Electric Vehicle Charging Guide

A primer for EV charging enthusiasts, professionals and business people

Trends, fundamentals (charging modes, charging time ...), design and characteristics of EV charging stations, integration of Electric Vehicle Supply Equipment (EVSE) into existing or new building electrical installations (sizing and protection rules, architecture guidelines and examples). And digital architectures (load management systems, advanced AI-based analytics, smart charging ...) to optimize the usage and efficiency of EV charging infrastructure)

The book has been compiled from content gathered from The Electrical Installation Guide Wiki (Electrical Installation Wiki), a collaborative platform by Schneider Electric. The original content can be accessed from the online Wiki.

You can reach out to the editors at editor@eeekenya.com or visit www.eeekenya.com/ev

.

Table of Contents

Chapter 1-Electric Vehicle Trends

1.1 Planetwide sustainability and environmental concerns

A growing number of electric vehicle drivers are demanding easy access to car charging facilities. They are also looking for car parking amenities where they can rest, have fun or go shopping, but just as importantly, they require access to e-car recharging on such sites.

Why is this trend growing today? The simple answer is global warming. The Paris Agreement sets out a global framework designed to avoid dangerous climate change by limiting global warming to below 2°C. It also aims to strengthen countries' abilities to deal with the impact of climate change and to support them in their efforts. The European Union has been at the forefront of international efforts to fight climate change. It was instrumental in brokering the Paris Agreement and continues to show global leadership.

By 2030, the European Union as a whole is committed to reducing greenhouse gas emissions by 55% compared to 1990 levels. **Transport contributes almost one-quarter (23%)** of current global energy-related greenhouse gas (GHG) emissions and is growing faster than any other energy end-use sector. By the year 2030, GHG emissions from transport are anticipated to rise by nearly 20% and close to 50% by 2050 unless major action is undertaken.

According to the International Energy Agency, such a transition requires the implementation of global rail transport electrification, which is already underway, as well as the electrification of a major part or all road transport vehicles.

It is no surprise, then, that many countries and cities have already initiated such green initiatives. Going green has many benefits - companies can boost their image, and moreover, they can benefit from government assistance and attract new customers. On average, analyses show that green customers have an elevated profile, good salaries, and better shopping and cultural behaviours.

Here we list some of the most important worldwide initiatives:

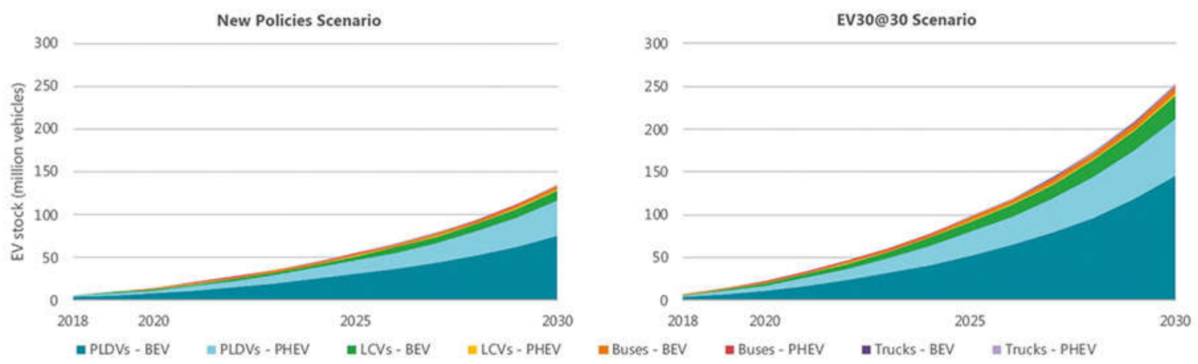


Fig.1.1 – Future global EV stock and sales by scenario, 2018-30 (Source: IEA, Global EV Outlook 2019).

- C40 CITIES is a network of the world's megacities that are committed to addressing climate change.
- EV100 campaign is a global initiative that brings together 113 forward-looking companies committed to accelerating the transition to electric vehicles and making electric transport the 'new normal' by 2030.

- EVAPP - the Electric Vehicle Association of Asia Pacific is an international membership organization that promotes the development and use of electric and hybrid vehicles in the Asia and Pacific region.

On top of those initiatives, government policies are also key to reaching environmental targets.

To date, 17 countries around the world have proposed a future ban on the sale of passenger vehicles that are powered by fossil fuels such as gasoline, liquefied petroleum gas and diesel. Europe, with very advanced countries such as Norway, The Netherlands, Iceland, and Sweden, is leading the way in terms of regulation and EV fleet size (60% of new car sales in Norway are electric, and Europe became in 2020 the first EV market in terms of sales before China). Nevertheless, even though they don't have yet committed to official targets, many other countries and cities around the world are working toward an ICE vehicle ban plan.

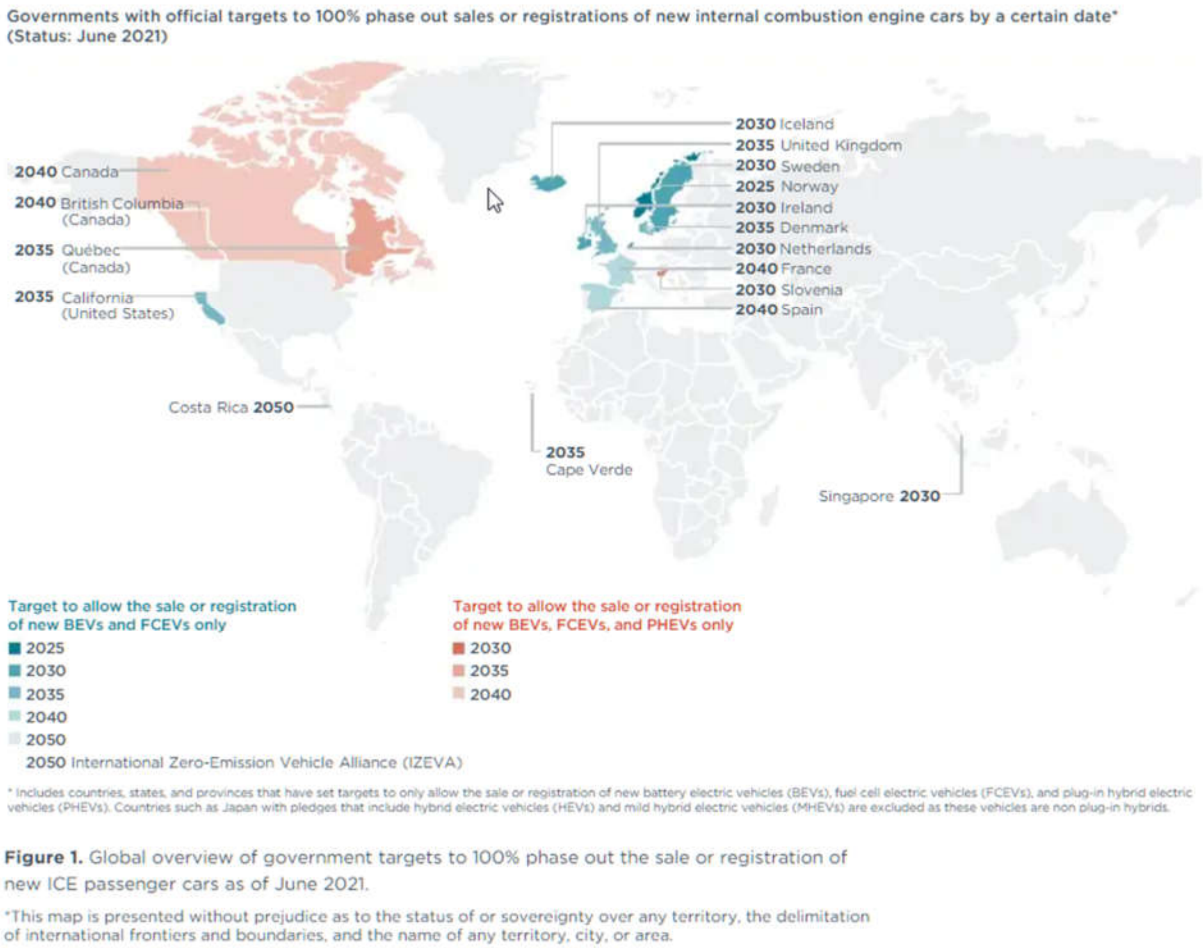


Fig. 1.2 – Official ICE vehicle ban targets by region (Source: International Council on Clean Transportation, June 2021).

1.2 Government regulation and incentives in the European Union

In 2014, the Alternative Fuels Infrastructure Directive (AFID) was adopted. At that time, the electric vehicle market in Europe was just starting out, with only a few models available on the market, such as the Renault

Zoe, Nissan Leaf, BMW i3 and Tesla Model S. Back then, policymakers trying to determine the future EV market uptake and infrastructure needs had very limited experience.

Today, the situation is different: battery and charging technologies have progressed and will continue to do so for many years. With EU car and van CO2 standards in place for 2021-2025-2030, a wave of electric vehicle models is arriving in Europe, and policymakers now have much more clarity with regard to expected market uptake. Many elements that seemed uncertain in 2014 have now become much clearer.

AFID is currently elaborating a climate strategy, "The European Green Deal". This strategy presents key political directions, flagships and funding mechanisms to support decarbonization, including the deployment of a charging infrastructure. AFID has committed to reviewing the Directive in 2021 to accelerate the deployment of zero- and low-emission vehicles and to deploy a funding call to support the deployment of public recharging and refuelling points from 2020.

In most European countries, the main incentives are related to the ownership of e-cars: that's to say, no purchase tax, road benefits, exemption or reduction of ownership and company car taxes. More importantly, new regulations are in favour of the electrical vehicle infrastructure; specific EV public infrastructure investments are in place in Norway, Germany, France, the UK, Netherlands, Sweden, Finland and Spain. New buildings will have to be equipped or pre-equipped, depending on the country, for electrical vehicle charging, and there are plans to upgrade electrical installations in residential and commercial buildings.

1.3 Electric vehicle: Fast growth

Since 2020, we have been witnessing a new phase in the Electrical Vehicle market. Up to 2019, we were witnessing fast growth driven by subsidies, with very few e-Cars models and few clear improvements and choices. The next phase will be accelerated by indirect policy mechanisms and the electrification of general transport beyond passenger vehicles.

In 2020, more than 10 million passenger electric vehicles (BEV + PHEV) were on the road globally. By the end of 2025, this figure could reach 53 million. EV adoption is also becoming more popular and attractive for segments like buses, two-wheelers, ride-hailing services, and delivery vans. In 2020, there were more than 1 million electric buses and electric commercial vehicles, and there were 263 million electric 2 and 3-wheelers. Those numbers could reach respectively 6 million and 331 million by the end of 2025. Charging infrastructures are also growing, with 4.2 million connectors now in place globally.

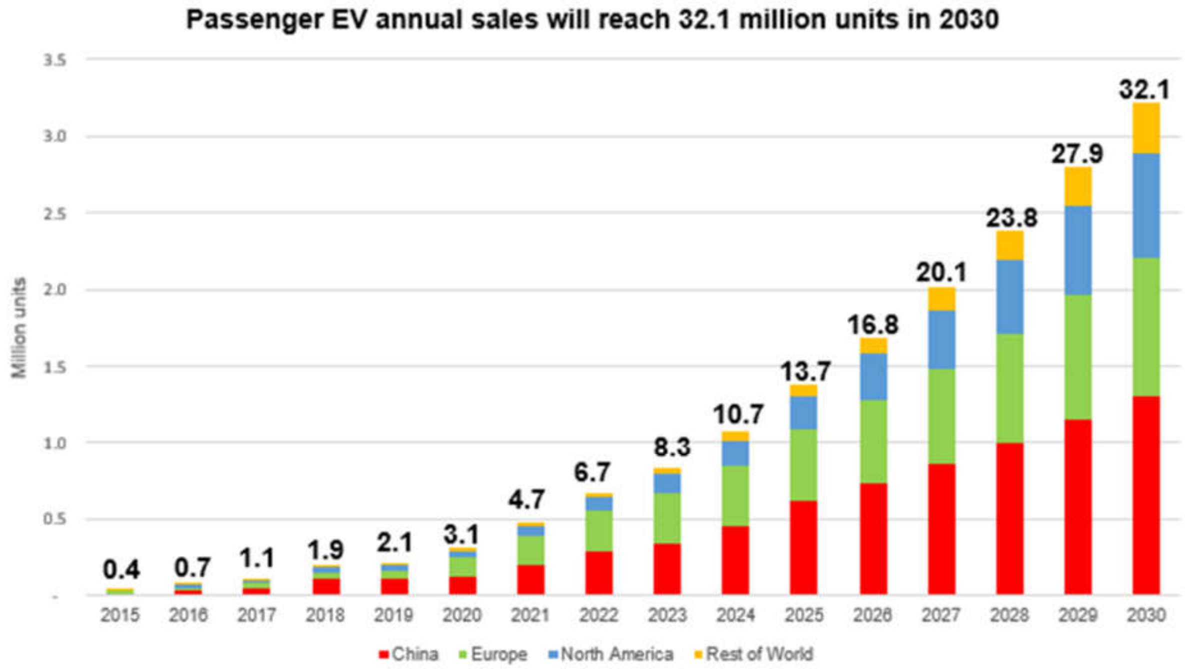


Fig. 1.3 – Passenger EV sales by market (BEV + PHEV), in million units (Source: BloombergNEF 2021).

The global market share for electric passenger cars is 0.8% in 2020 (BEV + PHEV), but this figure is growing fast thanks to new e-Car models and prices, which are attracting more consumers who are also making the most of the incentives and benefits associated with driving a zero-emission car. Indeed, even if e-cars are currently more expensive than ICE vehicles, this trend is evolving as battery costs are decreasing. Price parity between EV and ICE vehicles should be hit by 2023 and convince additional consumers to switch from ICE to EV.

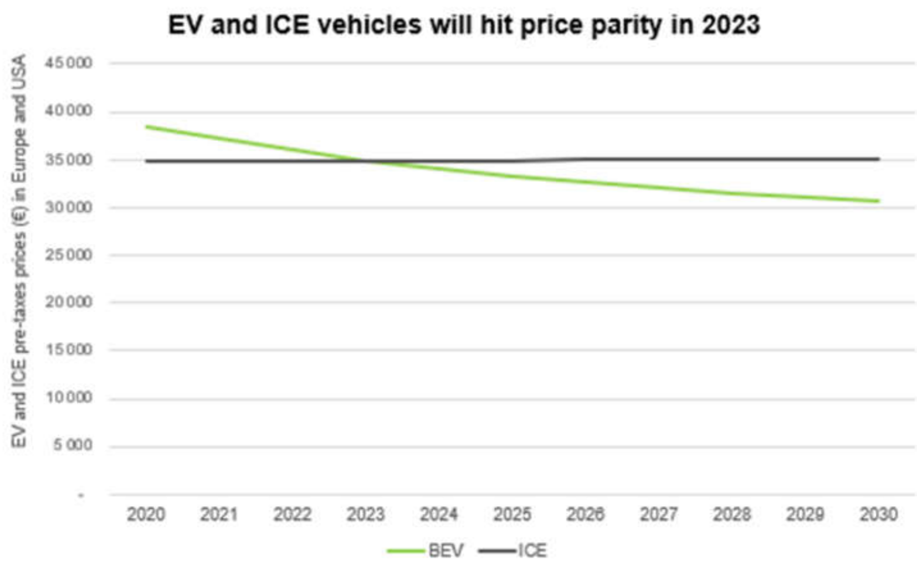


Fig. 1.4 – BEV and ICE pre-tax prices in Europe and USA, in euros (Source: BloombergNEF 2021).

Globally, between 2019 and 2020, passenger car sales overall declined by 12%, but the demand for electric passenger cars (BEV + PHEV) increased by 46%.

China used to be the leading country for electric vehicles, not only due to its commitment to electrification but also due to the popularity of electrification amongst consumers. Recently, European EV sales have also risen significantly. This trend has been driven by national incentives, increased model availability and the rising concern over urban air quality. In terms of sales, Europe used to be the second largest EV market after China, but since 2020, it has become the first largest EV market. Within Europe, the market trends are very different from one country to another. Indeed, in 2020, the UK, Germany, France and Italy represented 61% of all EV sales in Europe.

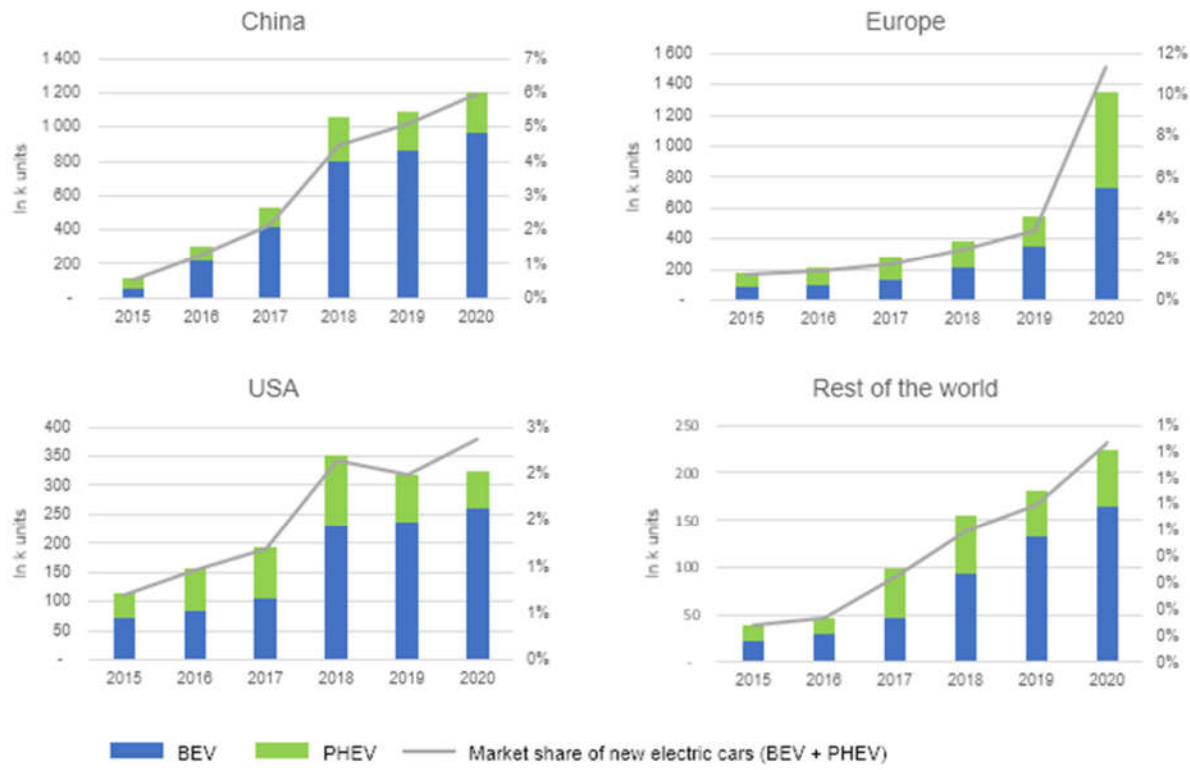


Fig. 1.5 – Passenger EV sales by market and by drivetrain, in k units (Source: BloombergNEF 2021).

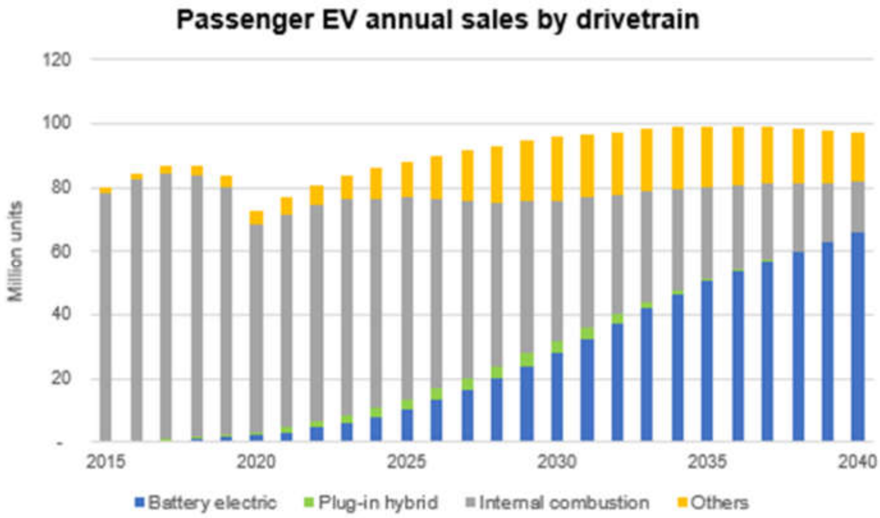


Fig. 1.5b – Global long-term passenger vehicle sales by drivetrain, in million units (Source: BloombergNEF 2021).

1.4 Electric vehicle charging infrastructure: also growing fast

As regards the EV infrastructure, there are around 4.2 million public and private connectors worldwide, which equates to around 2 passenger cars by connector, which is sufficient for the current market. Beyond 2020, this charging infrastructure will need to be developed in order to keep pace with the growing e-mobility industry. This is why new regulations for infrastructure for public and private investments are playing an important role in this new phase.

The charging deployment should be spread across the world to ensure all countries get the same opportunity to shift to zero-emission mobility.

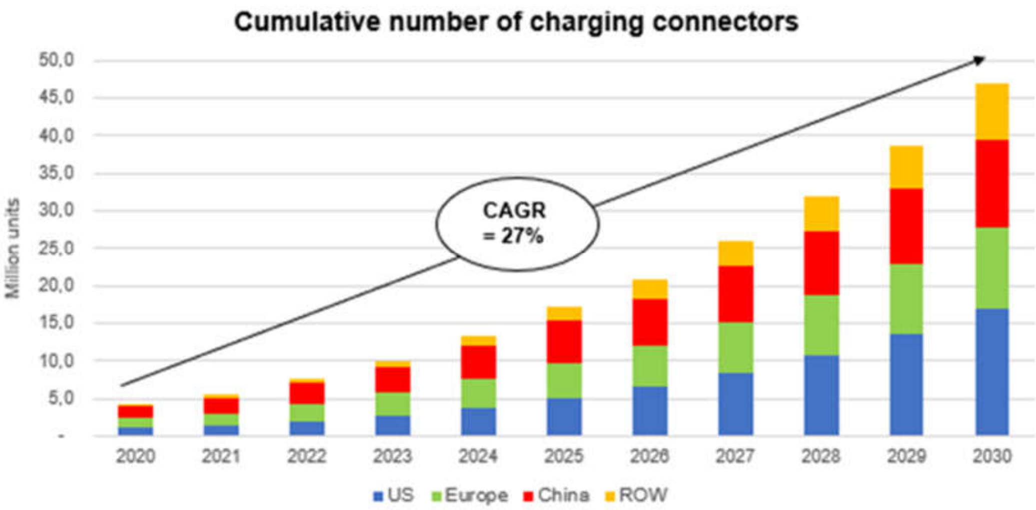


Fig.1.6 – Global cumulative number of charging connectors by market, in a million units (Source: BloombergNEF 2021).

Chapter 2-Electric Vehicle and EV Charging Fundamentals

2.1 The different types of electric vehicles

In 2020, the electrical vehicle market is today shared equally between two main technologies: Battery electric vehicles (BEVs) and Plug-in hybrid electric vehicles (PHEVs). Both technologies are expected to grow fast in the coming years, with the growth of BEVs expected to increase its share up to 60% of total EV production in 2025 and around 40% for PHEVs.

Battery Electric Vehicles (BEV)

Battery Electric Vehicles are electric vehicles propelled by an electric motor drawing current from an onboard battery energy storage system. BEVs are also called "100% pure electric vehicles" or "all-electric vehicles" because they are powered by electrical energy storage ***only***. They do not have an internal combustion engine (ICE) as a backup in case the battery is fully discharged.

The BEV's driving distance per charge is, on average, between 150 and 400km, with the trend to extend even further as battery technologies continue to improve.

Examples of BEVs include:

- Tesla Model 3
- Mini Electric
- MG ZS EV
- Nissan Leaf
- Renault Zoe
- Hyundai Kona Electric
- Kia e-Niro
- Jaguar I-Pace
- Audi e-tron 55 quattro

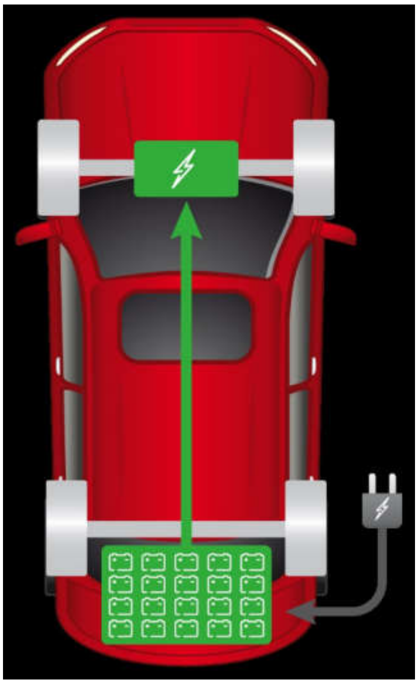


Fig. 2.1 – Battery Electric Vehicle: electrical vehicle powered only by a rechargeable battery.

Battery Electric Vehicles do not produce any on-road emissions, as they are powered exclusively by electricity. They have longer electric driving ranges compared to other electric vehicle technologies.

Plug-in hybrid electric vehicles (PHEV)

A plug-in hybrid electric vehicle is an electric vehicle that can be powered by two energy sources: a battery that can be recharged by plugging into an external source of electric power and a diesel or petrol engine.

The battery capacity of a plug-in hybrid EV is significantly smaller than that of a 100% electric vehicle. A PHEV can, using its battery power, cover, on average, between 30 to 50km. After this, the petrol/diesel engine takes over.

When powered by a battery, the PHEV does not produce emissions. When powered by its diesel/petrol engine, the PHEV pollutes the environment.

PHEVs are considered a "transitional" technology. Indeed, with the development of fast-charging electrical infrastructures, the increase of onboard battery capacity, and government regulation requirements, BEV (100% electric) technology is expected to grow faster.

Examples of PHEVs include:

- Mitsubishi Outlander
- Volvo XC60 Twin Engine
- BMW 225xe
- Volkswagen Golf GTE
- Toyota Prius PHV
- Mercedes-Benz E350 e SE
- Chevrolet Volt family

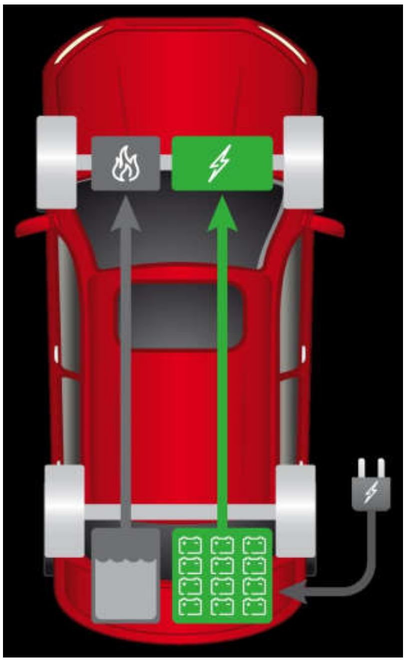


Fig.2.2– Plug-in Hybrid Electric Vehicle: electric vehicle equipped with both diesel/petrol engine and electric motor with battery.

Other low-carbon vehicles and technologies

Hybrid Electric Vehicles (HEV)

Hybrid electric vehicles are internal combustion engine vehicles equipped with a small battery that can be recharged by braking energy recovery, but not by plugging into an external electricity source. These vehicles are not zero nor low emission but provide an additional CO2 reduction compared to conventional internal combustion engine vehicles.

Examples of HEVs include:

- Toyota Corolla Hybrid
- Toyota Yaris Hybrid
- Lexus RX450h
- Ford Mondeo Hybrid
- Honda NSX

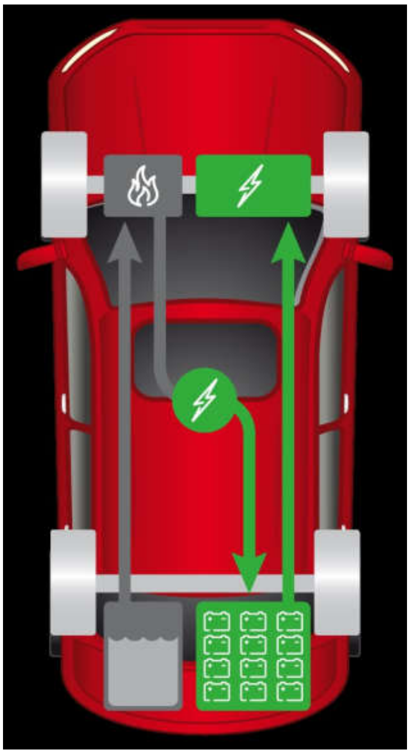


Fig. 2.3– Hybrid Electric Vehicle: internal combustion engine vehicle equipped with a small battery used for energy recuperation, with no capacity to recharge from an external source.

Fuel Cell Electric Vehicle (FCEV)

A fuel cell vehicle is powered by electricity produced by a fuel cell instead of electricity stored in an electrical battery. The fuel cell produces electricity using oxygen and hydrogen as primary sources.

The FCEV does not yet have the maturity of other electric vehicle technologies, such as BEV and PHEV, and currently has only a small share (<1%) in EV production.

FCEV manufacturers:

- Volkswagen
- Honda
- Hyundai

Regenerative braking

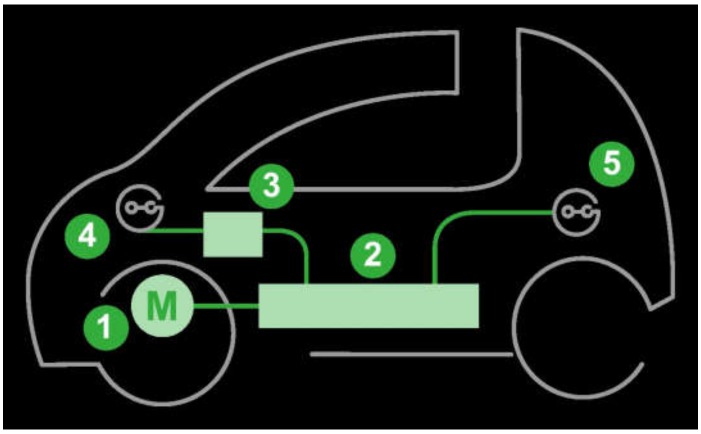
Regenerative braking is an energy recovery mechanism in which the electric motor acts as a generator during the braking, and the generated energy is used to charge the battery. This technology can be used in electric vehicles, such as HEVs, BEVs, and PHEVs.

Integrating photovoltaic cells onto the car rooftop

Some car manufacturers offer electrical vehicle models with integrated solar PV cells on the vehicle roof. The onboard produced energy is not sufficient to charge the electrical battery but can be used to supply some accessory loads.

2.2 How do electric vehicles work?

An electric vehicle (electric car) is a vehicle propelled by an electric motor, using energy stored in rechargeable batteries. Electric vehicles are equipped with a charging inlet(s) and an onboard charger that converts AC power into DC so that it can be stored in the battery. An onboard controller ensures the performance of the electric vehicle.



1. Electric motor,
2. Battery,
3. Onboard charger,
4. Charging inlet (AC),
5. Charging inlet (DC fast charging)

Fig.2.4–Main components of an electric car.

Electric vehicle motor

An electric vehicle is propelled by an electric motor. The typical power range for an electric vehicle motor is between 15kW and 500kW.

Electric-vehicle battery

Electric cars are usually equipped with a lithium-ion battery energy storage system. The battery typically has a power range of 5 to 100 kWh and operates at voltage levels from 300 to 800 V.

The battery determines the autonomy of the electric car. As a rough estimation, 1kWh of energy storage is equivalent to 5km driving distance.

The battery lifespan depends on the use of the car and the type of charging. Usually, the battery set lasts more than 10 years. However, if DC fast charging is used frequently (more than 3 times/month), the battery capacity, performance and lifetime are reduced.

Onboard charger

Electric vehicles include an onboard charger, which converts the power from AC to DC to charge the battery. The charging capacity of the onboard charger is limited to 22kW AC. In fast DC charging (see charging mode 4), the onboard charger is bypassed, and the DC electricity is supplied directly to the battery.

Charging inlet

The charging inlet port is used to plug the car into a power supply in order to recharge the battery.

An electric vehicle has at least one AC charging inlet port. Electric cars can have a second DC charging inlet for fast charging (mode 4). The DC charging inlet may or may not be an option, depending on car models or countries. Also, some models offer a single port for both AC and DC charging.

2.3 Electric vehicle connectors

There are different types of connectors to plug the charging cable into the vehicle inlet.

AC connectors are defined by IEC 62196-2, and DC connectors are defined by IEC 62196-3.

Type 1 connector (SAE J1772)

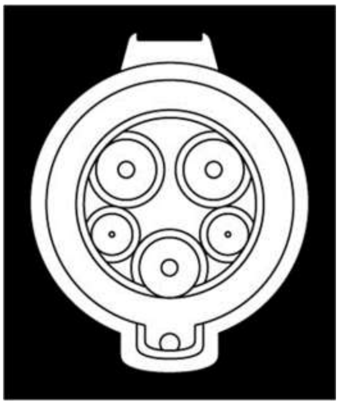


Fig.2.5 Type 1 connector is used with an AC charging station.

The J1772 connector is easily identifiable by three large pins – similar to the power outlet layout at home – and two smaller pins for the car connection. The three broad pins are for Phase, Neutral and Ground, while the two small pins are used for communication between the charger and the electric car (Pilot Interface).

It can deliver between 3 and 7.4 kW and supports only a single phase with a maximum current of 32 A. It includes extra protection to lock the connector while charging in order to avoid disconnection by a third party. It's mainly used in the USA and Japan but is also accepted in Europe.

Type 2 connector (IEC 62196-2)

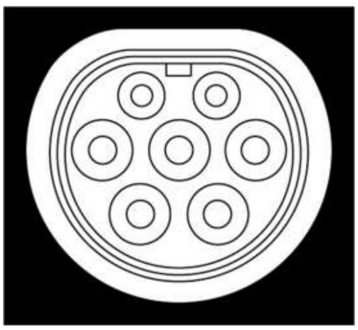


Fig.2.6 Type 2 connector is used with the AC charging station.

This type of connector is approved as the European standard. The connector stands out with a unique design, rounded but with a flat edge on the top. Its pins distribution is similar to type 1, but includes two more pins, corresponding to the two extra phases needed for three-phase charging.

It allows a recharge between 3 and 43 kW and can support a single phase up to 16 A and three phases up to 63 A.

An evolution of this connector is the T2-S, which includes an additional lock to the connector. In France, connector version T2-S is mandatory.

Type 3

This type of connector is abandoned in favour of a type 2 connector.

CHAdeMO

CHAdeMO connector is used with a DC charging station.

CHAdeMO is the contraction of "Charge Move". But the acronym is also present in the Japanese sentence: "O cha demo ikaga desuka", which translates as "You will have tea while the car is charging". This sentence represents the will of the association composed of Toyota, Mitsubishi and Nissan, among others: fast charging with direct current. It can, therefore, be installed as a second socket by vehicle manufacturers next to an alternating current charging socket.

It can deliver up to 62.5 kW and can reach 125 A, yet the revised CHAdeMO 2.0 specification allows for up to 400 kW.

Combined Charging System (CCS) Combo 1

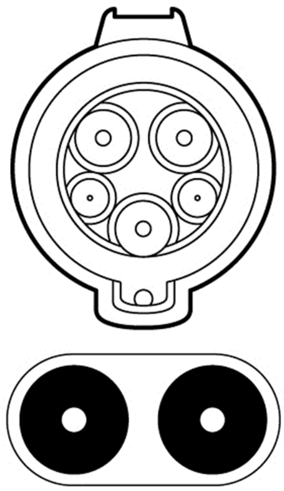


Fig.2.7 Combined Charging System (CCS) Combo 1.

CCS Combo 1 is based on the J1772 Type 1 connector by adding two additional pins. The Combined Charging System is made for DC Fast Charging. The connector can do both AC and DC charging up to 350 kW.

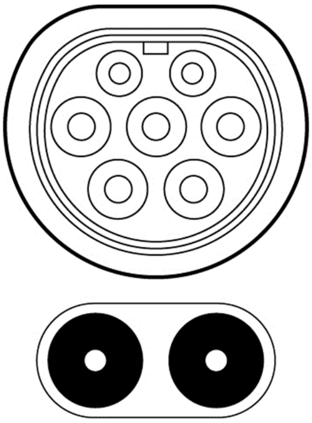


Fig.2.8 Combined Charging System (CCS) Combo 2 (IEC 62196-3).

CCS Combo 2 is based on a Type 2 connector by adding two additional pins. The Combined Charging System is made for DC Fast Charging. The connector can do both AC and DC charging up to 350 kW.

2.4 Electric vehicle charging modes

The international standard IEC 61851-1 « Electric vehicle conductive charging system» defines four modes of charging:

- **Mode 1** – Standard socket-outlet - domestic installation
- **Mode 2** - Standard socket outlet with an AC EV supply equipment– domestic
- **Mode 3** - AC EV equipment permanently connected to an AC supply network
- **Mode 4** - DC EV Supply equipment

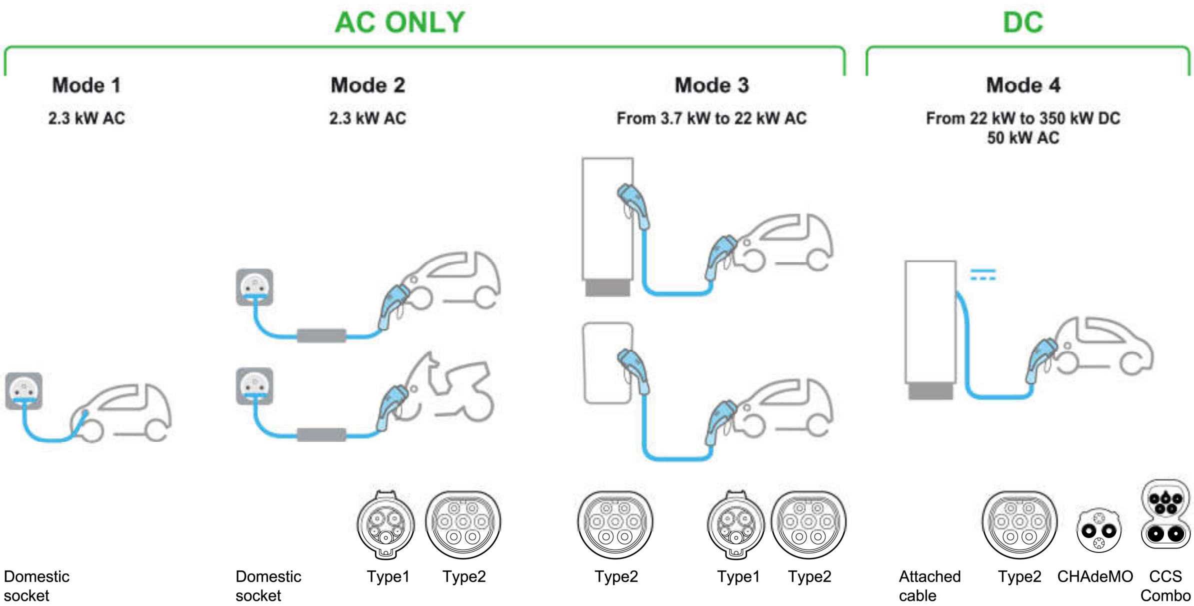


Fig.2.9–Four electric vehicle charging modes, as defined by IEC 61851-1.

Mode 1 – Standard socket-outlet - domestic installation

Fig. 2.10–EV charging mode 1: Standard socket outlet and cable for domestic installation.

Mode 1 is a method for connecting an electric vehicle to a standard socket outlet on an AC supply network using a standard cable and plug without any additional equipment.

The rated values for current and voltage must not exceed:

- 16 A and 250 V AC for single-phase.
- 16 A and 480 V AC for three-phase installation according to the IEC 61851-1.

Local standards may be more stringent.

Due to this power limitation, charging time takes several hours.

Mode 1 is the simplest mode, but as there is no dedicated circuit or equipment for electric vehicle charging, it presents the following risks:

- Breaker tripping: Since the recharging socket used shares the same switchboard outgoing circuit as other power sockets, if the sum of power consumption exceeds the protection limit (generally 16A), the circuit breaker will trip, interrupting the vehicle charging.
- Risk of fire or electric shock in case of obsolescence or non-compliance of the electrical installation.

For these risks and limitations, the use of this mode is limited and even forbidden in some countries (e.g., the USA)

Mode 2 - Standard socket outlet with AC EV supply equipment

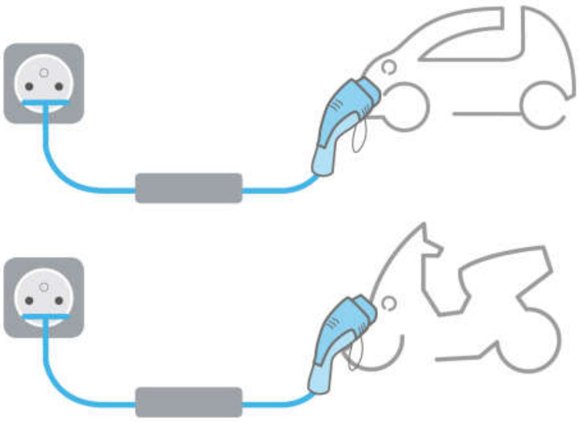


Fig.2.11–EV charging mode 2: Standard socket outlet with a special cable, integrating a system for power control and protection for domestic installations

Charging mode 2 is a method for the connection of an EV to a standard socket outlet, with a control pilot function and a system for personal protection against electric shock integrated into the connection cable between the standard plug and the EV.

The rated values for current and voltage must not exceed 32 A and 250 V AC in single-phase and 32 A and 480 V AC in a three-phase installation, as defined in IEC 61851-1

This mode is limited to domestic electric installations. The connection cable is usually provided with the electric car. As with mode 1, a standard socket outlet is used, but in this case, the protection device and the socket outlet should be able to carry higher charging currents, up to 32A, which is usually not the case for standard domestic power socket circuits.

Mode 3 - AC EV equipment permanently connected to an AC supply network

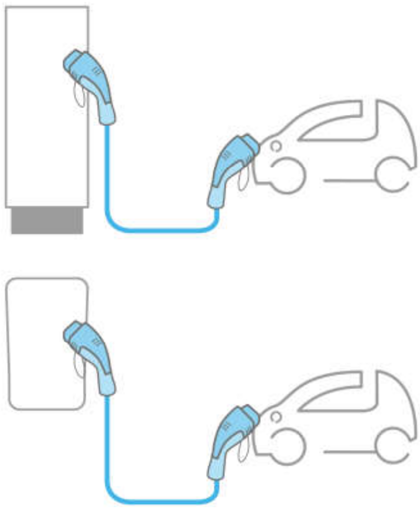


Fig.2.12–EV charging mode 3: Dedicated circuit and specific charging system (EV charger), integrating protection and control functions. Cable integrating a pilot wire.

In Mode 3, electric vehicles are charged by specific equipment, called EV charging stations (or EV chargers), permanently connected to an AC supply network and integrating protection and control functions.

Because Mode 3 uses a dedicated EV charger (and not a standard socket outlet), the power range is higher, from 3.7kW up to 22kW AC. This higher power range enables fast charging of electric cars, compared to Modes 1 and 2.

The addition of a pilot wire inside the charging cable enables communication between the vehicle and the charging equipment through standard protocols. It also allows the implementation of control functions, such as:

- Verification that the electric vehicle is correctly connected to the EV supply equipment.
- Continuous verification of the integrity of the protective conductor.
- Energization and de-energization of the power supply.
- Transmission of information about the maximum permitted current to draw.

Specifically designed for electrical vehicle charging, mode 3 is recommended for the following reasons:

- The use of a dedicated and independent electrical circuit eliminates the risk of connection to a non-compliant installation, thus guaranteeing the safety of property and people.

- The control function manages the charging period of the vehicle and optimizes electric consumption according to user needs. It ensures optimal charge of the batteries and preserves their lifespan.

Mode 4 - DC EV Supply equipment

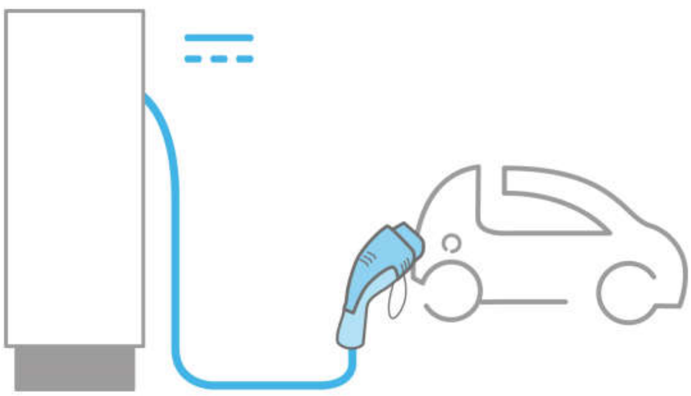


Fig.2.13–EV charging mode 4: Dedicated DC EV supply equipment for fast EV charging.

In Mode 4, charging is done through DC EV supply equipment, called EV charging station (or EV charger), connected to an AC or DC supply network. The EV charging station delivers DC current directly to the battery, e.g. bypassing the onboard charger. Charging of the electric vehicle can be done much faster than in modes 1, 2 and 3, as the electrical power charging range is higher than 24kW.

In mode 4, the digital communication between the electric vehicle and the EV supply equipment is mandatory and should comply with the requirements described in IEC 61851-24

2.5 How Long Does It Take to Charge an Electric Car?

The charging time can be roughly calculated as the ratio between the electric vehicle battery capacity and the charging power. The charging power is limited to the power that the charging station can deliver and that which the Electrical Vehicle can accept.

$$Charging\ time(hr) = \frac{EV\ Battery\ Capacity(kWh)}{Charging\ Power\ (kW)}$$

$$Charging\ power(kW) = \min(EV\ onboard\ charger\ rate; Charging\ station\ delivery\ rate)$$

For example, for an electric vehicle with:

- 40kWh battery set
- 6.6kW onboard charger for AC charging

The estimated full charging time is:

- **11h** for home charging station of **3.7kW** (40kWh / 3.7kW)
- **6h30** for AC charging station of **11kW** (40kWh / 6.6kW, 6.6kW due to the limitation of the onboard charger)
- **50min** for DC fast charging station of **50kW** (40kWh / 50kW)
- **10min** for DC ultra-fast charging station of **250kW** (40kWh / 250kW)

Note that this formula provides a rough estimation. The actual charging time is usually longer for the following reasons:

- The charging speed profile is not linear. Electric vehicles are not continuously charged at maximum power. In particular, DC charging (mode 4) is charging very fast until the battery reaches 80% - 90% of its capacity and slows down significantly for the remaining 10-20%.
- The charging speed depends on the battery temperature. The optimum temperature for charging is between 20°C and 30°C. If the battery temperature is outside of this range, charging can be slower.
- Charging speed also depends on the electric vehicle model and on the charging strategy/algorithm of the charging station.

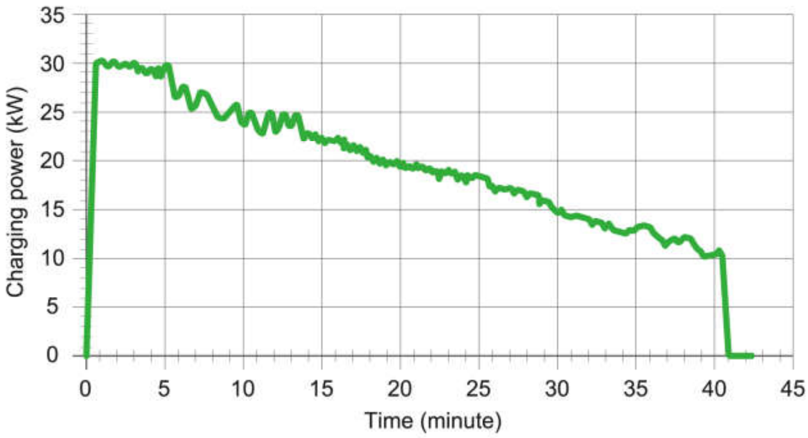


Fig.2.14 – Example of an EV DC charging power versus time.

2.6 Electric vehicle charging location

Unlike conventional internal-combustion engine (ICE) vehicles, which refuel at gas stations, electric vehicles can recharge at multiple locations: @home (residential buildings), @work (small to large office buildings ...), @destinations (public parking, hypermarkets ...), @fleet (city buses, delivery trucks, company cars ...), @transit (highways, city stations ...). The charging time and cost for the end user, the charging mode, the number of chargers and their power range depend on the charging station location.

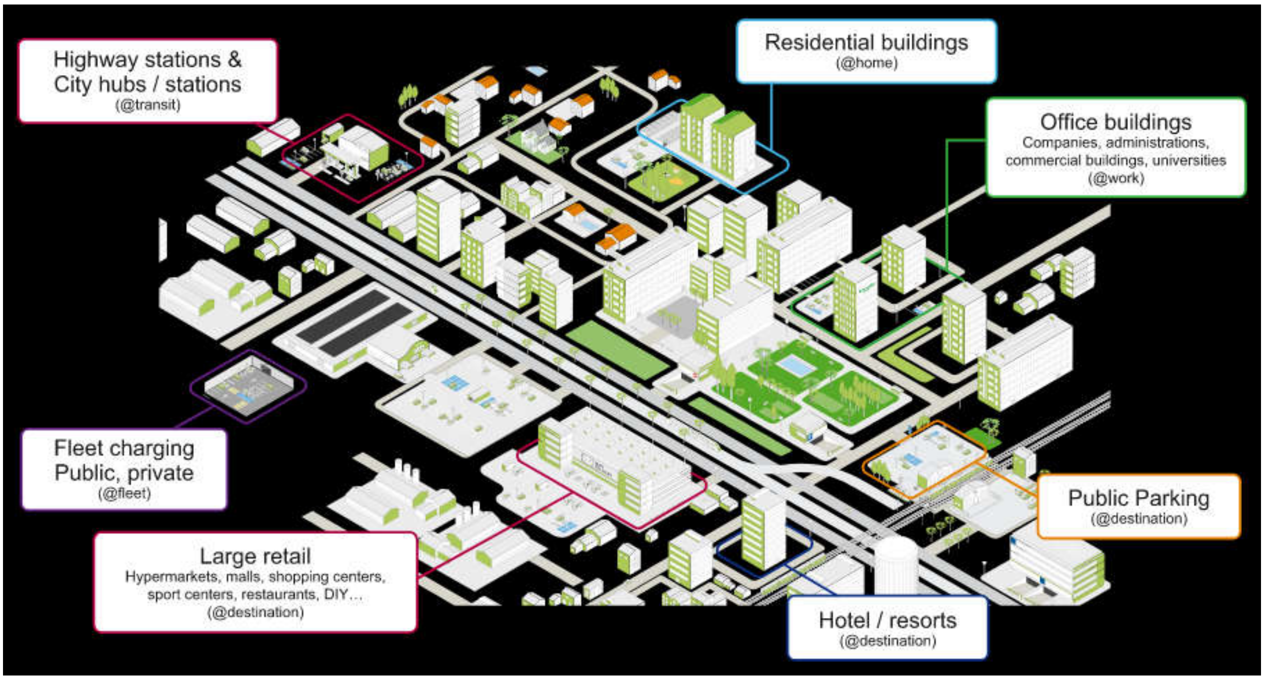


Fig.2.15– Electric vehicles can be charged at multiple locations.

Residential EV charging stations

Home is the most common place to charge. Home charging is cost-effective and usually sufficient for daily trips. It is generally considered more convenient than refuelling ICE vehicles at gas stations.

Residential (home) charging can be:

- Single-family: low-rise individual houses with a private garage usually equipped with one or two charging points
- Multi-family: residential buildings with multiple apartments (condominium), where charging points may be private (individual garage) or shared between condominium inhabitants (a number of EV charging points located in the common parking place)

Residential charging is done mainly at night, when the car is not in use and when electricity is usually cheaper. EV charging equipment is most commonly single-phase and has a power delivery rate up to a maximum of 7.4 kW. Charging is slow and may require several hours. Charging Mode 3 is recommended for its built-in safety features.

Workplace EV charging stations

Workplace EV chargers are becoming available at a growing number of companies, especially those committed to the reduction of greenhouse gas emissions. It can be attractive for employees, especially if the price for charging is equivalent to or lower than the price for charging at home. Workplace charging can be an opportunity to encourage electric vehicle adoption for employees who do not have charging points at home or for employees needing to charge both at home and at work for their daily usage.

Workplace charging is done mainly during the day. EV chargers in the workplace are usually 3-phase with a power range of 11kW and 22kW. Charging Mode 3 is recommended for safety reasons.

Commercial building EV charging stations

Other destinations, such as supermarkets, shopping malls, restaurants, public car parks and commercial facilities equipped with EV charging points, can provide occasional charging opportunities for their users.

Because a car is parked at these locations for a few hours only, fast charging is usually preferred, typically with 22kW-EV charging stations, using charging mode 3.

Fast in-transit EV charging stations

Fast in-transit charging stations provide efficient charging when the charging time is an important consideration. They are usually located on highways or at city hubs.

Charging is done in mode 4 (DC charging, also sometimes called DC fast charging). The power range of the EV charging station is from 50kW up to 350kW. The charging time depends on the power range – usually less than 30 minutes.

Even though fast charging is convenient, it is to be used sparingly, as frequent usage of fast DC charging reduces the EV battery lifetime.

Charging modes - synthesis

Residential EV charging stations

Home is the most common place to charge. Home charging is cost-effective and usually sufficient for daily trips. It is generally considered more convenient than refuelling ICE vehicles at gas stations.

Residential (home) charging can be:

- Single-family: low-rise individual houses with a private garage usually equipped with one or two charging points
- Multi-family: residential buildings with multiple apartments (condominium), where charging points may be private (individual garage) or shared between condominium inhabitants (a number of EV charging points located in the common parking place)

Residential charging is done mainly at night, when the car is not in use and when electricity is usually cheaper. EV charging equipment is most commonly single-phase and has a power delivery rate up to a maximum of 7.4 kW. Charging is slow and may require several hours. Charging Mode 3 is recommended for its built-in safety features.

Workplace EV charging stations

Workplace EV chargers are becoming available at a growing number of companies, especially those committed to the reduction of greenhouse gas emissions. It can be attractive for employees, especially if the price for charging is equivalent to or lower than the price for charging at home. Workplace charging can be an opportunity to encourage electric vehicle adoption for employees who do not have charging points at home or for employees needing to charge both at home and at work for their daily usage.

Workplace charging is done mainly during the day. EV chargers in the workplace are usually 3-phase with a power range of 11kW and 22kW. Charging Mode 3 is recommended for safety reasons.

Commercial building EV charging stations

Other destinations, such as supermarkets, shopping malls, restaurants, public car parks and commercial facilities equipped with EV charging points, can provide occasional charging opportunities for their users.

Because a car is parked at these locations for a few hours only, fast charging is usually preferred, typically with 22kW-EV charging stations, using charging mode 3.

Fast in-transit EV charging stations

Fast in-transit charging stations provide efficient charging when the charging time is an important consideration. They are usually located on highways or at city hubs.

Charging is done in mode 4 (DC charging, also sometimes called DC fast charging). The power range of the EV charging station is from 50kW up to 350kW. The charging time depends on the power range – usually less than 30 minutes.

Even though fast charging is convenient, it is to be used sparingly, as frequent usage of fast DC charging reduces the EV battery lifetime.

2.7 Charging modes - synthesis

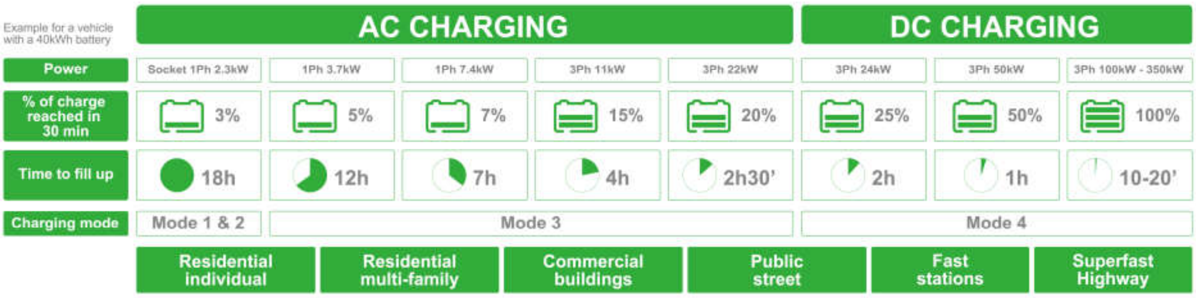


Fig.2.16– Charging scenarios with typical values for charging station delivery rate, time of charge and charging mode

Chapter 3-EV Charging Station Design

The term "EV charging station", as defined by IEC 61851-1, is the stationary part of the EV supply equipment that is connected to the supply network. It can be either wall-mounted or floor-standing, AC or DC. It is the dedicated equipment for charging EVs through Mode 3 (AC) and Mode 4 (DC).

The following paragraphs provide details on the design and characteristics of EV charging stations in mode 3 and mode 4.

3.1 Charging station design – IEC standards

Charging stations in mode 3 and mode 4 must be compliant with standard **IEC 61851**.

This standard covers the mechanical, electrical, communications, EMC and performance requirements for electric vehicle supply equipment in mode 3 and mode 4.

Part 1 of this standard covers the general requirements, which is the basis for all subsequent standards in the series. It includes the requirements for AC charging stations. Edition 3 of this standard will be mandatory by February 2022 in the European Union.

Part 21-2 covers the EMC requirements for off-board electric vehicle charging systems, which defines whether the charging station is Class A or Class B.

Class A off-board electric vehicle charging systems are equipment that are suitable for use in all locations apart from residential, as well as those directly connected to a low voltage power supply network that supplies buildings used for residential purposes.

Class B off-board electric vehicle charging systems are equipment that are suitable for use in residential establishments as well as in establishments directly connected to a low-voltage power supply network which supplies buildings used for residential purposes.

Part 23 covers the requirements for DC charging stations that are both permanently wired and plug-connected.

Part 24 covers digital communication between a DC charging station and an electric vehicle for control of DC charging.

In general, the main characteristics of the charging station depend on usage and on the location where it is installed.

3.2 Charging station design - Mode 3 and Mode 4 common characteristics

Environmental characteristics

The charging station can be installed indoors or outdoors.

As a general rule, IP protection is at least IP54 for outdoor usage, even if IEC 61851-1 recommends only IP44. Shock IK protection is generally IK10. To be IEC 61851-1 compliant, the charger must be able to operate up to 2000 meters altitude and to a minimum temperature of at least -25°C in outdoor environments and -5°C for indoor environments.

In practice, charging stations can usually operate within a range of -30°C to +50°C and within a relative humidity range of 5% to 95%.

Charging station output

Charging station output is called socket-outlet, where there is no attached cable, and is called electric vehicle connector, where there is an attached cable.

The charging station can feature single or multiple outputs. In the case of AC charging stations, single output is usually used for single-family individual houses. Multiple output is usually used for chargers installed in public car parks. Outputs can be of the same type or different types.

The advantage of having several outputs is that the user can potentially charge several electric vehicles at the same time. In this case, the charging station can either share its total power between each of the outputs or it can have dedicated full power for each output, independently of the other outputs. However, it is possible that a charging station with several outputs is unable to manage several charges simultaneously.

It is also possible that a charging station can include a combination of DC and AC output.

Authentication

Fig.3.1 – Example of a charging station with an authentication mechanism

Where the charging station is located in a public space, it may feature an authentication mechanism, for example, an RFID reader. Such a mechanism allows identification of the charging station user, which will determine whether or not to authorize him to use the charging station or whether or not to charge him for its usage.

It is also possible to allocate different privileges to different users; for example, giving priority to VIP users so that they can charge their electric vehicle where there is a multiple output charging station.

Authentication can be managed in a different way - for example, it can be managed locally or remotely through a third-party application. In the case of a third-party application, the charging station should be able to manage off-line (degraded) mode in case communication is lost with the remote application: for example, in off-line mode, the charge could be allowed to all badges, or only to the one present in the cache memory of the charger (last badges used), or to no badges.

A charging station that is installed at home usually will not require an authentication mechanism.

Charging station communication

Charging stations can function as standalone with no external communication. However, they can also feature several types of communication modes - through Ethernet, Wi-Fi, 3G/4G, Bluetooth, NFC and even dry contact.

External communication can be used for a number of scenarios:

- Configuration of the charging station (for example, configuration of RFID authorization management, parameters, etc.)
- Maintenance (for diagnosis of any issues)
- Remote authorization to charge (if charging station authorization is from an external system)
- To receive commands for power limitation (for example, receiving on-peak / off-peak hour signal from an electronic meter or from a load management system)

3.3 Mode 3 charging station design

AC charging station - power and current delivery

Power delivered by AC charging station is 3.7 kW, 7.4 kW, 11 kW or 22 kW. The standard maximum current delivered is 32 A.

AC charging station - installation type

Wall mounted

Floor standing

Fig.3.2– Examples of charging stations.

Two main types of AC charging station installation are possible - on a wall or on the floor.

Wall solution is convenient for installation in scenarios such as single-family individual houses.

Floor installation is made with a pedestal that supports one or several charging stations. Charging stations can also be embedded with a pedestal. This type of solution can be used for workplace car parks, for example.

AC Charging station - with or without attached cable

AC charging stations can either feature an attached cable or require the use of a separate cable. In some cases, local legislation requires the use of one solution or the other, like, for example, the country of Singapore, where an attached cable is mandatory.

An AC charging station with an attached cable is designed for scenarios where the same type of connection will always be used, for example, in a location where the charging station will always be used by the same vehicle.

An AC charging station without an attached cable is more flexible because it is designed for any car. It includes type 1, type 2 or, type 2S connector, etc…or even a domestic plug. EV drivers use their own personal cable to connect from the charging station to their vehicle. In this scenario, there may be local regulations that demand the usage of a specific type of socket, for example, in France, where a type 2 connector for a charging station is prohibited. Instead, a type 2-S must be used.

This type of charging station (with no attached cable) is used especially in commercial buildings where many different types of vehicles are charging at any one time.

3.4 Mode 4 Fast Charging Station Design

Fast charging station - power delivery

Power delivered by DC charging stations ranges from 24 kW to more than 900 kW with a Combo CCS connector and up to 400 kW with a CHAdeMO connector.

Fast charging station - installation type

Fast DC charging station power range can range from 24 kW to more than 900 kW. Therefore, the mechanical design of the charging station can vary significantly from one to the next.

In general, however, we can put them into three main categories.

The first style, **wall installation**, is a good option for chargers around 24 kW. For higher power values, the weight of the charger increases, so the installation needs to be positioned on the floor.

The second type of design is **centralized standalone chargers**, which are floor-standing.

The final category of charger consists of a **charging cabinet and one to several satellite charging poles**. Inside the cabinet are power modules. In this way, the charging power can be dynamically distributed to each satellite pole. This type of solution is generally used for DC charging stations providing power above > 500 kW.

Fast charging station - attached cable

A fast DC charging station requires attached cables.

Chapter 4-EV charging - Electrical Installation Design.

Electric vehicle charging is a new load for low-voltage electrical installations that can present some challenges. Specific requirements for safety and design are provided in ***IEC 60364 Low-voltage electrical installations – Part 7-722: Requirements for special installations or locations – Supplies for electric vehicles***.

Fig. 4.1 below provides an overview of the scope of application of IEC 60364 for the various EV charging modes.

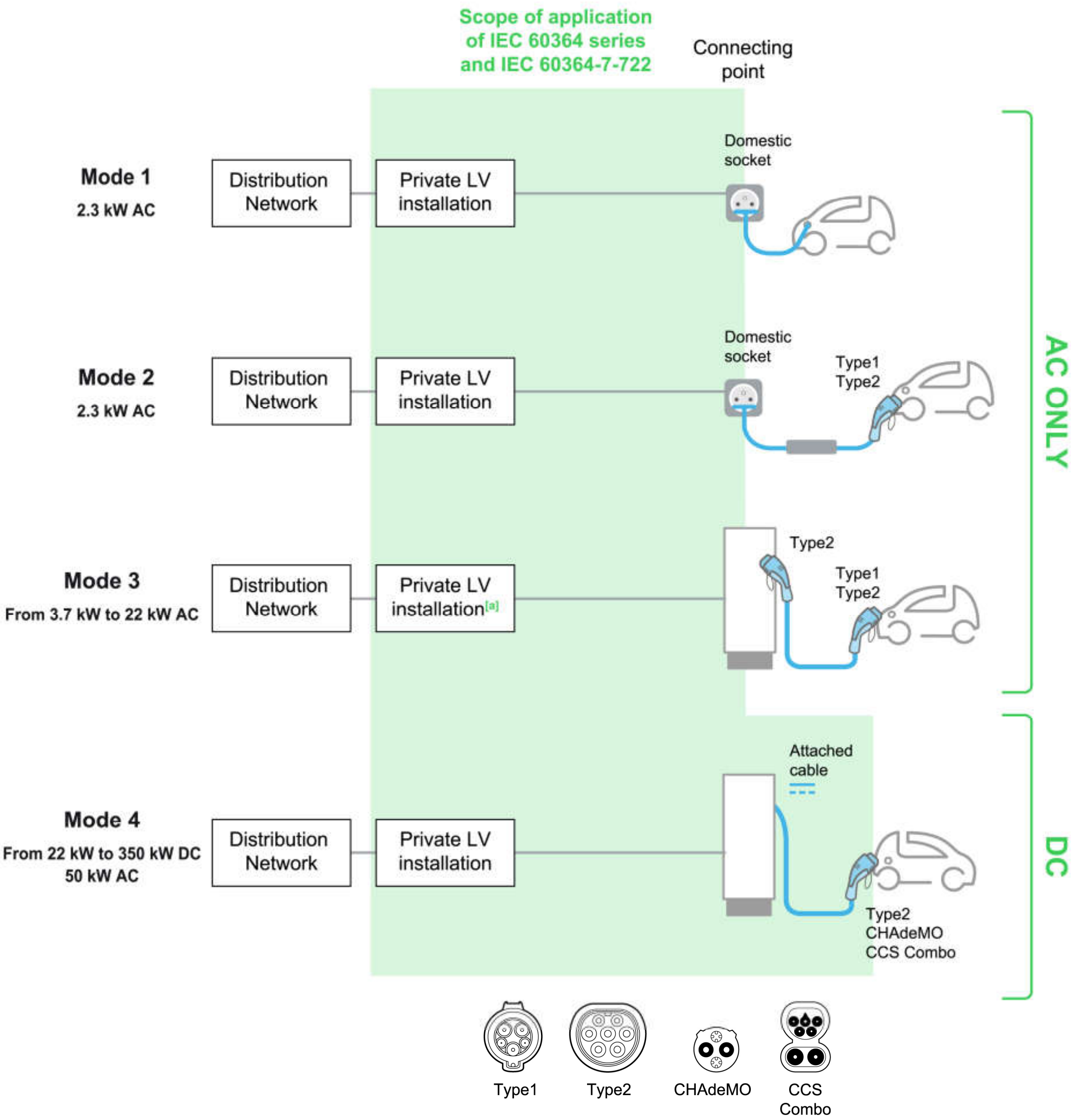


Fig. 4.1 Overview of the scope of application of IEC 60364 for the various EV charging modes.

[a] In the case of street-located charging stations, the "private LV installation set-up" is minimal, but the IEC60364-7-722 still applies from the utility connection point down to the EV connecting point.

Fig.4.1 – Scope of application of IEC 60364-7-722 standard, which defines the specific requirements when integrating an EV charging infrastructure into new or existing LV electrical installations.

It should also be noted that **compliance with IEC 60364-7-722 makes it mandatory that the different components of the EV charging installation fully comply with the related IEC product standards**. For example, (not exhaustive):

- EV charging station (modes 3 and 4) shall comply with the appropriate parts of the IEC 61851 series.
- Residual Current Devices (RCDs) shall comply with one of the following standards: IEC 61008-1, IEC 61009-1, IEC 60947-2 or IEC 62423.
- **RDC-DD** shall comply with IEC 62955
- Overcurrent protective device shall comply with IEC 60947-2, IEC 60947-6-2 or IEC 61009-1 or with the relevant parts of the IEC 60898 series or the IEC 60269 series.
- Where the connecting point is a **socket-outlet or a vehicle connector**, it shall comply with IEC 60309-1 or IEC 62196-1 (where interchangeability is not required), or IEC 60309-2, IEC 62196-2, IEC 62196-3 or IEC TS 62196-4 (where interchangeability is required), or the national standard for socket-outlets, provided the rated current does not exceed 16 A.

4.1 Impact of EV charging on maximum power demand and equipment sizing

As stated in IEC 60364-7-722.311, *"It shall be considered that in normal use, each single connecting point is used at its rated current or at the configured maximum charging current of the charging station. The means for configuration of the maximum charging current shall only be made by the use of a key or a tool and only be accessible to skilled or instructed persons."*

The sizing of the circuit supplying one connecting point (modes 1 and 2) or one EV charging station (modes 3 and 4) should be done according to the maximum charging current (or a lower value, providing that configuring this value is not accessible to non-skilled persons).

Table 4.1 – Examples of common sizing currents for Mode 1, 2, and 3

Characteristics	**Charging mode**				
	Mode 1 & 2	**Mode 3**			
Equipment for circuit sizing	Standard socket outlet	3.7kW single phase	7kW single phase	11kW three phases	22kW three phases
Maximum current to consider @230 / 400Vac	16A P+N	16A P+N	32A P+N	16A 3P+N	32A 3P+N

IEC 60364-7-722.311 also states that *"Since all the connecting points of the installation can be used simultaneously, the diversity factor of the distribution circuit shall be taken as equal to 1 unless a load control is included in the EV supply equipment or installed upstream, or a combination of both."*

The diversity factor to consider for several EV chargers in parallel is equal to 1 unless a Load Management System (LMS) is used to control these EV chargers.

The installation of an LMS to control the EVSE is therefore highly recommended: it prevents oversizing, optimizes the costs of the electrical infrastructure and reduces operating costs by avoiding power demand peaks. Refer to EV charging - electrical architectures for an example of an architecture with and without an LMS, illustrating the optimization gained on the electrical installation. Refer to EV charging - energy and asset management for more details about the different variants of LMS and the additional opportunities that are possible with cloud-based analytics and supervision of EV charging. And check Smart charging perspectives for optimal EV integration for perspectives on smart charging.

4.2 Conductor arrangement and earthing systems

As stated in IEC 60364-7-722 (Clauses 314.01 and 312.2.1):

- A dedicated circuit shall be provided for the transfer of energy from/to the electric vehicle.
- In a TN earthing system, a circuit supplying a connecting point shall not include a PEN conductor.

It should also be verified whether electric cars using the charging stations have limitations related to specific earthing systems: for example, certain cars cannot be connected in Mode 1, 2 and 3 in the IT earthing system (Example: Renault Zoe).

Regulations in certain countries may include additional requirements relating to earthing systems and PEN continuity monitoring. Example: the case of the TNC-TN-S (PME) network in the UK. To be compliant with BS 7671, in the case of an upstream PEN break, a complementary protection based on voltage monitoring must be installed if there is no local earthing electrode.

4.3 Protection against electric shocks

EV charging applications increase the risk of electric shock for several reasons:

- Plugs: risk of discontinuity of Protective Earth conductor (PE).
- Cable: risk of mechanical damage to cable insulation (crushing by rolling of vehicle tires, repeated operations…)
- Electric car: risk of access to active parts of the charger (class 1) in the car as a result of destruction of basic protection (accidents, car maintenance etc.)
- Wet or saltwater wet environments (snow on electric vehicle inlet, rain…)

To take these increased risks into account, IEC 60364-7-722 states that:

- Additional protection with an RCD 30mA is mandatory
- Protective measure "placing out of reach", according to IEC 60364-4-41 Annex B2, is not permitted
- Special protective measures, according to IEC 60364-4-41 Annex C, are not permitted

- Electrical separation for the supply of one item of current-using equipment is accepted as a protective measure with an isolating transformer complying with IEC 61558-2-4, and the voltage of the separated circuit shall not exceed 500 V. This is the commonly used solution for Mode 4.

Protection against electric shocks by automatic disconnection of the supply

The paragraphs below provide the detailed requirements of the IEC 60364-7-722:2018 standard (based on Clauses 411.3.3, 531.2.101 and 531.2.1.1 etc.).

Each AC connecting point shall be individually protected by a residual current device (RCD) with a residual operating current rating that does not exceed 30 mA.

RCDs protecting each connecting point in accordance with 722.411.3.3 shall comply at least with the requirements of an RCD type A and shall have a rated residual operating current not exceeding 30 mA.

Where the EV charging station is equipped with a socket-outlet or vehicle connector that complies with IEC 62196 (all parts - "Plugs, socket-outlets, vehicle connectors and vehicle inlets – Conductive charging of electric vehicles"), protective measures against DC fault current shall be taken, except where provided by the EV charging station.

The appropriate measures for each connection point shall be as follows:

- The use of an RCD type B or
- The use of an RCD type A (or F) in conjunction with a Residual Direct Current Detecting Device (RDC-DD) that complies with IEC 62955

RCDs shall comply with one of the following standards: IEC 61008-1, IEC 61009-1, IEC 60947-2 or IEC 62423. RCDs shall disconnect all live conductors.

Fig. 4.2 and Table 4.2 below summarize these requirements.

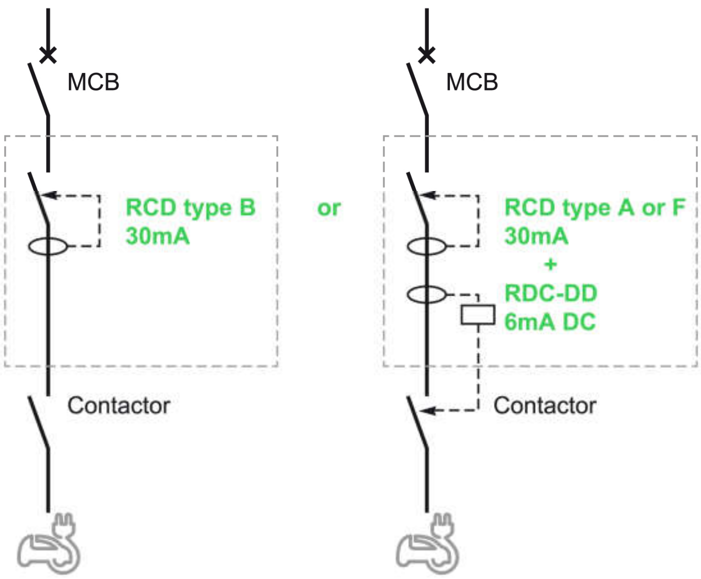


Fig. 4.2 – The two solutions for protection against electric shocks (EV charging stations, mode 3).

Fig. 4.2 – Synthesis of IEC 60364-7-722 requirement for additional protection against electric shocks by automatic disconnection of the supply with RCD 30mA

Mode 1 & 2	Mode 3	Mode 4
RCD 30mA type A	RCD 30mA type B, or RCD 30mA type A + 6mA RDC-DD, or RCD 30mA type F + 6mA RDC-DD	Not applicable (no A

Notes:

- The RCD or appropriate equipment that ensures disconnection of the supply in case of a DC fault can be installed inside the EV charging station, in the upstream switchboard, or in both locations.
- Specific RCD types, as illustrated above, are required because the AC/DC converter included in electric cars and used to charge the battery may generate DC leakage current.

What is the preferred option, RCD type B or RCD type A/F + RDC-DD 6 mA?

The main criteria to compare these two solutions are the potential impact on other RCDs in the electrical installation (risk of blinding) and the expected continuity of service of EV charging, as shown in **Table 4.3**.

Table 4.3 – Comparison of RCD type B and RCD type A + RDC-DD 6mA solutions

Comparison criteria	**Type of protection used in EV circuit**	
	RCD type B	**RCD type A (or F)** **+ RDC-DD 6 mA**
Maximum number of EV connecting points downstream of a type A RCD to avoid the risk of blinding	0[a] (not possible)	Maximum 1 EV connecting point[a]
Continuity of service of the EV charging points	OK DC leakage current leading to the trip is [15 mA … 60 mA]	Not recommended DC leakage current leading to the trip is [3 mA … 6 mA] In humid environments, or due to the ageing of insulation, this leakage current is likely to increase up to 5 or 7 mA and may lead to nuisance tripping.

[A] 1, 2. These limitations are based on the DC max current acceptable by type A RCDs according to IEC 61008 / 61009 standards. Refer to the next paragraph for more details on the risk of blinding and for solutions that minimize the impact and optimize the installation.

Important: These are the only two solutions that comply with the IEC 60364-7-722 standard for protection against electric shocks. Some EVSE manufacturers claim to offer "built-in protective devices" or "embedded protection". To find out more about the risks and to select a safe charging solution, see the **White Paper** entitled [Safety measures for charging electric vehicles](#).

How to implement people protection throughout the installation despite the presence of loads that generate DC leakage currents

EV chargers include AC/DC converters, which may generate DC leakage current. This DC leakage current is let through by the EV circuit's RCD protection (or RCD + RDC-DD), until it reaches the RCD/RDC-DD DC tripping value.

The maximum DC current that may flow through the EV circuit without tripping is:

- 60 mA for 30 mA RCD type B (2*IΔn as per IEC 62423)
- 6 mA for 30 mA RCD Type A (or F) + 6mA RDC-DD (as per IEC 62955)

Why this DC leakage current may be a problem for other RCDs of the installation

The other RCDs in the electrical installation may "see" this DC current, as shown in Fig. EV26:

- The upstream RCDs will see 100% of the DC leakage current, whatever the earthing system (TN, TT)
- The RCDs installed in parallel will only see a portion of this current, only for the TT earthing system and only when a fault occurs in the circuit they protect. In the TN earthing system, the DC leakage current going through the type B RCD flows back through the PE conductor and, therefore, cannot be seen by the RCDs in parallel.

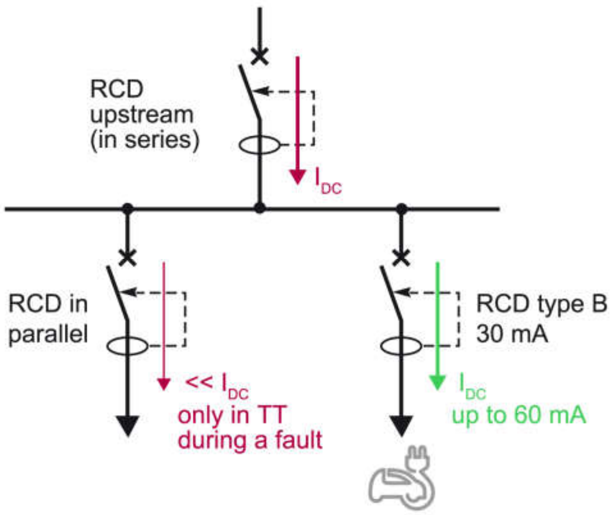


Fig. 4.3 – RCDs in series or in parallel are impacted by the DC leakage current that is let through by the type B RCD

RCDs other than type B are not designed to function correctly in the presence of DC leakage current and may be "blinded" if this current is too high: their core will be pre-magnetized by this DC current and may become insensitive to the AC fault current, e.g. the RCD will no longer trip in case of AC fault (potential hazardous situation). This is sometimes called "blindness", "blinding" or desensitization of the RCDs.

IEC standards define the (maximum) DC offset used to test the correct functioning of the different types of RCDs:

- **10 mA** for type F,
- **6 mA** for type A
- and **0 mA** for type AC.

That is to say that, considering the characteristics of RCDs as defined by IEC standards:

- **RCDs type AC cannot be installed upstream of any EV charging station**, regardless of the EV RCD option (type B or type A + RDC-DD).
- **RCDs Type A or F can be installed upstream of a maximum of one EV charging station**, and only if this EV charging station is protected by an RCD type A (or F) + 6mA RCD-DD.

The RCD type A/F + 6mA RDC-DD solution has less impact (less blinking effect) when selecting other RCDs; nevertheless, it is also very limited in practice, as shown in **Fig.** EV27.

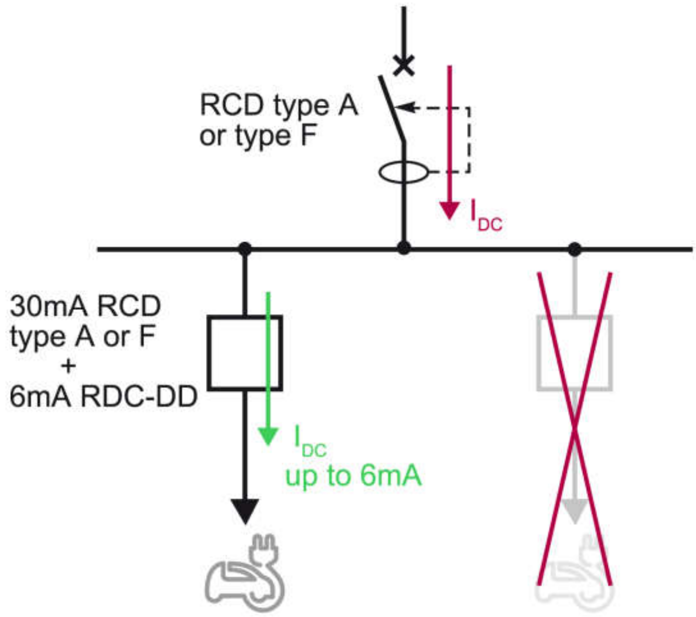


Fig. 4.4 – Maximum one EV station protected by RCD type A/F + 6mA RDC-DD can be installed downstream of RCDs type A and F

Recommendations to ensure the correct functioning of RCDs in the installation

Some possible solutions to minimize the impact of EV circuits on other RCDs of the electrical installation:

- **Connect the EV charging circuits as high as possible in the electrical architecture** so that they are in parallel to other RCDs to significantly reduce the risk of blinding
- **Use a TN system** if possible, as there is no blinding effect on RCDs in parallel
- For **RCDs upstream of EV charging circuits**, either

- Select type B RCDs unless you have only 1 EV charger that uses type A + 6mA RDC-DD

or

- **Select non-type B RCDs that are designed to withstand DC current values beyond the specified values required by IEC standards** without impacting their AC protection performance. One example with Schneider Electric product ranges the Acti9 300mA type A RCDs, which can operate without blinding effect upstream up to 4 EV charging circuits protected by 30mA type B RCDs. For further information, consult the Schneider Electric [Earth Fault Protection guide,]() which includes **selection tables and digital selectors**.

Examples of EV charging electrical diagrams

Below are two **examples of electrical diagrams for EV charging circuits in mode 3**, that are compliant with IEC 60364-7-722.

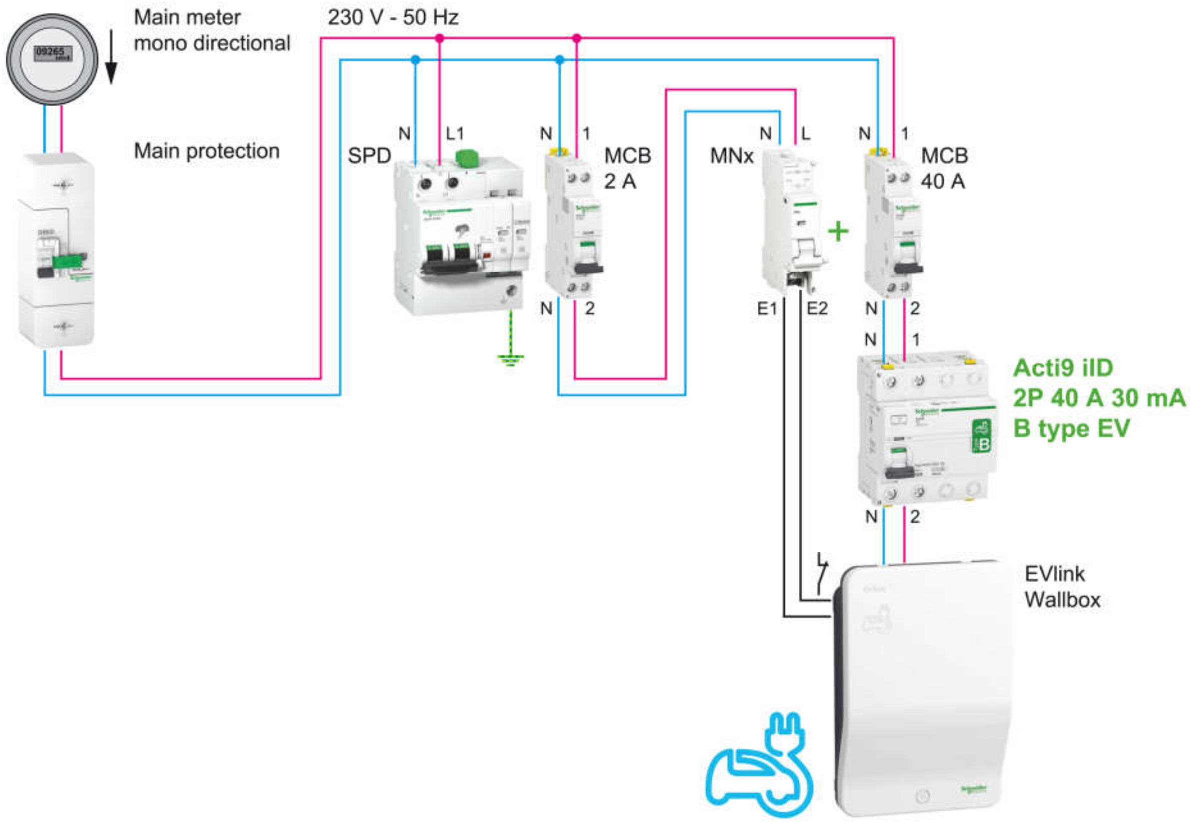


Fig.4.5 – Example of electrical diagram for one charging station in mode 3 (@home - residential application)

- A dedicated circuit for EV charging, with 40A MCB overload protection
- Protection against electric shocks with a 30mA RCD type B (a 30mA RCD type A/F + RDC-DD 6mA may also be used)

- The upstream RCD is a type A RCD. This is only possible due to enhanced characteristics of this Schneider Electric RCD: no risk of blinding by the leakage current that is let through by the type B RCD
- Also integrates Surge Protection Device (recommended)

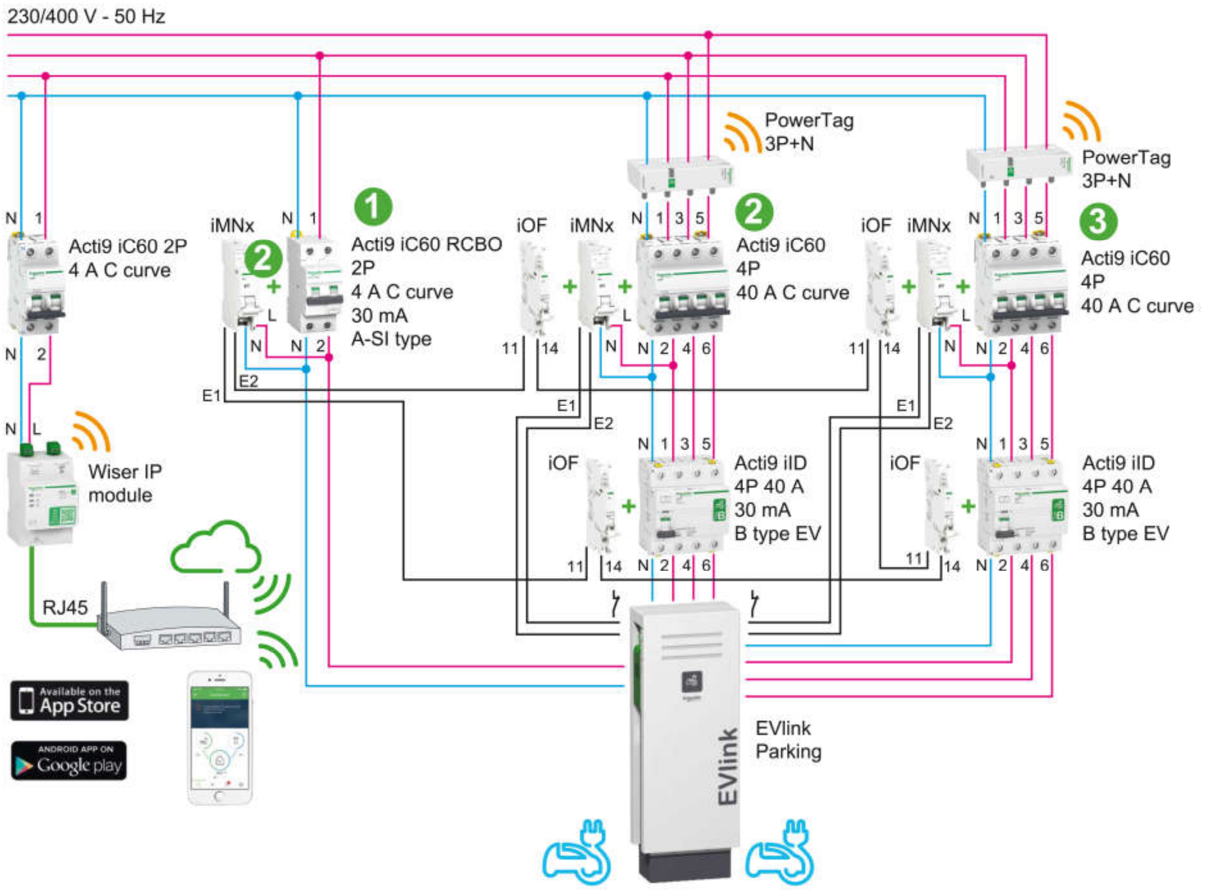


Fig. 4.6– Example of electrical diagram for one charging station (mode 3) with 2 connecting points (commercial application, parking ...)

- Each connecting point has its own dedicated circuit
- Protection against electric shocks by 30mA RCD type B, one for each connecting point (30mA RCD type A/F + RDC-DD 6mA may also be used)
- Overvoltage protection and RCDs type B may be installed in the charging station. In this case, the charging station could be powered from the switchboard with a single 63A circuit
- iMNx: Some country regulations may require emergency switching for EVSE in public areas
- Surge protection is not shown. It may be added to the charging station or in the upstream switchboard (depending on the distance between the switchboard and the charging station)

4.4 Protection against transient overvoltages

The power surge generated by a lightning strike near an electricity network propagates into the network without undergoing any significant attenuation. As a result, the overvoltage likely to appear in an LV installation may exceed the acceptable levels for withstand voltage recommended by standards IEC 60664-1 and IEC 60364. The electric vehicle, being designed with an overvoltage category II according to IEC 17409, should, therefore, be protected against overvoltages that could exceed 2.5 kV.

As a consequence, IEC 60364-7-722 requires that EVSE installed in locations accessible to the public be protected against transient overvoltages. This is ensured by the use of a type 1 or type 2 surge protective device (SPD), complying with IEC 61643-11, installed in the switchboard supplying the electric vehicle or directly inside the EVSE, with a protection level Up ≤ 2.5 kV.

Surge protection by equipotential bonding

The first safeguard to put in place is a medium (conductor) that ensures equipotential bonding between all the conductive parts of the EV installation.

The aim is to bond all grounded conductors and metal parts so as to create equal potential at all points in the installed system.

Surge protection for indoor EVSE - without lightning protection system (LPS) - public access

The IEC 60364-7-722 requires protection against transient overvoltage for all locations with public access. The usual rules for selecting the SPDs can be applied (See Overvoltage protection).

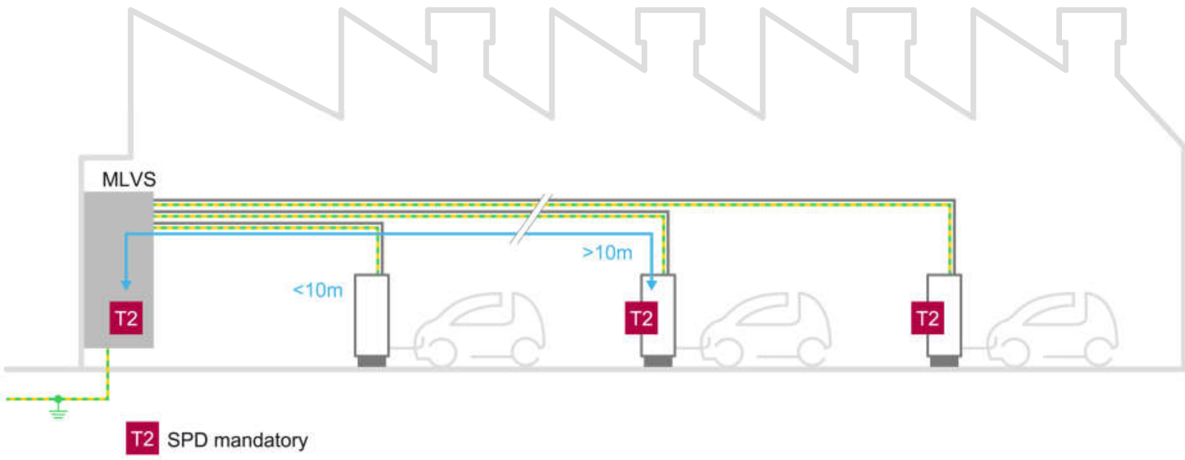


Fig.4.7 – Surge protection for indoor EVSE - without lightning protection system (LPS) - public access

When the building is not protected by a lightning protection system:

- A type 2 SPD is required in the main low-voltage switchboard (MLVS)
- Each EVSE is supplied with a dedicated circuit.
- An additional type 2 SPD is required in each EVSE, except if the distance from the main panel to the EVSE is less than 10m.
- A type 3 SPD is also recommended for the Load Management System (LMS) as sensitive electronic equipment. This type 3 SPD has to be installed downstream of a type 2 SPD (which is generally recommended or required in the switchboard where the LMS is installed).

Surge protection for indoor EVSE - installation using busway - without lightning protection system (LPS) - public access

This example is similar to the previous one, except that a busway (busbar trunking system) is used to distribute the energy to the EVSE.

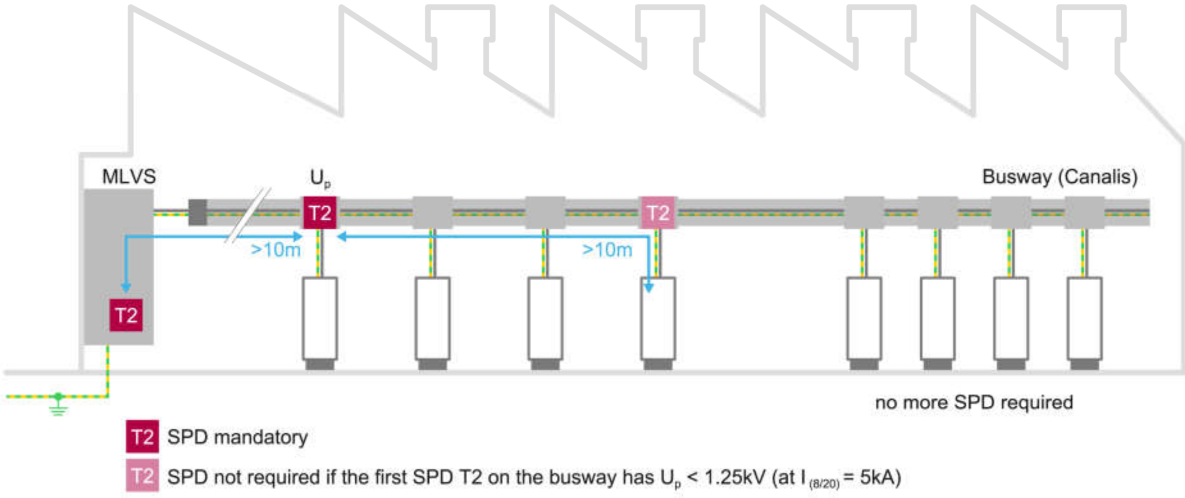


Fig.4.8 – Surge protection for indoor EVSE - without lightning protection system (LPS) – installation using busway - public access

In this case, as shown in Fig. 4.8:

- A type 2 SPD is required in the main low-voltage switchboard (MLVS)
- EVSEs are supplied from the busway, and SPDs (if required) are installed inside busway tap-off boxes
- An additional type 2 SPD is required in the first busway outgoer feeding an EVSE (as generally, the distance to the MLVS is more than 10m). The following EVSEs are also protected by this SPD if they are less than 10m away
- If this additional type 2 SPD has U_p < 1.25kV (at $I_{(8/20)}$ = 5kA), there is no need to add any other SPD on the busway: all following EVSE are protected.
- A type 3 SPD is also recommended for the Load Management System (LMS) as sensitive electronic equipment. This type 3 SPD has to be installed downstream of a type 2 SPD (which is generally recommended or required in the switchboard where the LMS is installed).

Surge protection for indoor EVSE - with lightning protection system (LPS) - public access

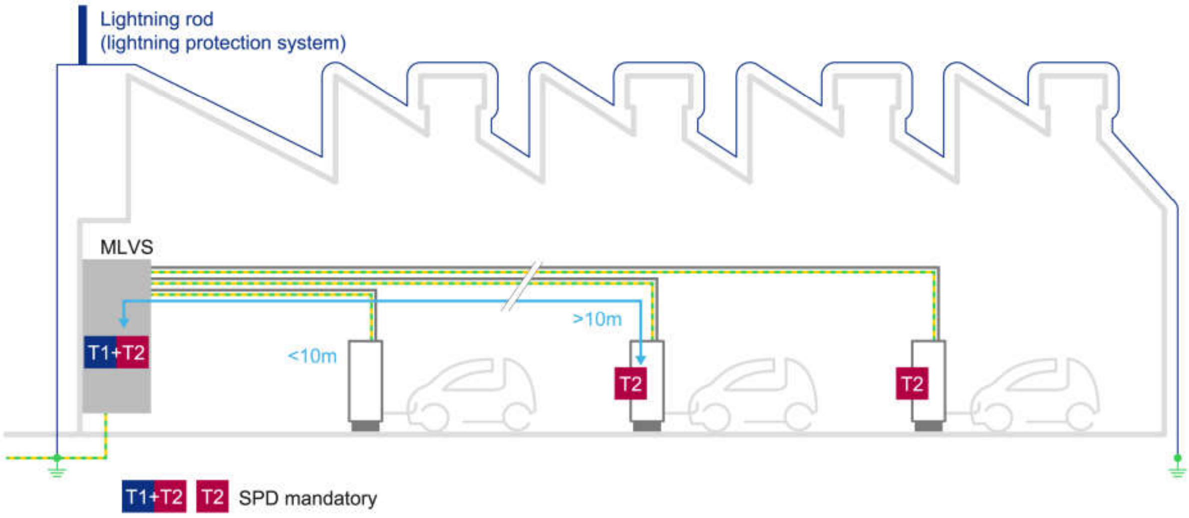


Fig.4.9 – Surge protection for indoor EVSE - with lightning protection system (LPS) - public access

When the building is protected by a lightning protection system (LPS):

- A type 1+2 SPD is required in the main low-voltage switchboard (MLVS)
- Each EVSE is supplied with a dedicated circuit.
- An additional type 2 SPD is required in each EVSE, except if the distance from the main panel to the EVSE is less than 10m.
- A type 3 SPD is also recommended for the Load Management System (LMS) as sensitive electronic equipment. This type 3 SPD has to be installed downstream of a type 2 SPD (which is generally recommended or required in the switchboard where the LMS is installed).

Note: If you use a busway for the distribution, apply the rules shown in the example without LTS, except for the SPD in the MLVS = use a Type 1+2 SPD and not a Type 2 because of the LPS.

Surge protection for outdoor EVSE - without lightning protection system (LPS) - public access

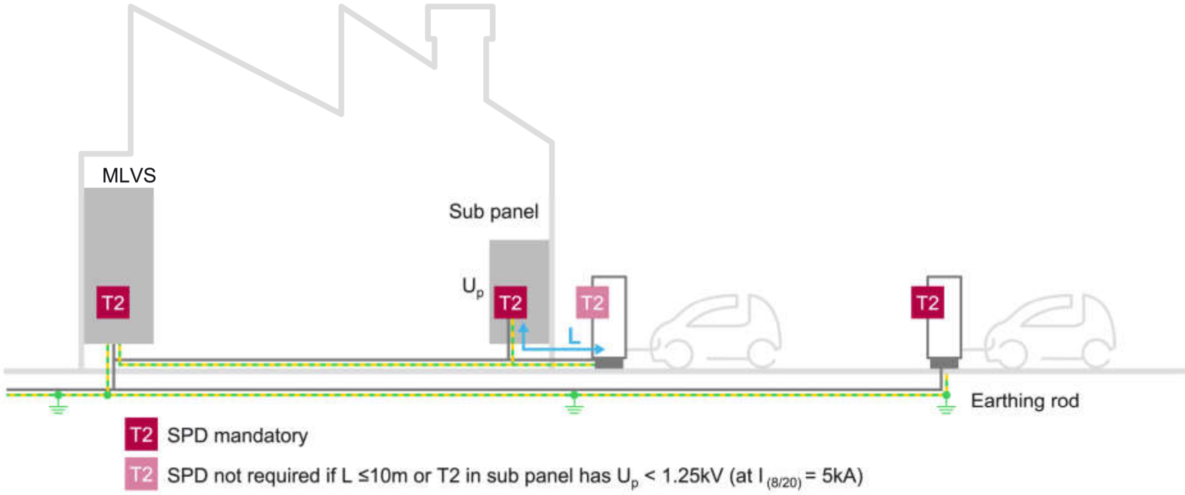


Fig.4.10 – Surge protection for outdoor EVSE - without lightning protection system (LPS) - public access

In this example:

- A type 2 SPD is required in the main low-voltage switchboard (MLVS)
- An additional type 2 SPD is required in the sub-panel (distance generally >10m to the MLVS)

In addition:

When the EVSE is linked with the building structure:

- Use the building's equipotential network
- If the EVSE is less than 10m from the sub panel, or if the type 2 SPD installed in the sub panel has $U_p < 1.25kV$ (at $I_{(8/20)} = 5kA$), there is no need for additional SPDs in the EVSE

When the EVSE is installed in a parking area and supplied with an underground electrical line:

- Each EVSE shall be equipped with an earthing rod.
- Each EVSE shall be connected to an equipotential network. This network must also be connected to the building's equipotential network.
- Install a type 2 SPD in each EVSE.

A type 3 SPD is also recommended for the Load Management System (LMS) as sensitive electronic equipment. This type 3 SPD has to be installed downstream of a type 2 SPD (which is generally recommended or required in the switchboard where the LMS is installed).

Surge protection for outdoor EVSE - with lightning protection system (LPS) - public access

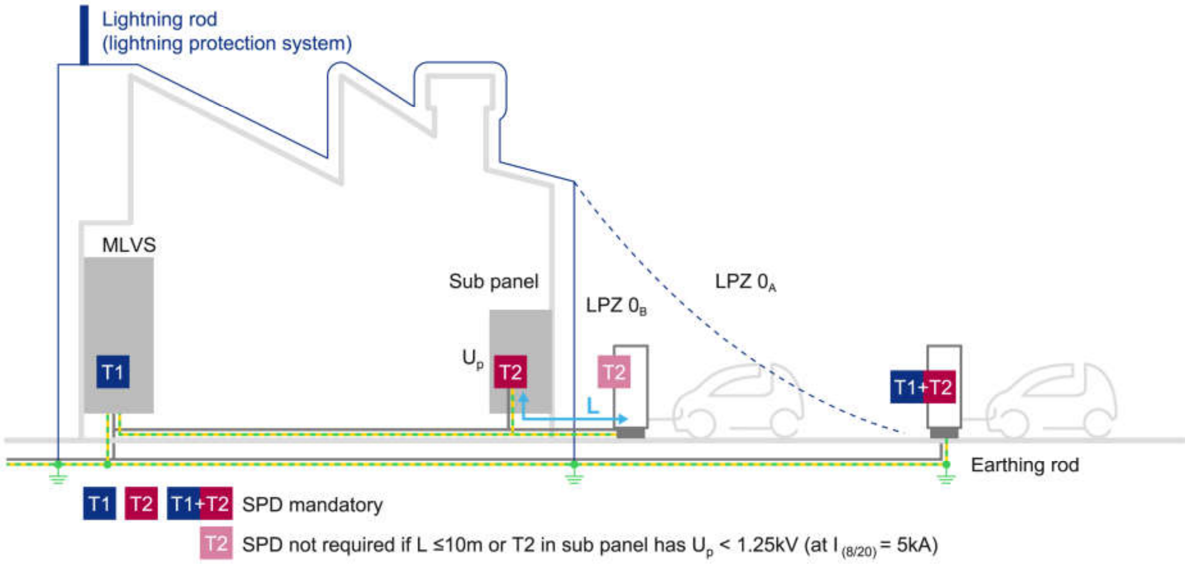


Fig.4.11 – Surge protection for outdoor EVSE with lightning protection system (LPS)-public access.

The main building is equipped with a lightning rod (lightning protection system) to protect the building.

In this case:

- A type 1 SPD is required in the main low-voltage switchboard (MLVS)
- An additional type 2 SPD is required in the sub-panel (distance generally >10m to the MLVS)

In addition:

When the EVSE is linked with the building structure:

- Use the building's equipotential network
- If the EVSE is less than 10m from the sub panel, or if the type 2 SPD installed in the sub panel has $U_p < 1.25$kV (at $I_{(8/20)} = 5$kA), there is no need to add additional SPDs in the EVSE

When the EVSE is installed in a parking area and supplied with an underground electrical line:

- Each EVSE shall be equipped with an earthing rod.
- Each EVSE shall be connected to an equipotential network. This network must also be connected to the building's equipotential network.
- Install a type 1+2 SPD in each EVSE.

A type 3 SPD is also recommended for the Load Management System (LMS) as sensitive electronic equipment. This type 3 SPD has to be installed downstream of a type 2 SPD (which is generally recommended or required in the switchboard where the LMS is installed)

Chapter 5-EV charging - Electrical Architectures

5.1 Integration of EV supply equipment into an existing installation

The integration of EV charging supply equipment requires an integration of several high-power loads and an adaptation to the existing electrical infrastructure.

This section presents basic principles for designing the EV charging infrastructure and its integration into the existing electrical installation.

EV charging power demand is lower than the installed power demand

If the amount of charging points and their capacity is significantly lower than the installed power, an option to investigate could be to integrate the EV chargers into the existing electrical installation.

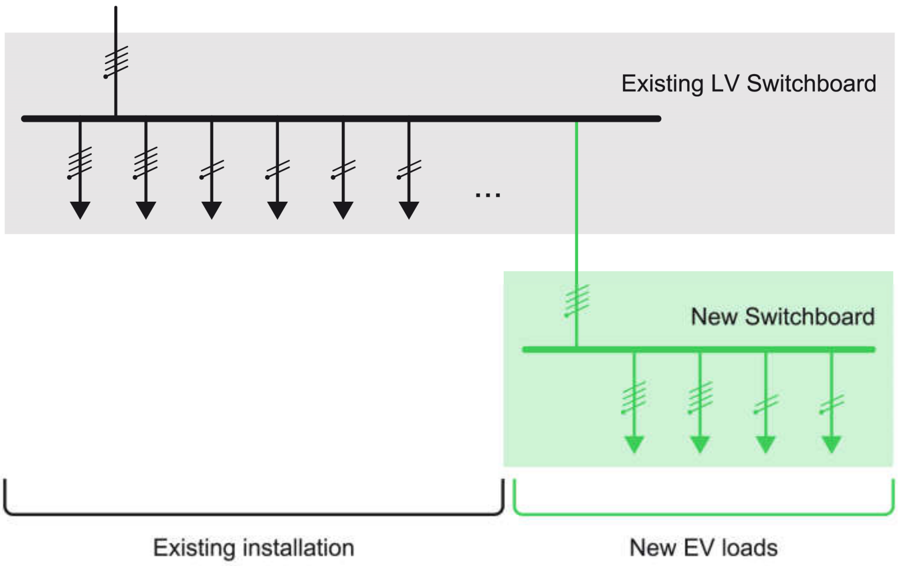


Fig.5.1 – EV loads integrated into the existing electrical infrastructure

A preliminary audit is required to assess the capacity of the existing installation to absorb the power demand of the new loads. It should be checked that:

- The utility can provide the new power demand.
- The existing busbar is adequately sized to absorb the new power demand.
- The existing LV panel is adequately sized to absorb the new power demand and to integrate the additional protection equipment for the EV circuits.
- Overcurrent protection selectivity can be achieved between the main circuit breaker and the circuit breakers at the EV circuits.
- Selectivity can be achieved for the residual current protections between the main Residual Current Device (RCD) and the RCDs in the EV circuits.
- The RCDs of the existing installation can operate in the presence of DC leakage currents induced by the EV supply equipment.
- Overvoltage protection, including the new EV charging stations, is achieved, with the addition of SPDs if necessary (risk assessment).

The integration of EV chargers into the existing electrical infrastructure is an interesting option if it does not require significant changes or replacement of equipment.

It is important at this stage to perform an audit to identify the power load that can be added without changing the existing electrical infrastructure. Energy efficiency measures could be proposed to reduce the existing consumption and, therefore, increase the power demand that can be added. Local power supplies and storage could be proposed to compensate for the impact of integrating the EV charging equipment.

If the existing LV switchboard cannot accommodate the additional power and/or devices required, the option described in the next paragraph is recommended.

EV charging power demand is equivalent to or higher than the existing power demand.

If the power demand of the new EV loads is equivalent to or higher than that of the existing electrical installation, it could be preferable to install a new main LV switchboard to integrate all EV loads.

The existing electrical infrastructure will be connected to this new main LV switchboard. An overcurrent and residual current protection selectivity need to be achieved between the existing installation feeder and the new main incomer.

If there are several EV chargers located in the same area, secondary LV switchboards could be installed close to the EV charging area in order to optimize the cable length.

The creation of a new main LV switchboard presents the advantage of minimizing the changes to the existing electrical installation. In addition, it offers the opportunity to coordinate protection devices and thus optimize power availability.

Fig.5.2 – EV loads integrated into a new main low-voltage switchboard

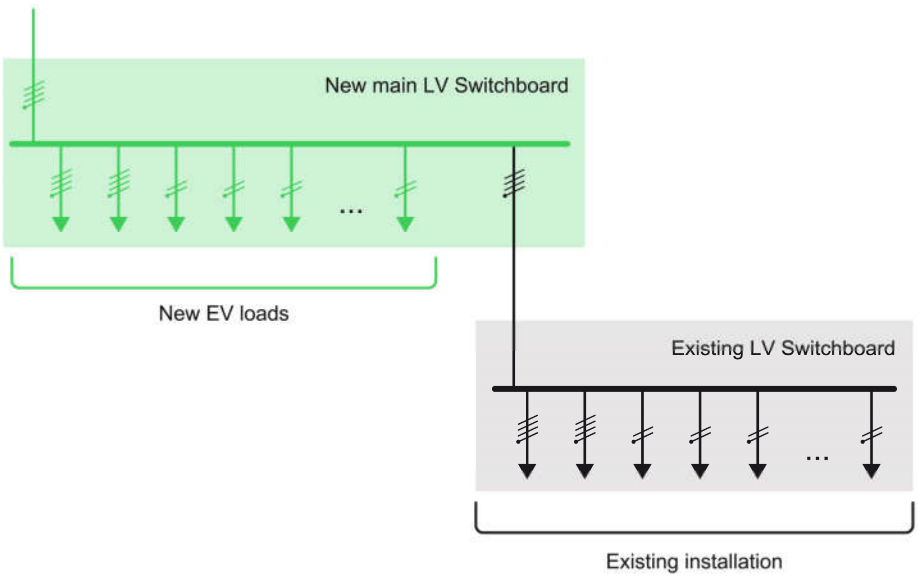


Fig.5.2– EV loads integrated into a new main low-voltage switchboard

Use of local energy supplies to compensate for the EV charging power demand

The integration of EV loads increases the power demand of the electrical installation significantly.

An extension of the local energy infrastructure is often required. A switch from an LV grid connection to an MV grid connection could be necessary in certain cases.

In addition to the electrical infrastructure, the electricity contract with the energy provider needs to be reviewed.

To limit or avoid these types of significant modifications to the existing local installation, local energy power supplies can be added, such as:

- Photovoltaic system: for local energy production and a commitment to sustainability
- Energy storage system: to avoid power demand peaks and optimize solar production use
- Combined heat and power (CHP): combined heat and power production, if relevant

Local power supplies can be connected to the new main LV switchboard. Their integration into an existing electrical infrastructure requires a preliminary audit.

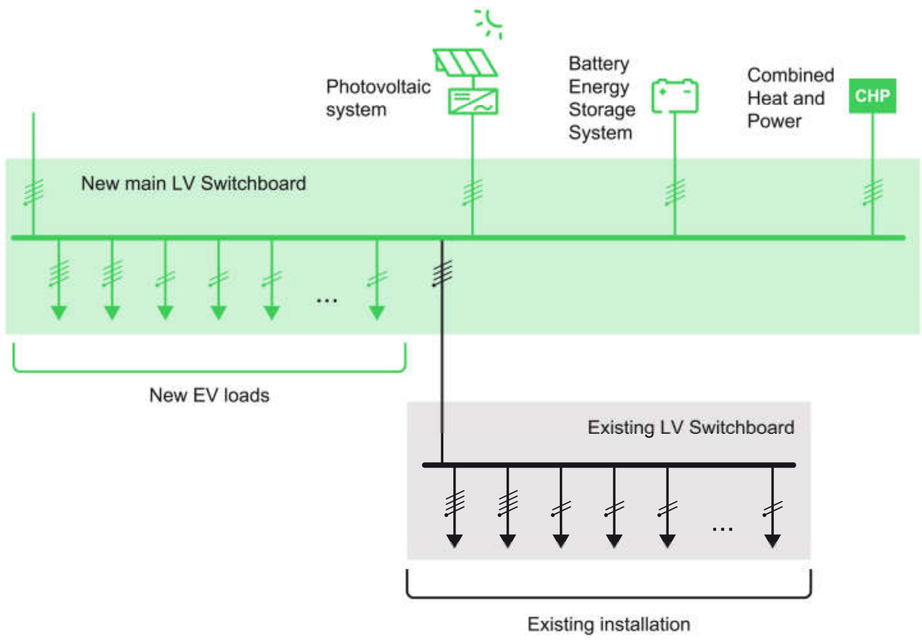


Fig.5.3– EV loads and local power supplies integrated into a new main low-voltage switchboard

5.2 Examples of EV charging installations

The examples below are used to illustrate the implementation of the design rules described in "Chapter- EV charging - electrical installation design" (power demand and diversity factor, protection against electric shocks, etc.). They also show that EV charging requirements can vary significantly depending on the application: charging station powers and quantities to fit the times and speeds of charging for each targeted end user, and so on.

Example of architecture with mode 3 charging stations according to different load management strategies

Several countries have already set some regulatory goals for retail buildings, requiring that a minimum percentage of parking slots be equipped with charging stations.

It is a required minimum, and as the speed of adoption of electric vehicles is not clearly known, and because these regulations will probably become more stringent in the near future, it may be advisable to prepare the electrical installation for future upgrading. Busways (busbar trunking systems) are particularly suitable to facilitate this future evolution. The load management strategy will also impact the sizing of the installation.

In this example, we consider a retail building with 30 parking slots. The objective is to provide 10% of parking slots with charging stations, so 3 slots equipped with EV supply equipment (EVSE), with a possible later extension to 7 slots, e.g. 7 charge points. Charging mode 3 only is selected.

Solution 1: Without a load management system

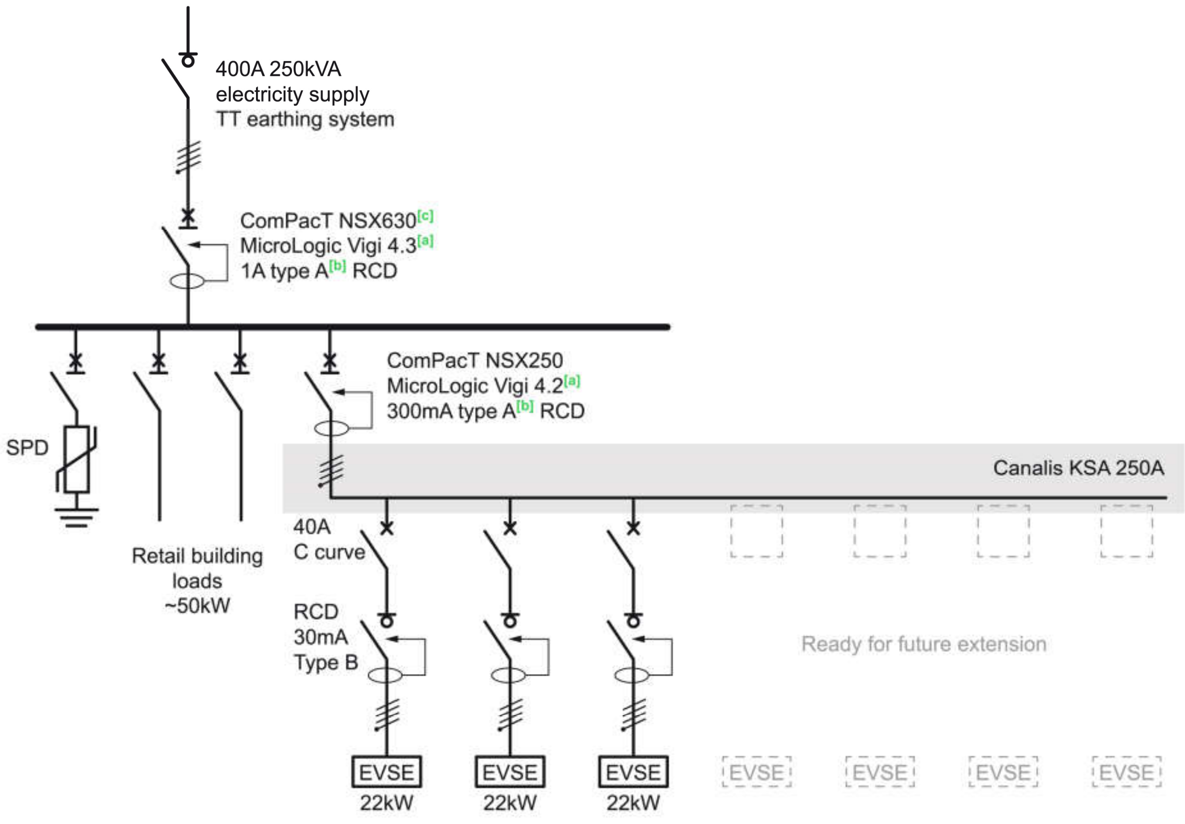


Fig. 5.4 – Solution 1: without load management system. The contract with the utility is for the full final power. The busway is also designed for the full EVSE power.

[a] In TN, these RCDs may not be necessary. In that case, Micrologic 4.3 (4.2) may be replaced by Micrologic 2.3 (2.2) or 5.3E (5.2E)
[b] Schneider Electric type A RCDs can be connected in series with a type B RCD, with no blinding effect.
[c] ComPact NSX630 is selected for 400A to achieve selectivity with NSX250

With such a solution, the electrical installation is sized for the complete power, including the future extension to 7 EVSE. Because there is no load management system, all charging points may be used simultaneously, so the diversity factor is 1 (IEC 60364-7-722).

The busway is sized for 7x 22kW = 154kW, e.g. ~225A.

All 7 charging stations can be used simultaneously at full charging power to supply 7 electric vehicles.

Solution 2: With a static load management system

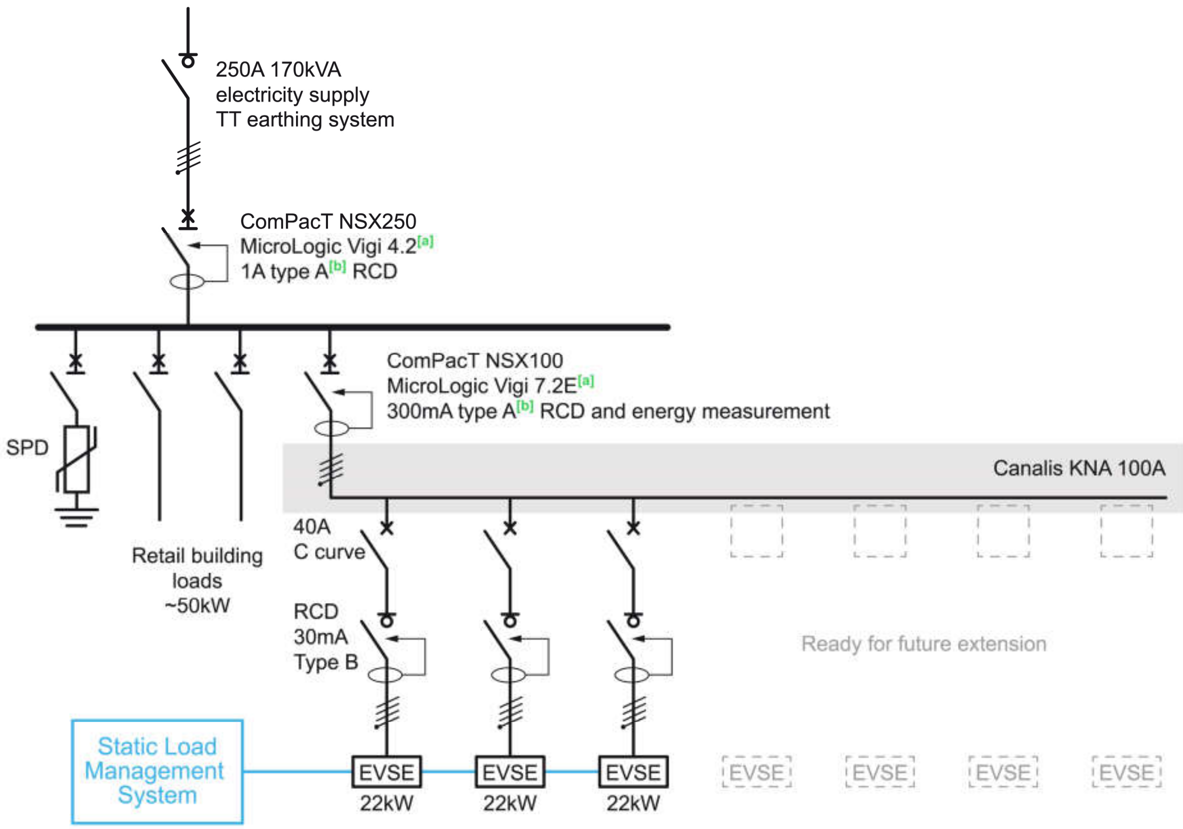


Fig. 5.5 – Solution 2: with static load management system. Allows the global power and busway sizing to be reduced but does not take advantage of all the available power of the installation

[a] In TN, these RCDs may not be necessary. In that case, Micrologic 4.2 (7.2E) may be replaced by Micrologic 2.2 (5.2E)
[b] Schneider Electric type A RCDs can be connected in series with a type B RCD, with no blinding effect.

The electrical installation is sized for the complete power, including future extension, but with a diversity factor of 0.4, and therefore, a power limitation of the EV charging stations to stay below 100A. A Load Management System is set up with a static setpoint of 100A; it communicates with the EVSE to ensure that the total power consumed by the EV charging stations remains below 100A. It will never use more than 100A for EV charging, even if the available power from the electrical installation is higher at certain times.

The busway is, therefore, sized for 100A.

All 7 charging stations can be used simultaneously but not at full charging power, up to a max total of 100A. For example, it is only possible to supply 3 electric vehicles simultaneously at full charging point power.

Solution 3: With a dynamic load management system

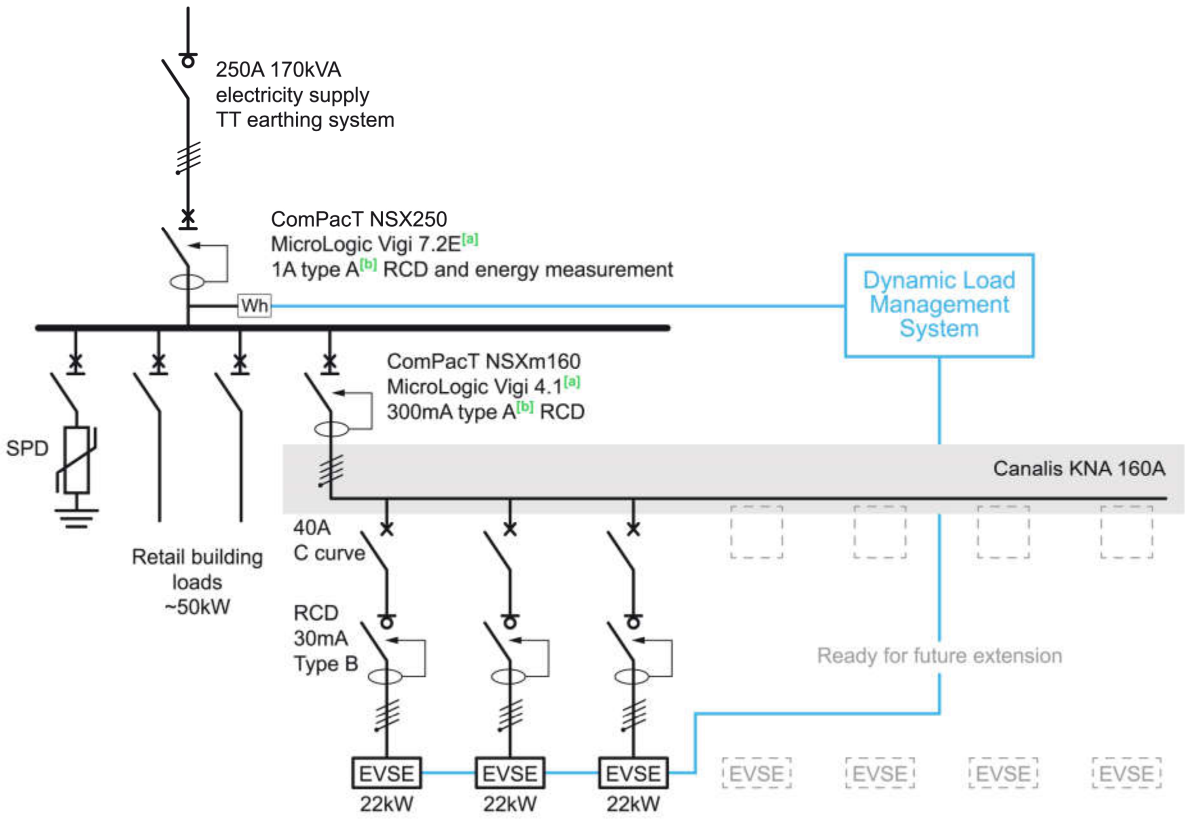


Fig. 5.6 – Solution 3: With a dynamic load management system, allowing all available power of the electrical installation to be dynamically allocated to EV charging

[a] In TN, these RCDs may not be necessary. In that case, Micrologic 7.2E may be replaced by Micrologic 5.2E, and NSXm Micrologic 4.1 by NSXm160 TM160D
[b] Schneider Electric type A RCDs can be connected in series with a type B RCD, with no blinding effect.

The electrical installation is sized for the complete power, including future extension, but with a diversity factor of 0.7, e.g. up to 160A for EV charging. A dynamic load management system will allocate 100% of the electrical installation's available power dynamically, therefore allowing the number of vehicles charged simultaneously to be increased when the other site's loads are not used.

The busway is sized for 160A.

All 7 charging stations can be used simultaneously but not at full charging power, up to a max total of 160A. With this solution, it is possible to supply 3 to 5 vehicles simultaneously and at full charge, according to the site's other load consumption.

This solution is suitable for installation where the peak building load is not correlated to car charging requirements: a hotel at night, for example.

Synthesis

For all 3 solutions: The 1A and 300mA RCDs shown on the single-line diagrams are type A (and not type B) only because these Schneider Electric type A RCDs can operate properly in the presence of the DC leakage current generated by the seven downstream charging stations protected by type B RCDs.

Table 5.1 – Overview of performance when fully equipped with 7 EV charging stations.

Solution	**Diversity factor**	**Busway sizing**	**Utility subscribed power**	**No. of vehicles charging simultaneously**	**Type of LMS**
Solution 1	1	250 A	250 kVA	7	no LMS
Solution 2	0.4	100 A	170 kVA	3	Static
Solution 3	0.7	160 A	170 kVA	3-5	Dynamic

Table 5.2 – Example of Schneider Electric busway capacity without and with smart charging station

Busway type	**Busway rating**	**EVlink Wallbox - Wallbox plus**				**EVlink Smart Wallbox**	
		Single phase		**Three phase**		**Single phase**	**Three phase**
		3.7kW / 16A	**7.4kW / 32A**	**11kW / 16A**	**22kW / 32A**	**7.4kW / 32A (8A)**	**22kW / 32A (8A)**
KNA63	63 A	9	3	3	1	3 (21)	1 (7)
KNA100	100 A	18	9	6	3	9 (36)	3 (12)
KNA160	160 A	27	12	10	5	12 (60)	5 (20)
KSA250	250 A	45	21	15	7	21 (93)	7 (31)

- The values indicate the quantity of EVlink Wallbox that can be installed on the busway, with the following assumptions:
  - network 230/400V,
  - single phase EVSEs distributed evenly on the 3 phases
  - diversity factor defined as 1 (no load management system, e.g. EV chargers always at full charging power, and all chargers can be used simultaneously)
- The additional numbers between parenthesis are for the same assumptions but for a maximum charging current limited to 8A.

Architecture with various charging time requirements: Example of a car dealership

Charging areas and charging capacity

Car dealers are faced with the following major trends:

- New models and enlarged offer portfolio.
- Expected volume growth for electric vehicles (both BEV and PHEV).
- EV battery capacities will increase substantially over the coming years.

As a result, car dealerships need an adequate charging infrastructure to get the EVs charged.

This charging infrastructure is created taking the assumed needs of the different areas and activities at dealerships where electric vehicles should be charged into consideration.

Table 5.3 – Example of EV charging requirements per zone/usage for a car dealership

Zone	EV charging requirements
Demo cars and company cars	The charging recommendation for demo cars and company cars will depend on their use. This application may require relatively rapid EV charging (22kW AC or more) during the day.
Delivery area for new cars	New cars are usually partially charged before delivery to retailers. They should be fully charged (at 100%) before delivery to the customer. This type of charging can be done at night, at the 7.4kW power range.
Test drives	Electric vehicles for test drives should be charged rapidly in order to maximize their availability. The main charging can be done at night. A top-up charge may be required during the day. The charging should be relatively rapid in such cases – for example, 22kW AC charging.
Courtesy car service	Both BEV and PHEV courtesy cars should be fully charged before delivery. The charging could be done at night at 7.4kW or 22kW.
Serviced and repaired customer cars	Serviced and repaired customer cars should be fully charged after maintenance for premium customer service. Ideally, the charging should be done in a few hours, usually during the day, with EV charging stations at 22kW. Additional DC EV supply equipment may be required to perform tests with DC charging (e.g. 50kW DC)
Customer parking (part of BMW Retail Standards)	Car dealership customers may need to charge their electric vehicle during their visit. This charging will be done during the day. For premium customer service, the use of a 22kW EV charger is recommended.
Employee parking	Car dealership employees should have the opportunity to recharge their electric vehicles at their workplace. As employees' cars will stay in the car park for several hours, the EV chargers could be in the 7.4 kW power range. The charging is done during the day.

Example of EV charging infrastructure design

The figure hereafter presents an example of an EV charging infrastructure corresponding to the described assumptions.

All EV loads are connected to a new Main Low Voltage Switchboard (MLVS).

- Each EV circuit is protected by a circuit breaker and a 30mA type B residual current device (RCD), as required by IEC 60364-7-722 (check whether an RCD is already integrated into the EV charging station).
- EVSE should be protected against transient overvoltages due to lightning strikes. Surge protection devices may be required on the EVSE depending on the building's lightning protection, the location of the EVSE (indoor or outdoor), and the distance between the EVSE and the SPD at the LV switchboard.
- EVSE should provide means for automatic disconnection
- Residual current and overcurrent protection can be combined in one device (as in the EVSE 150 kW circuit). It should be checked whether the EVSE has built-in galvanic isolation between the AC and DC side and the protection equipment selected accordingly.
- As there are several single-phase EVSE of 7.4kW, it is recommended these are connected equally among the 3 phases to avoid imbalance.
- As there are several EVSE located in the same area (customer parking), it could be worth installing an LV sub panel nearby for these EV loads in order to optimize the quantity and length of cables.
- As there are several EVSE located in the same area (employee parking), a busbar trunking system can be used to provide a flexible, cost-effective and future-proof solution
- As the existing dealership installation is connected to the new main LV switchboard, overcurrent and residual current protection selectivity need to be considered.

The new EV loads increase the power demand significantly. An additional photovoltaic system and storage can help to partially compensate for the increased power demand.

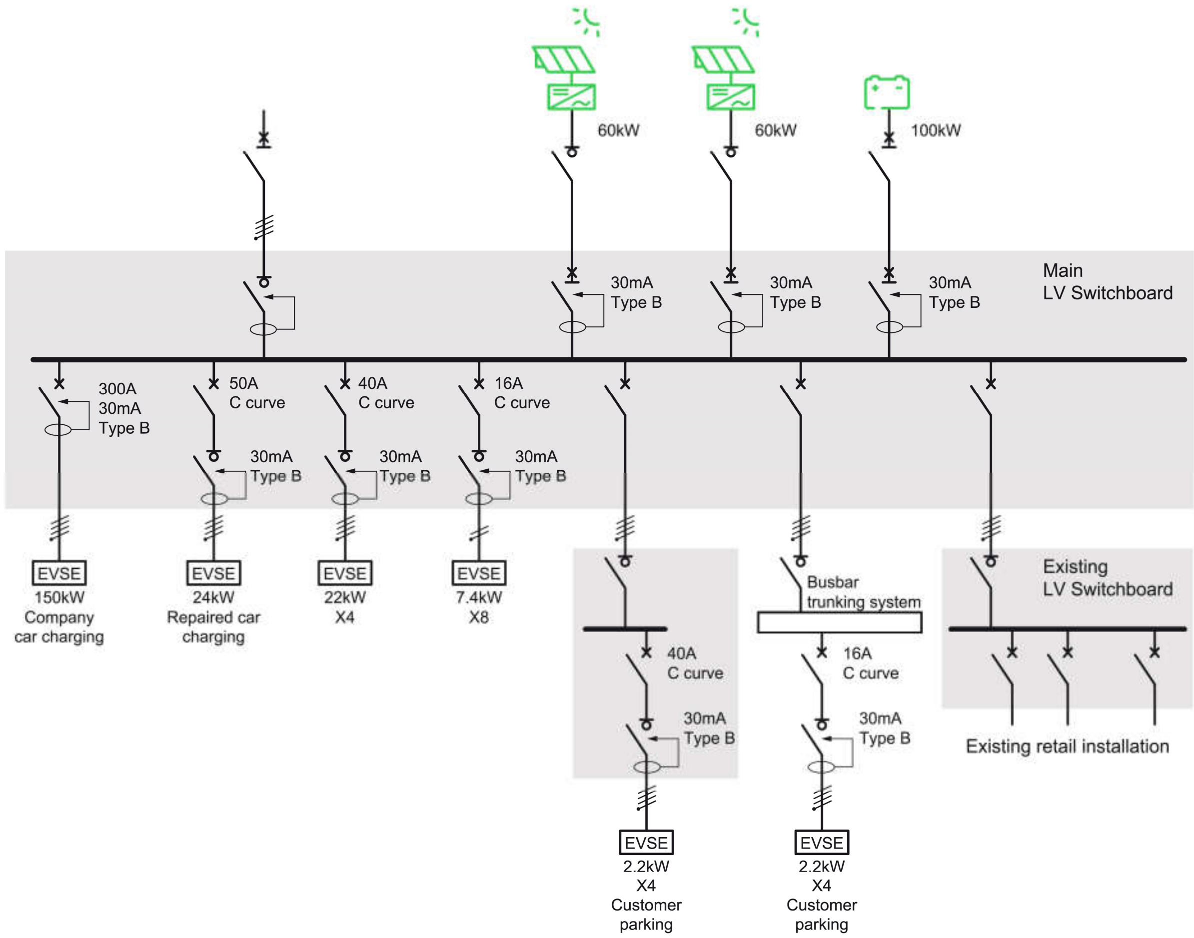


Fig. 5.7 – Example of EV charging infrastructure for a car dealership, taking into account the different charging needs per zone/usage.

Chapter 6-EV Charging-Energy and Asset Management

Electric Vehicle charging (EV charging) is a **high power load** (for example, up to 22kW for a charging station in mode 3). It is also a **controllable and shiftable load**.

This is why EV charging Energy Management is a must and plays an essential role on the demand side to optimize energy cost and usage and on the grid side to contribute to the grid balance.

Also, with the booming of EV adoption, the **availability of EV charging points** becomes essential for EV driver's satisfaction.

This makes EVSE asset management (Electric Vehicle Supply Equipment) a must for charge point operators to optimize the usage and profitability of their EV charging infrastructure.

6.1 EV charging Energy Management.

EV charging is a new kind of electric load, with unique characteristics in terms of where and when it is used, but also in terms of variable power and energy demands. It is worth noting that its connection to new or existing electrical installations may have a significant impact on the overall power distribution system.

Power management of EV charging stations is therefore essential in order to minimize the impact on the existing or new electrical infrastructure while distributing available energy between all connected loads.

There are 3 main levels of power management, depending on the set objective:

- Static Load Management: limits the power drawn by the EV charging loads to a fixed power level
- Dynamic Load Management: optimizes energy use at the building level and allocates available building power to the EV charging loads
- Artificial Intelligence-based Load Management: optimizes energy use and costs based on EV planning, energy tariffs, local production and energy consumption forecasts

These power management levels are detailed in this section. You can also check this example with 3 EV infrastructure scenarios: it is the same application, implemented without a Load Management System (LMS), with static LMS and with dynamic LMS, to illustrate how it can impact the electrical installation sizing.

EV charging management may also be part of a larger eco-system, such as integration into a next-generation Building Management System (BMS), contributor to Demand Response for Smart Grid ...

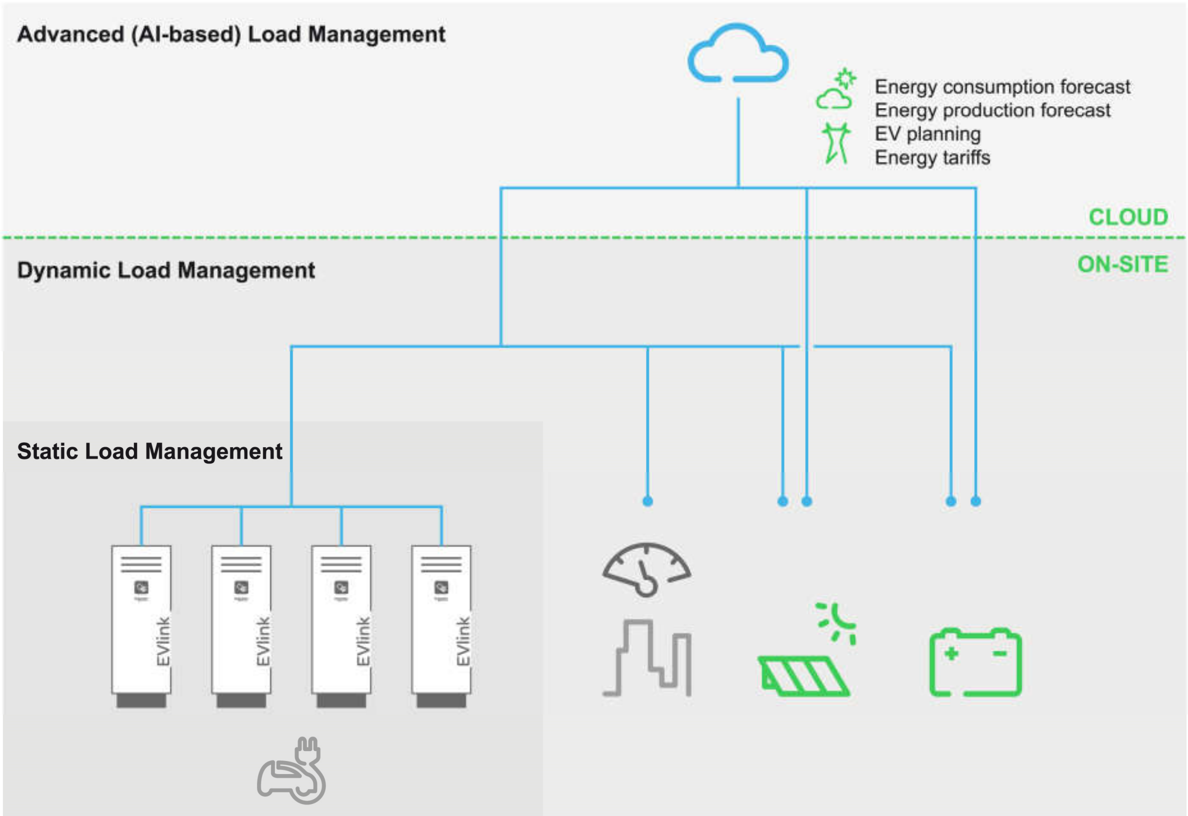


Fig.6.1 – The different levels of EV charging power management

EV charging with STATIC Load Management

In static mode, the Load Management System regulates and distributes energy evenly and in real time between all connected vehicles so as not to exceed the general STATIC setpoint for the vehicle loads.

Example: In a building, a static setpoint of 100 kVA is defined as the power available for the EV chargers, and there is a requirement to install 10x 22 kVA charging points. With the energy management system, regardless of the number of terminals (EV chargers) that are being used simultaneously, it ensures that the 100kVA limit is never exceeded and that any risk of tripping is avoided.

The current setpoint for each of the charging points is transmitted in real-time to the electric cars, which have 5 seconds to apply it. If this instruction is not applied by the car, then the charge point contactor will be instructed to open the circuit.

This allocation method allows you to:

- Evenly distribute available energy between all vehicles that are being charged.
- Sequence loads between the vehicles that are connected simultaneously.
- Optimize occupant comfort by ensuring that the main power supply does not trip as a result of an influx of vehicles requiring a recharge.
- Reduce the cost and dimensions for the electrical panel dedicated to the power supply of the electric vehicle charging network (100 kVA in this example).

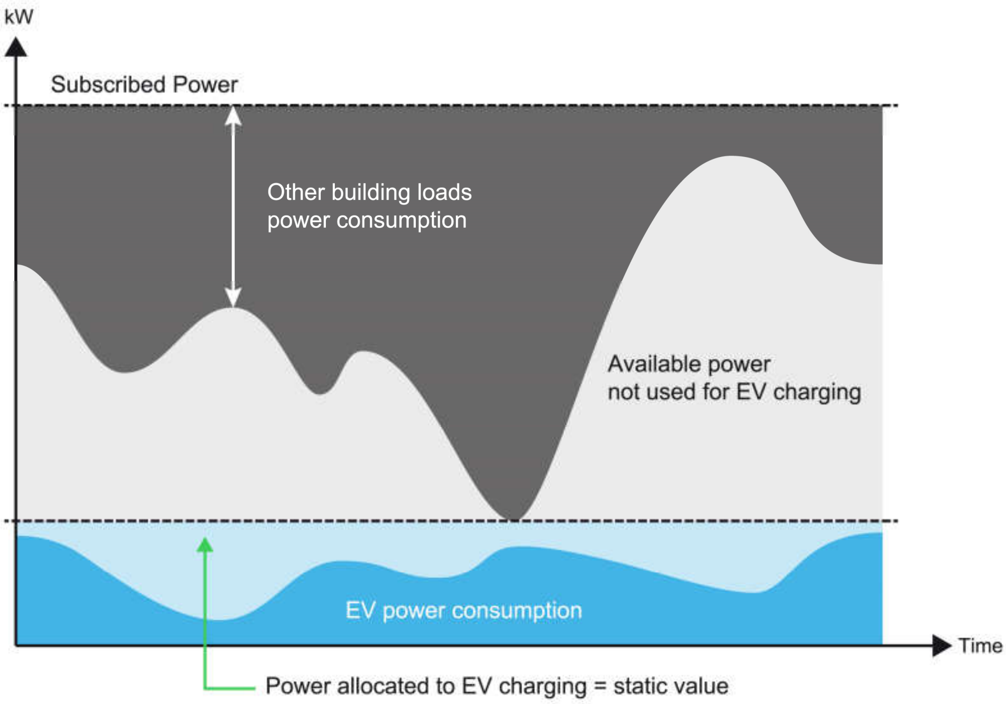


Fig.6.2– EV load management with static setpoint

EV charging with DYNAMIC Load Management.

In dynamic mode, the Load Management System allocates available on-site energy in real-time to the electric vehicle charging network. In doing so, it also temporarily limits the charging power to meet the energy constraints imposed by the rest of the electrical installation. Conversely, the power allocated may be higher at times when energy consumption for the rest of the electrical installation is low.

Example: The total power of the building is 250 kVA, and the objective is to install 10x 22kVA charging points. With this system, whatever the load of the building and the number of terminals (EV chargers) used at the same time, total consumption must never exceed 250kVA by instructing the terminals to adapt in real-time to the other loads of the building.

The current setpoint for each charger is transmitted in real-time to the cars, which have 5 seconds to apply it. If this instruction is not applied by the car, then the charge point contactor will be instructed to open.

This allocation method allows you to:

- Evenly distribute available energy between all vehicles being charged.
- Sequence the loads between the connected vehicles simultaneously.
- Optimize occupant comfort by ensuring that the main power supply does not trip as a result of an influx of vehicles requiring a recharge.
- Control energy costs by subscribing to the optimal energy contract from the energy supplier (which may not be applicable in countries where the energy contract has no limit).

To determine, in real time, the DYNAMIC setpoint allocated to the charging infrastructure, the system must measure the available power at the building level.

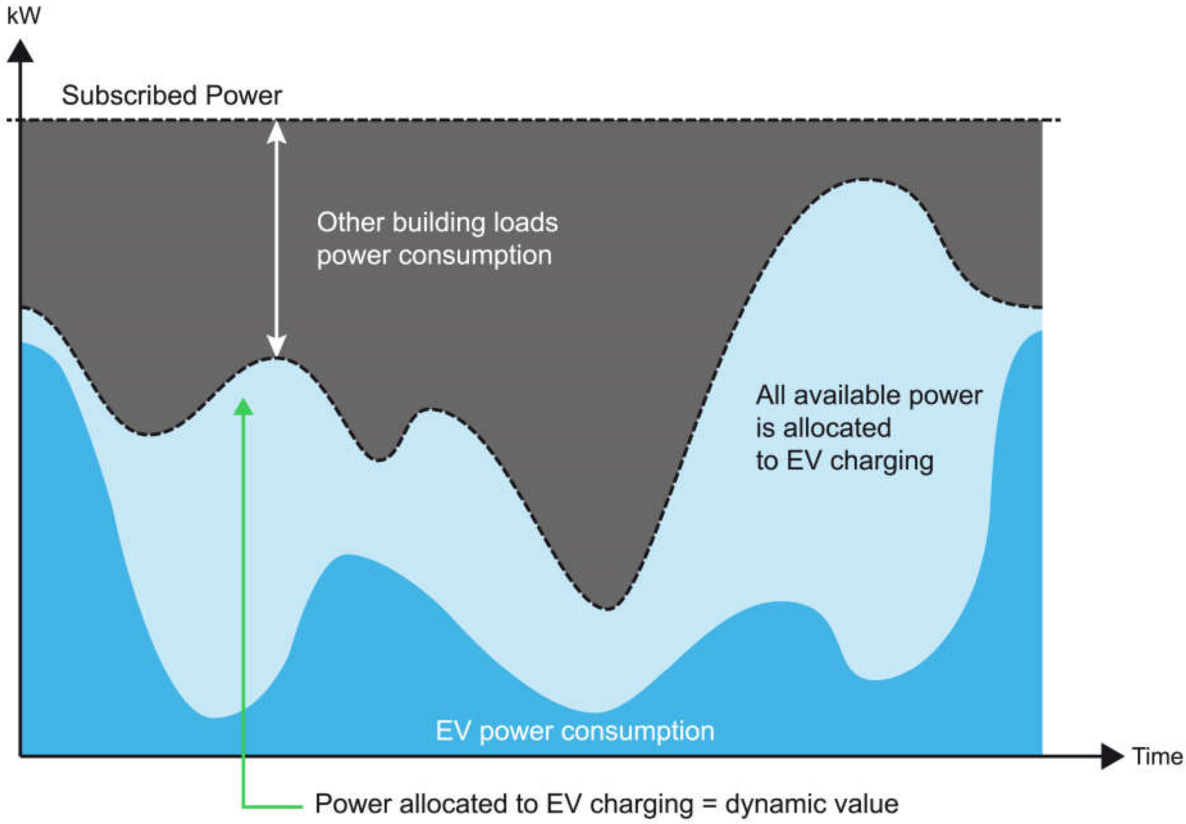


Fig.6.3– EV load management with dynamic setpoint

Dynamic load management with additional power from local production

In case of the presence of a renewable energy system in the building, the Load Management system can also measure this local production and take it into consideration as additional available power for the charging stations.

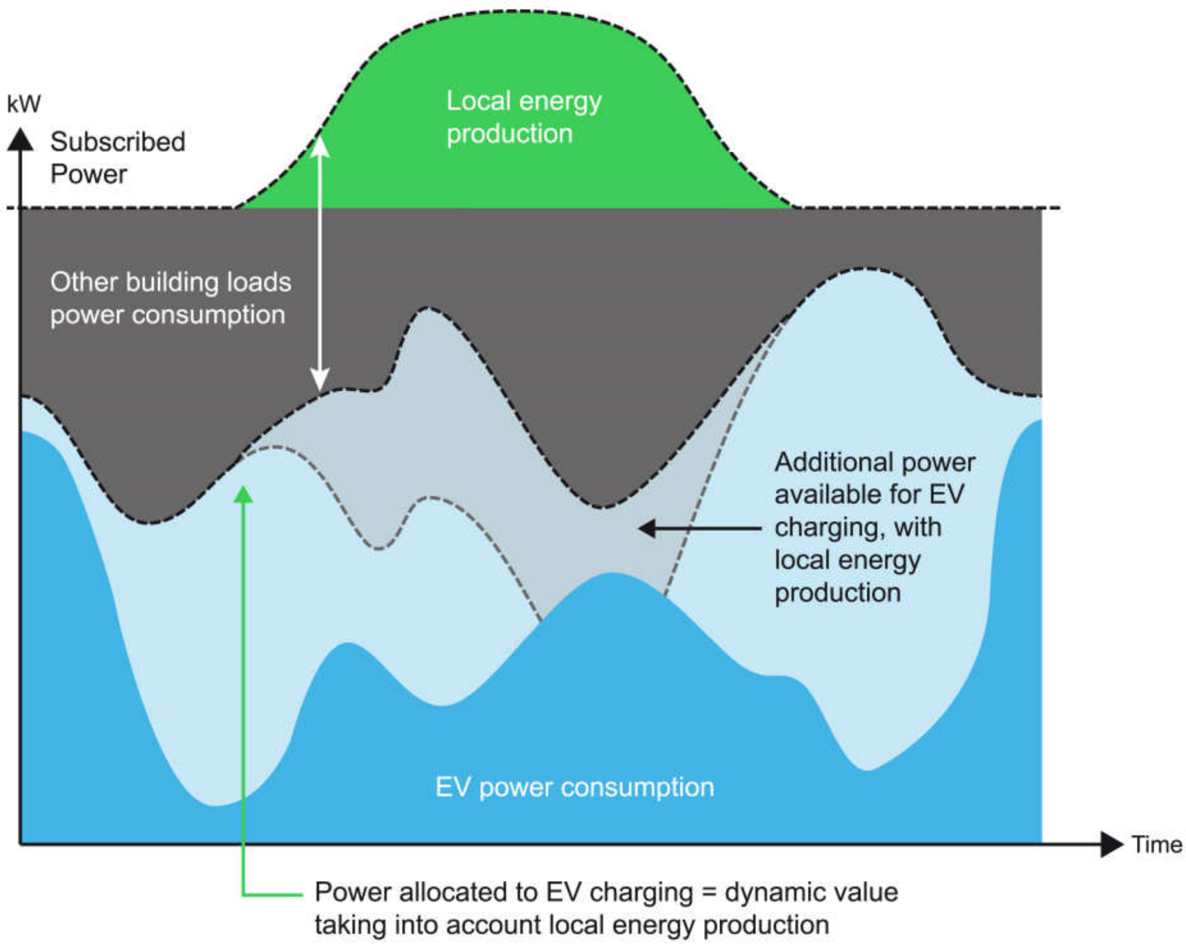


Fig. 6.4 – EV load management with dynamic setpoint, including the additional power from Local Production.

Demand Response - Peak Shaving applied to EV charging

Distribution Network Operators (DNOs) regulate energy intake according to peaks and lows in energy demand. Operating that way, DNOs provide more reliable services to their customers.

Electrical Vehicles (EVs) simply plug and charge, taking from the grid all the energy they need to. Smart charging allows the grid operators to optimize energy flow into EVs. When needed, smart charging reduces demand on the grid as a form of demand response.

Thanks to demand response, Charge Point Operators (CPOs) act with Distribution Network Operators (DNOs) in adjusting the energy demands of the EV charge point network.

EV charging - Artificial Intelligence-based Load Management

Principle

Advanced AI-based EV charging management is used to generate an optimal dynamic setpoint based on a number of criteria. These include electric vehicle planning, grid energy tariffs, prediction of building consumption, and prediction of local energy source production, if any.

Advanced AI-based EV charging management usually relies on two techniques: forecast and model predictive control.

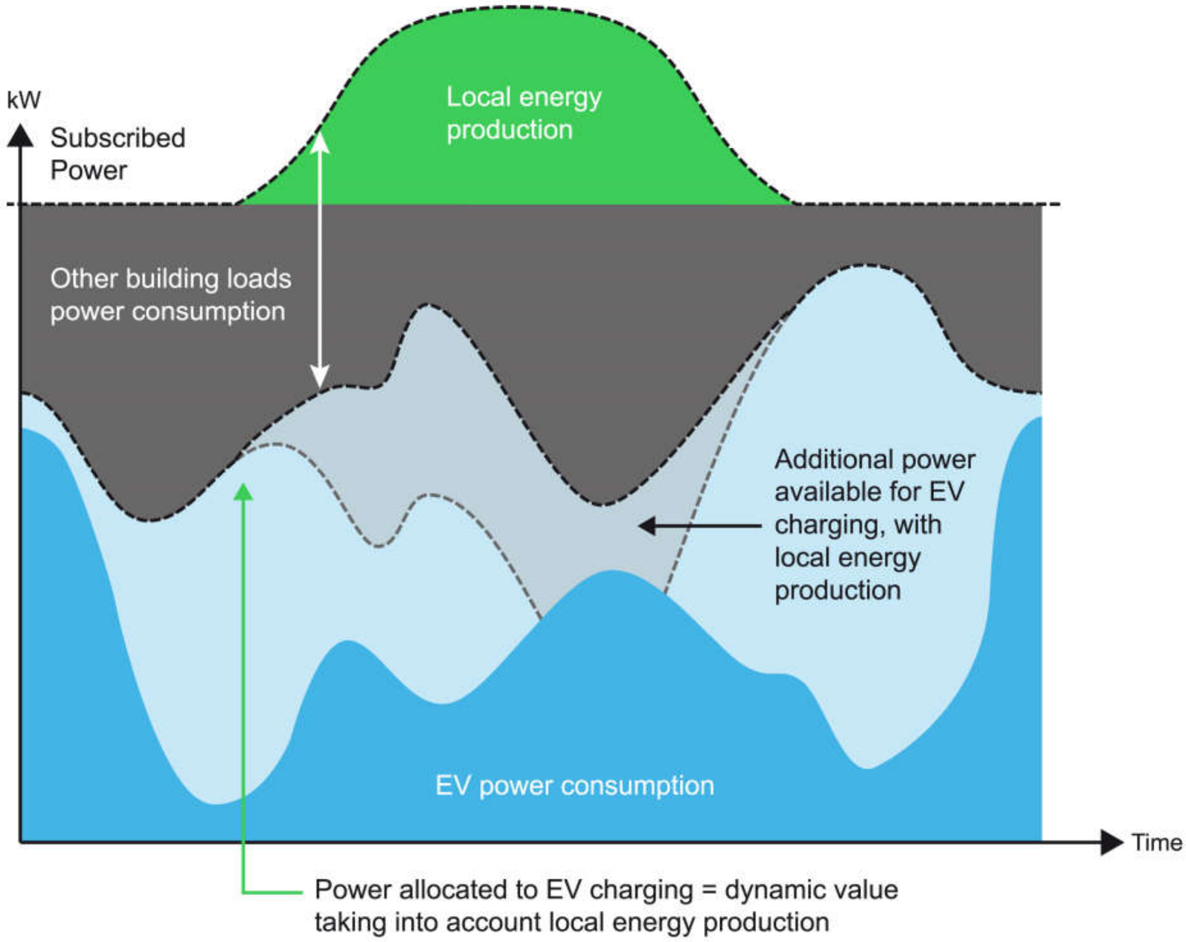


Fig.6.5– Advanced AI-based EV charging management with forecasting and predictive control

Forecasting energy consumption, EV charging needs and local production

A forecasting component is used to predict local energy demands and local energy production. This enables short-term energy resource planning and optimized local energy use.

The forecasting component uses supervised machine learning techniques to learn the relationship between the variables at hand and the variable we intend to forecast.

Photovoltaic production forecasting is similar to the solar radiation forecast provided by a weather forecast service.

Building energy consumption and EV charging needs can be forecasted based on historical energy consumption that identifies recurrent patterns. This forecast can be improved by adding additional drivers like weather forecast information or EV charging planning.

The accuracy of the forecast is critical for an optimal Model Predictive Control.

Model Predictive Control

Model Predictive Control (MPC) techniques can be used to optimize energy usage over the following 24 hours by anticipating energy demands (EV charging and other loads) as well as local renewable production.

The Model Predictive Controller relies on:

- A model with the description of the electrical network, the assets' characteristics and constraints that should be respected.
- Forecasts over the following 24 hours include the energy consumption of the installation, EV charging demand, photovoltaic production, and grid energy tariffs.
- Knowledge of the assets' current state, for example, the state of charge of the electric cars or Energy Storage System.

By updating the local controller based on the latest site measures and updating forecast information every 15 minutes, the AI-based management can continuously adapt to prediction and model errors to ensure optimal closed-loop control performance.

Optimize usage with local source/microgrid/demand response

Microgrids are integrated energy systems consisting of a group of interconnected Distributed Energy Resources within clearly defined electrical boundaries that act as a single controllable entity with respect to the grid.

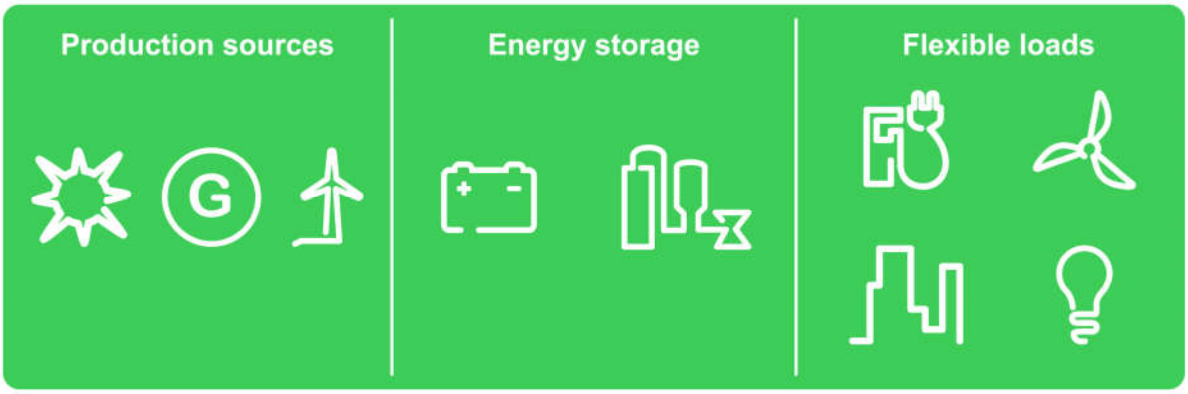


Fig. 6.6 – Elements of a microgrid.

New EV loads need to be managed according to the operational activity of the building, and at the same time, they have to be coordinated with other energy sources, like photovoltaic or battery storage, in order to optimize energy as well as energy-related costs.

In such a scenario, two systems are required to efficiently manage this group of Distributed Energy:

- A Load Management System is needed to control and split the EV charger's power demand and to manage the charging priority of the fleet.
- A Microgrid Advisor Solution is required to manage the energy of the different sources, based on the forecast of the fixed loads of building energy, and to manage the flexible loads (such as EV and HVAC) to optimize the contract with the utility.

Integration of EV charging into a Building Management System (BMS)

The building management system (BMS) is a critical tool for operating a building safely, efficiently, and reliably. However, a higher expectation of energy efficiency and sustainability combined with fundamental changes in tenant needs are straining traditional BMS implementations, pushing them to grow and evolve. At the same time, advancements in cloud computing, IoT, analytics, and artificial intelligence are leading to new and broader capabilities. With these as underlying technologies, next-generation BMSs become the integration and aggregation tool for all the building's data across multiple business and operations technology systems and sensors.

Sometimes, a traditional BMS integrates with other systems, but usually, this just means data points are pulled from the system and displayed in the BMS software for added context or situational awareness. Next-generation BMSs take this integration much further. Not only does it interact with more systems, but the connection is more tightly integrated in that the data can be combined with other system data and used for analytics, AI, and digital services that make operations more proactive and predictive.

To improve the energy usage and accountability of the building, the EV loads need to be integrated into the next generation of BMSs.

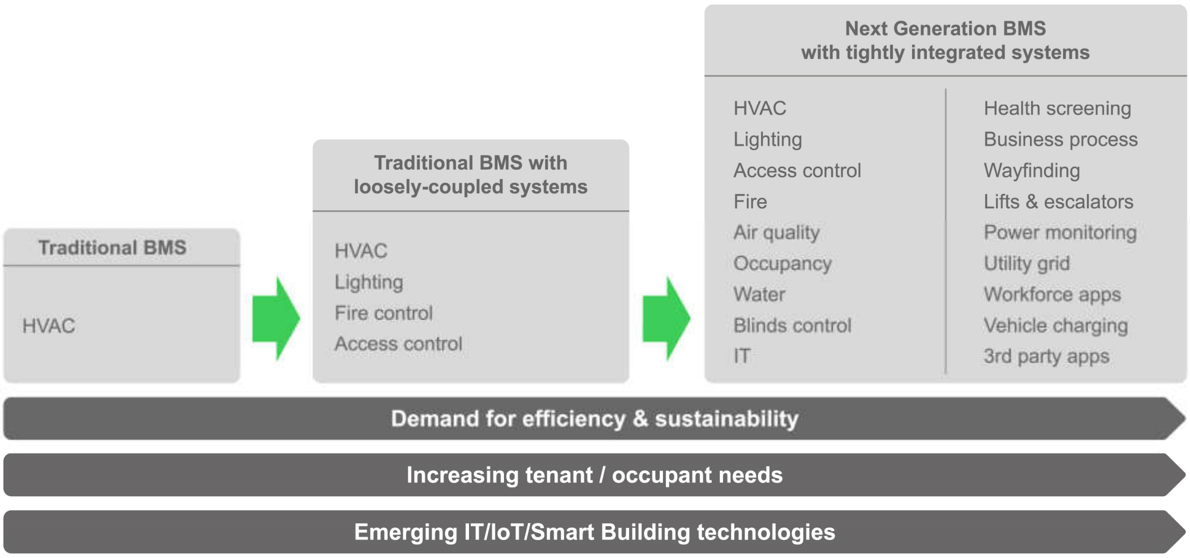


Fig.6.7– The scope of BMS implementations and depth of integration with other systems is evolving

6.2 EVSE Asset Management

Asset management refers to the process of installing, operating, and maintaining in a cost-effective manner. Most commonly used in finance, the term is used in reference to individuals or firms that manage assets on behalf of individuals or other entities.

Every infrastructure owner, individual or company needs to keep track of its assets.

Asset management is about processes to optimize the cost of my assets (CAPEX + OPEX) to support my business.

With the advent of Digital Solutions and the Internet of Things (IoT), asset managers often rely on dedicated software platforms to support their processes.

Asset management is key for Charge Point Operators to maximize chargers' availability and revenues associated while reducing their costs.

The asset management activity is built around 2 main families of services, which are described in the table below:

Table 6.1–Asset management activity main families of services

Asset Performance Management	Enterprise Asset Management
Asset Strategy and Risk Management	**Maintenance Scheduling**
Aggregation, analysis and correlation of asset information based on usage, status, and health to optimize Opex, reduce risk, and help optimize Capex over the long term	Assembling and coordinating the information, people, materials, and Equipment, along with all the other necessary resources (software planning, remote monitoring, etc.)
Reliability-Centered Maintenance	**Processes centralization**
Provides a structured framework for analyzing the functions and potential failures of a physical asset with a focus on preserving system functions rather than preserving Equipment	Centralizing workflows to perform maintenance and run operations in order to standardize and increase efficiency (e.g. cloud, hosted solution to standardize across organization)
Predictive and condition-based maintenance	**Data aggregation for Equipment**
Monitors the actual condition of an asset to decide what maintenance needs to be done, predict the likelihood of future failures, and determine asset failure factors that could impact plant or business operations	Component and asset tracking, health status, compliance, lifecycle management, updating asset records, etc.
Condition monitoring	**Data aggregation for mobile workforce**
Real-time measurements (e.g. charging power, temperature, or vibration) on a piece of Equipment	Skills management, enablement of remote assistance based on capabilities (AR, VR, Remote services), etc.

Asset management applied to EVSE.

EVSE asset managers will build their management plan with a subset of the upper-listed services by balancing the risk on the operational performance of the assets against its lifecycle cost.

- **Individual, standalone stations** tend to require relatively little maintenance over the course of their lifetimes. Typically, these EV chargers do not need many repairs or maintenance in and of themselves.
- **Charging stations, which are in public spaces and parking lots**, require more attention. Because these are larger units with more components, the chances that an individual component

malfunctions are somewhat higher than with a privately owned charger. Depending on the usage, the socket that is installed with the units could be replaced periodically.

- **DC Fast Charging stations** will certainly require more maintenance and repair over time. In fact, these units require continual maintenance due to their complexity. Superchargers require filers, cooling systems, and other advanced parts to function properly. Operators of such charging stations must work with manufacturers to establish a service program ahead of installation, as the extent of the electric vehicle charging station maintenance you'll require will vary based on location and anticipated frequency of use.

Several factors can play a role in the condition of the unit and the degree of EV charger repair you'll need over the lifetime of the unit, including frequency of use, climate, and whether the unit is covered or exposed to the elements. Generally, the units should be kept clean by wiping them down with a damp cloth, and any accessible parts need to be checked on occasion for basic wear and tear.

Therefore, **having a plan to protect your EV charging assets is key to the success of your charging infrastructure**.

This plan includes various activities that can be done on-site or remotely:

- Error diagnostics and troubleshooting
- Root cause failure analysis — Actions taken to determine why a particular failure or issue exists and correcting those causes
- Upgrading the charging station with the latest firmware and benefitting from additional features
- Restoration of factory default settings
- Changing spare parts

Corrective maintenance

Corrective maintenance is the category of maintenance tasks that are performed to rectify and repair faulty systems and Equipment. The purpose of corrective maintenance is to restore systems that have broken down.

Corrective maintenance in the case of EVSE

In many cases, a local electrician can troubleshoot problems with the units. Software Platforms also offer remote options that can reduce long-term maintenance costs.

When a product is connected, an alarm is created in the logs, and the team in charge of the maintenance could be notified to manage this event.

When an issue is raised, the first task of the maintenance is to diagnose the problem, usually with some specific tools.

Then, there are mainly 3 ways to solve an issue as per the corrective maintenance of the charging station:

- **Hardware change**: According to the type of products and type of defect, we see either a replacement of the charging station, especially with basic Wallbox or a replacement of a specific part (socket, RFID reader …)

- **Configuration update**: A defect could be triggered by a misconfiguration of the product. Changing the configuration of the product is sometimes a way to fix a defect.
- **Software update:** Issues are sometimes due to bugs in the firmware of the charging station. Updating to a new firmware solves bugs and usually fixes problems.

Configuration and firmware updates could be done on-site or remotely if the product is connected. When products are connected, maintenance could be done product by product or simultaneously on a set of products which face the same issue.

Preventive maintenance

The next level of maintenance is to prevent any unplanned downtime and expensive costs because of unexpected equipment failure. Preventive maintenance requires careful planning and scheduling of maintenance on Equipment before a problem arises, as well as keeping accurate records of past inspections and servicing reports.

As you can see on the graph, the optimal zone is when you have effective preventive maintenance tailored to the products that you are managing. This mode of maintenance would be even more efficient when the charging station is connected to a remote maintenance platform.

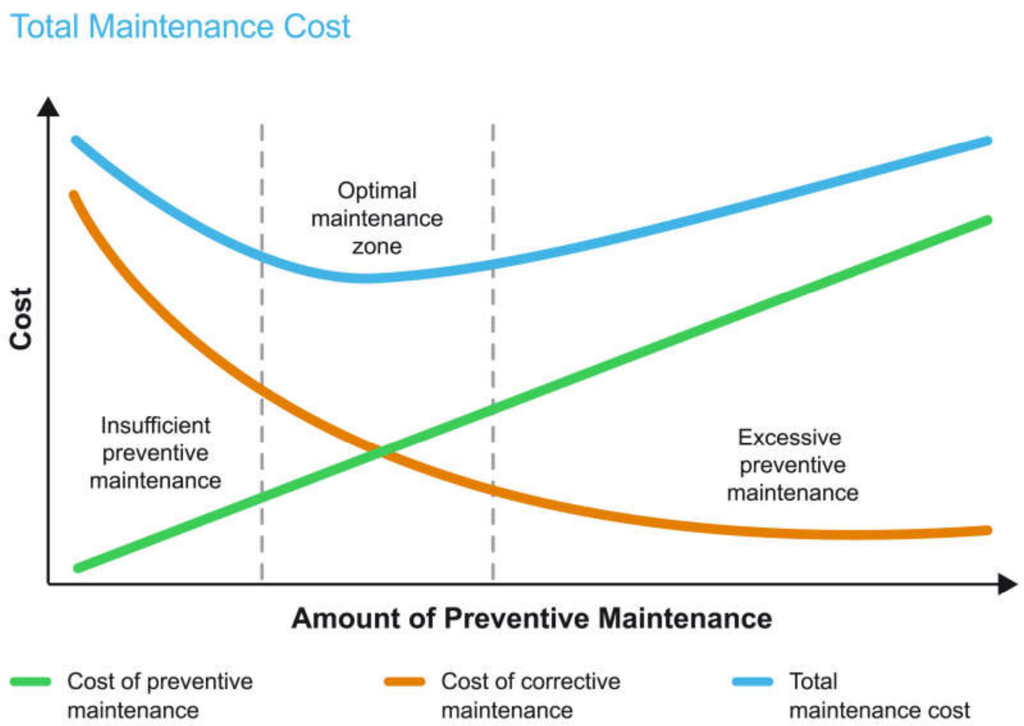


Fig. 6.8– Optimization of the asset's total maintenance cost

Preventive maintenance in the case of EVSE

Having a charging station connected to a remote platform provides reports that track usage, performance, and efficiency to help you better understand which units are being used with the most frequency as well as which units are performing optimally and which are not. You can also tap into the power of the users: with connected solutions, drivers could report violations, station misuse, or maintenance concerns so you can address EV charger repair issues before they become more serious problems}}.

Having a digital logbook is the right approach for efficient preventive maintenance. The digital logbook is a collaborative tool that keeps records of important documentation and maintenance schedules.

The creation of the Digital Logbook ensures the availability of project lifecycle documentation, including the single-line diagram, maintenance plan, and more.

- Track your assets for long-term maintenance schedules and task reminders.
- Log and access asset history, maintenance procedures, and collaborative information.
- Generate inspection and activity reports.
- Identify maintenance status.

Predictive maintenance

Predictive maintenance technologies enable companies to perform an effective amount of maintenance at an appropriate or practical time. Often referred to as condition-based maintenance, predictive maintenance tools monitor the condition of in-service Equipment, either continuously (connected products) or at periodic intervals. Having regular access to the current state of the Equipment provides valuable information, making it possible to reduce the disruptions of the EV charging infrastructure.

Predictive maintenance in the case of EVSE

Estimating and projecting equipment condition over time will help to identify particular units that are most likely to have defects requiring repairs. Such an exercise will also identify units whose unique stresses (i.e., a charging station that has a high number of sessions that often faces issues in locking a cable) have an increased probability of future failure. A condition-based maintenance method also identifies, through statistics and data, which equipment components most likely will remain in acceptable condition without the need for maintenance.

Maintenance can, therefore, be targeted where it will be more effective.

Condition-based maintenance data that is useful and available to help estimate the condition of the Equipment includes the following:

- Age.
- History of operating experience.
- Environmental history (temperature, voltage, run-time, abnormal events).
- Operating characteristics (private vs. public, low activity vs. High activity).

Chapter 7-Smart charging perspectives for optimal EV integration

7.1 Defining smart charging

Smart charging is a broad term that captures methods of shifting or modifying EV charging based on grid and market conditions. All EV charging points, whether in public or private locations, are concerned.

There are multiple definitions and concepts around smart charging. Here is the one proposed by IRENA[1], which defines 5 EV charging options to provide flexibility services.

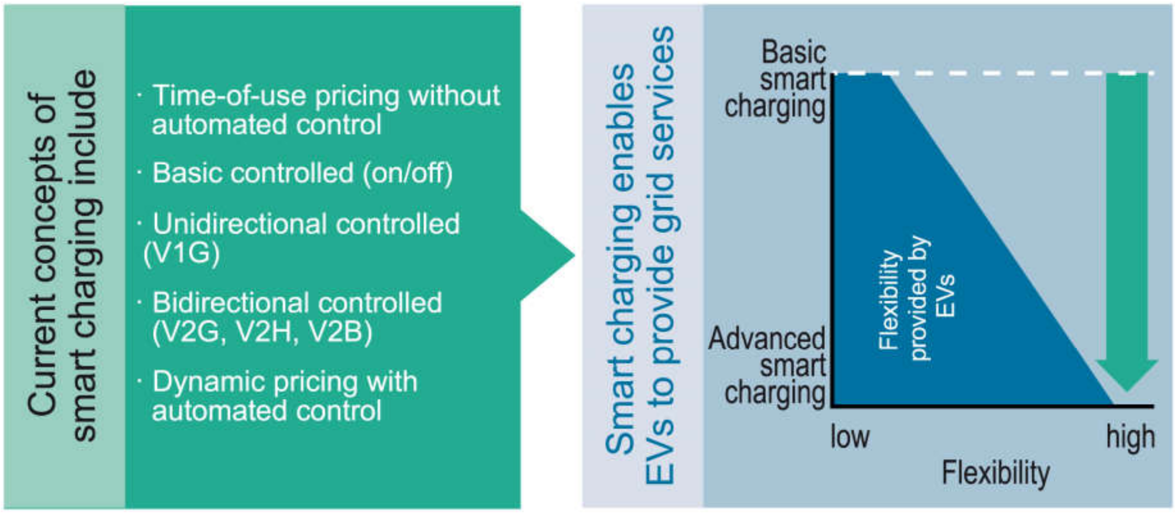


Fig.7.1– Example of smart charging options to provide flexibility services (source: IRENA[1])

There is an ongoing debate on the hierarchical position of V2G vs smart charging: Is V2G a specific, separate charging application, or just one option of the whole smart charging concept? The vision reflected above tends to include V2G as part of the smart charging.

7.2 Advanced smart charging: V1G, V2x options

While most home chargers offer basic on/off control, advanced chargers provide more sophisticated controls that provide benefits for multiple stakeholders.

V1G manages the power step-wise in a unidirectional manner.

V2x (including V2G) offers the same principle as V1G both in charging and discharging mode.

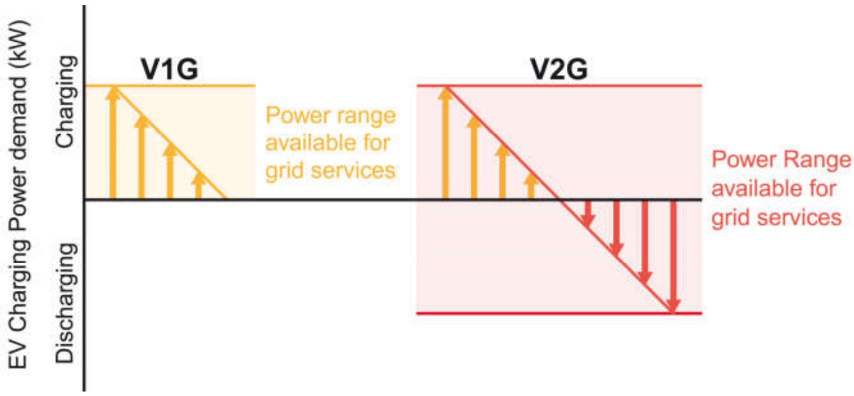


Fig. 7.2– Example of unidirectional (V1G) versus bidirectional (V2G) grid services provision (source: IRENA[1])

While V1G is not as popular as V2G in the media hype, it already offers interesting value for grid and building stakeholders and is not subject to the regulatory and grid code barriers applicable to the more disruptive V2G concept.

V2x: the most advanced form

Vehicle-to-Everything (V2X) is an umbrella term to explain the use of EV batteries to provide energy services and derive additional value from the battery asset during times of non-use.

V2X services aim to generate revenue from the battery asset through dynamic or bi-directional charge control to provide benefits to the electric grid or to reduce/flatten/shift peak energy consumption of buildings and homes.

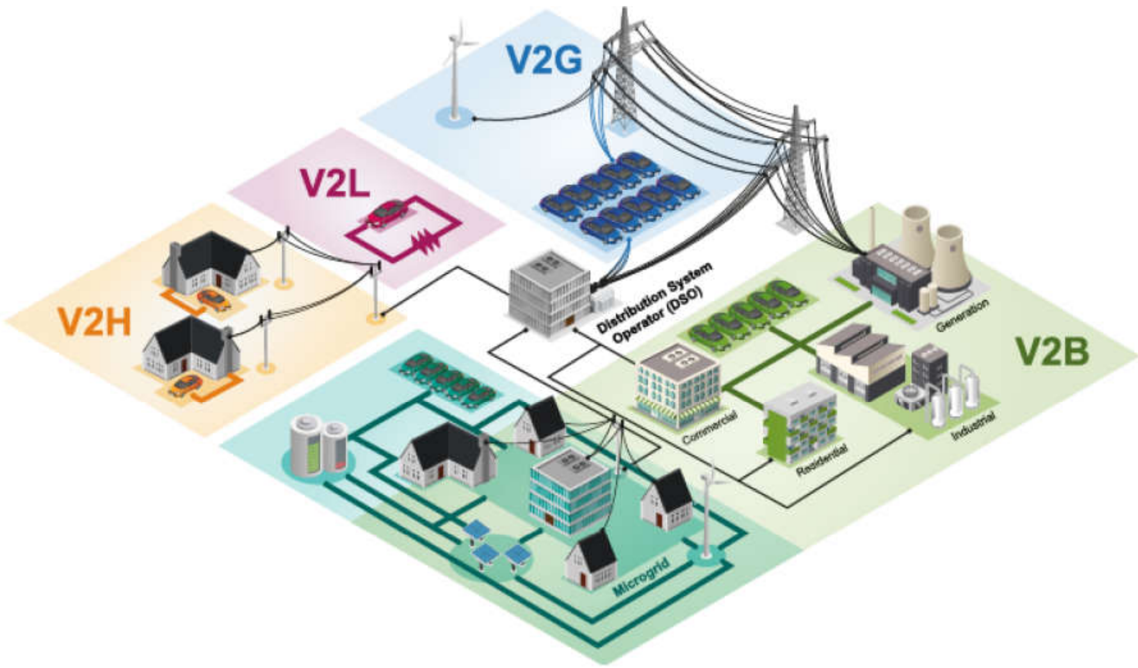


Fig.7.3 – V2X Topology Explained[2] .

Microgrid operation is classified as a special use-case of the V2B Topology expressed by the colour overlap of green shades.

Coloured connections indicate interactions within the topology, whereas black connections indicate connections/interactions with other grid elements.

We feature the Distribution System Operator (DSO) as a central figure due to the unique role of the distribution system in enabling much of V2X capability.

V2X can be classified into the following operating modes:

- **Vehicle-to-Grid (V2G)**: Using an EV battery to interact with/provide value to the electric grid (frequency control).
- **Vehicle-to-Building (V2B)**: Operating EV batteries to optimize building energy consumption.
- **Vehicle-to-Home (V2H)**: Optimizing home energy consumption or using EVs as emergency backup power.
- **Vehicle-to-Load (V2L)**: Any other instance of an EV battery providing energy to a load.

EVs located 'behind the meter' in homes and buildings have a dual value: optimizing their own energy consumption as well as interacting with the grid.

V2G is seen as a 'panacea' by grid operators since the EV battery offers the same functionality as a stationary battery for ancillary services such as frequency response.

7.3 Value of smart charging

Early forms of smart charging with Time-Of-Use pricing offer limited benefits in utility peak load reduction.

Advanced forms (V1G, V2x) reveal a much stronger value for all grid stakeholders.

For utility distribution network operators: more hosting capacity, faster implementation, less costs

- Differ or avoid grid reinforcements at a cost of 10% of the total cost of reinforcing the grid.
- Enable a much greater EV hosting capacity at the local level without distribution network reinforcements.

For utility transmission system operators:

- Limitation in system peak load, avoid construction of generation capacities (peaker plants)

For building managers: EV flexibility ideally complements other energy resources such as rooftop solar PV, CHP, stationary batteries, and flexible loads to optimize building own energy costs and monetize flexibility in utility demand response programs.

- Time Of Use tariff optimization: shifting building consumption to off-peak periods.
- PV balancing/optimization, maximizing self-consumption.
- Demand Charge Management & Demand Limitation.
- Load Balancing, reduction of connection fee.

7.4 Strong barriers to smart charging

While many recent studies at the regional or country level reveal strong benefits in EV hosting capacity and system cost reductions, the concept still faces many barriers at various levels.

Here are some of these limitations captured in the studies:

- First and above all, is the EV driver himself ready to allow control over his critical charging process?
- Many regulatory and legal barriers.
- Dynamic pricing needs smart meters in place with dedicated rates for EV charging.
- There is no obligation for smart EV chargers due to cost burden: many new chargers are still 'dumb'.
- Lack of standards: mainly in communications infrastructure, billing/roaming, data semantics…
- Cybersecurity compliance.
- Data privacy in some regions.
- Charges applicable to V2G ('double charging'), grid code limitations.
- High cost of bidirectional chargers for V2G.
- Space for aggregators managing fleets of EVs, ability to stack revenue of EV flexibility

Finally, smart charging is about an incredibly complex interaction between stakeholders from different industries: Grid stakeholders (incumbent utility companies, new aggregators…), IT/communications, services providers, and automotive OEMs. Each of them has a specific culture and interests.

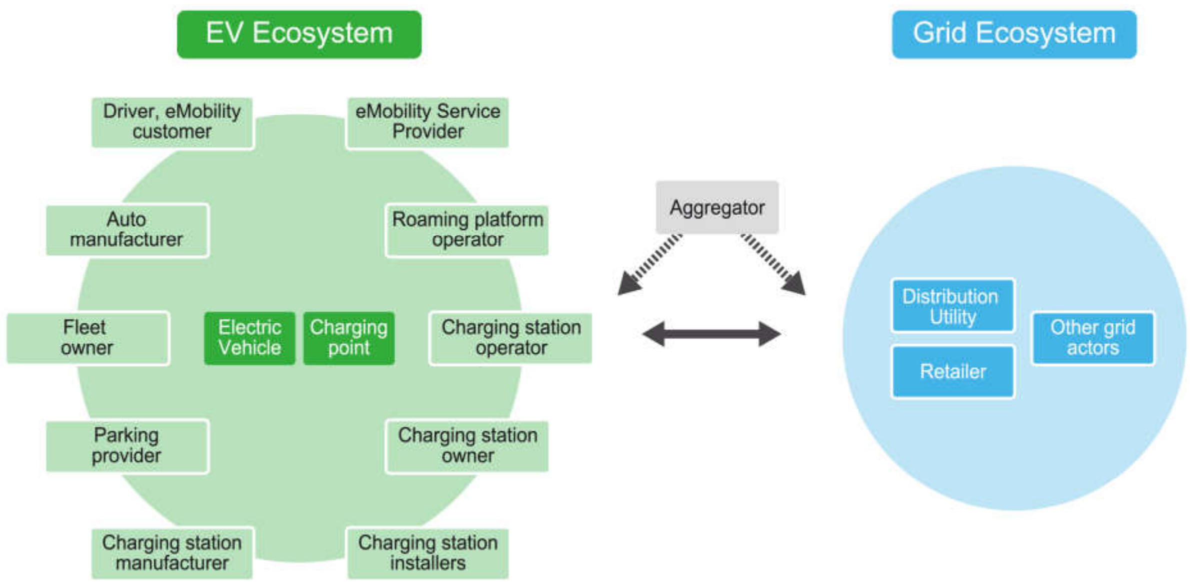


Fig.7.4 – A complex ecosystem.

Smart charging will be about a system-wide orchestration of this ecosystem, with clear rules and responsibilities for each stakeholder.

7.5 How soon will smart charging happen?

It all depends on policy mandates at the state or country level for mass EV roll-out.

For instance, some European policymakers stress the need to accelerate EV adoption to meet decarbonization targets, imposing conventional vehicle ban on a rather short-term horizon: originally in 2040 in many member states, sometimes in 2035 or even earlier.

As the policy pressure mounts, interest in defining a local smart charging frameworks grows. It's about scaling the right infrastructure at the right time and the right cost to generate EV driver satisfaction in his new e-mobility experience.

A big challenge ahead for the whole EV ecosystem, including building managers.

Notes

1. Innovation Outlook: Smart charging for electric vehicles, IRENA
2. Andrew W. Thompson, Yannick Perez (2020), Vehicle-to-Everything (V2X) energy services, value streams, and regulatory policy implications