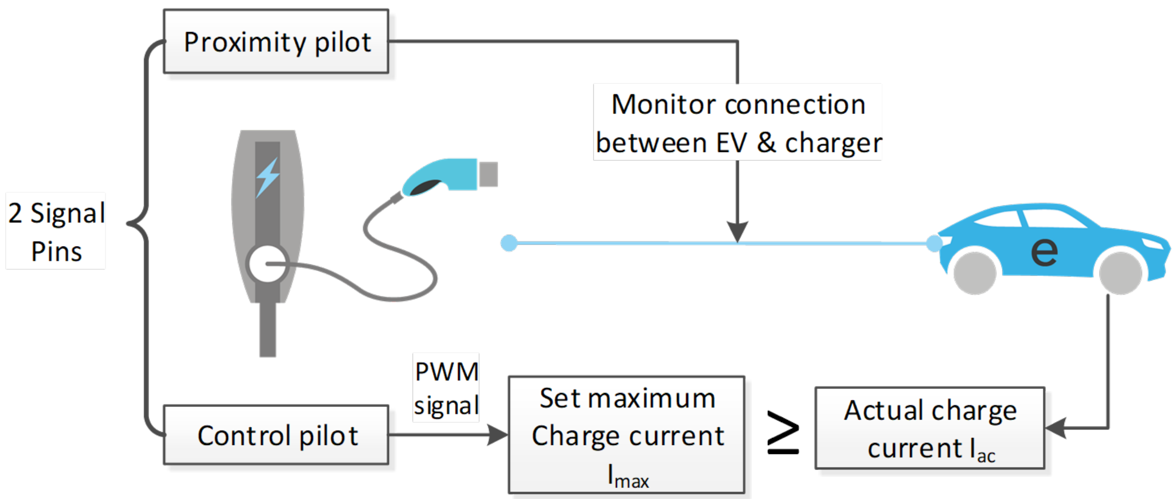
  Proprietary connectors are used in the USA for Tesla AC charging and DC charging. Has an adapter than help the connector to be used with Type 1 AC charging stations and Chademo DC charging stations.
- **Pin Configuration:**

  The connector consists of two small signal pins for control and three bigger power pins, which combine both AC and DC charging in one single connector. The three power pins are used for Neutral (N) and line phase (L1) and Protective earth (PE). The connector can be used only for single phase AC charging and not for three phase. Tesla uses the same connector for DC charging as well.
- **Maximum voltage and current ratings:**

  1Max charging power of 17.2kW when connected to 240V AC outlet.

Control and proximity pilot

- The Type 1 and Type 2 connectors have 2 common communication pins: the Control Pilot (CP) and the Proximity Pilot (PP).
- The Proximity Pilot (PP) checks if the vehicle connector is connected properly to the vehicle inlet. If the connection is not properly established, the Proximity Pilot will detect it, and the entire process will be disabled for safety.
- The second special pin is the control pilot (CP), and it is used for controlling the charging current. The control pilot continuously sends a pulse width modulated or PWM signal to the car. In this way, it tells the car the maximum current that can be drawn from the charging station, I_{max}. The car then can draw the desired current I_{ac}, as long as this value is smaller than the maximum current I_{max}.



Fast onboard AC chargers

AC charging typically needs an onboard AC/DC power converter. Quite interestingly, the motor and the motor drive inverter which converts the DC power from the battery into AC power for the motor can also be used as the onboard charger for the battery for AC/DC conversion. This eliminates the need for a separate AC/DC power converter for the onboard charger. Since the drivetrain power converter is usually high power >100kW, this also means that the EV can reach quite high charging rates >22kW. The challenge is to design the motor drive and its control to provide the dual functionality of EV charging when stationery and EV propulsion when in motion.

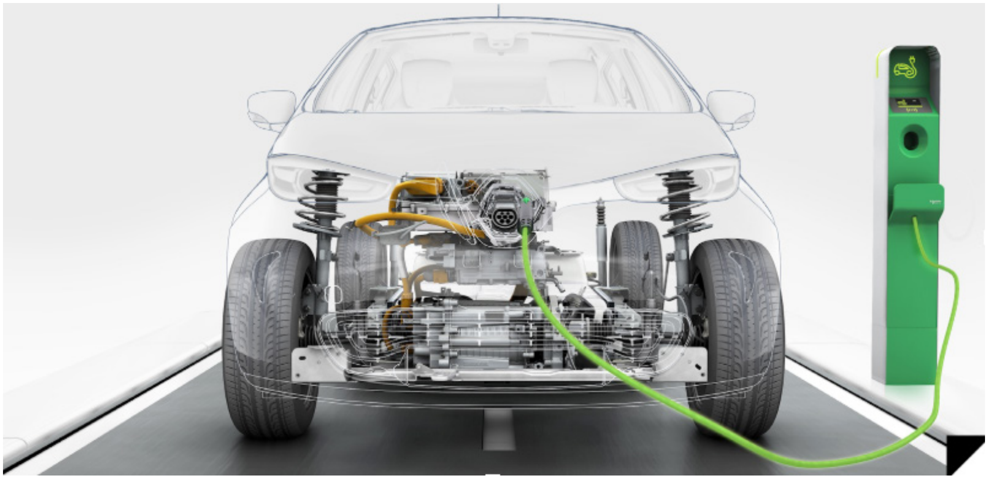


Image source: Renault

An excellent example of this implementation is the Renault ZOE EV which provides 43kW onboard AC fast charging. The Renault has claimed to use a junction box that helps in modifying the operation of the motor and motor drive components to be used as an onboard EV charger.

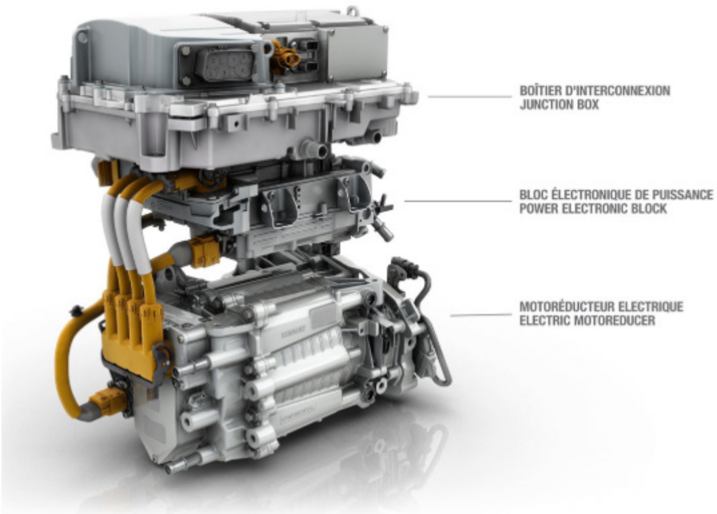


Image source: Renault

Calculating the AC charging power

Given a value of the charging power required to charge a battery and the AC grid voltage, we can estimate the charging current required. Assuming a power factor of unity and neglecting all losses, we come up with the following relations for power:

Single phase: $P_{ch} = V_{ac}I_{ac}$

Three phase: $\sqrt{3}(V_{3ac}I_{ac}) = 3V_{ac}I_{ac}$

where V_{ac}, is the single-phase AC voltage (V), V_{3ac} is the three-phase line-to-line AC voltage (V), P_{ch} is the charging power (W or kW) and I_{ac} is the grid current (A).

the phase voltages are given for a system, just multiply it by a factor of $3^{0.5}$ to get the line to line voltage.

Calculating the charging time and power

Given a value of the charging power required to charge a battery and the AC grid voltage, we can estimate the charging current required. Assuming a power factor of unity and neglecting all losses, we come up with the following relations for power:

$$E_{batt} = P_{ch} t_{ch}$$

$$t_{ch} = E_{batt} / P_{ch}$$

where P_{ch}, is the charging power (W or kW), t_{ch} is the charging power (hour) and E_{batt} is the energy delivered to the battery (kWh).