Electric Vehicle Charging

Frederico Moura
MEEC – Automação & Sistemas
ISEP – Instituto Superior de Engenharia do Porto
Porto, Portugal
1070950@isep.ipp.pt

Makario Fernandes
MEEC – Automação & Sistemas
ISEP – Instituto Superior de Engenharia do Porto
Porto, Portugal
1090036@isep.ipp.pt

Abstract—**This electronic document aims at one of the main research areas in electric vehicles: the charging of its batteries. Battery chargers have yet to settle a common ground since technological advances in different parts of the world keep progressing.**

Keywords - Charging, Vehicles, Electric, Batteries, Chargers, Induction.

I. Introduction

Recent social awareness about the abandonment of fossil energies and the use of renewable energies has been revealing significant improvements. The accentuated petrol price, and products that derive from it, have contributed to the increasing research of new, healthier, renewable and cheaper sources of energy. One of the main purposes of this type of research is the continuous hunt for the replacement of the conventional internal combustion engine that is so well implemented on vehicles and the improvement of current technology for electric vehicles. This paper aims at a glimpse at one of the main research areas: charging electric vehicles.

II. Electric Vehicles

Electric vehicles are dependent on an external supply of electricity to charge their batteries when needed. At first, most vehicles were charged used fixed, off-board chargers; this is still the case for electric vehicles which operate in a controlled environment such as industrial vehicles. For the connection of the electric vehicle to the network, the conductive technology remains up to now the most favoured, mostly because it allows connection of electric vehicles to existing electric power supplies apparently without the necessity for extra infrastructure. However, the advent of electric vehicles in different countries has led to the development of different approaches concerning conductive charging, taking into account specific safety and security issues. To this effect, several conductive charging modes have been defined by standardisation committees. These modes correspond to certain technologies being used, focused on specific applications and on the availability of infrastructure according to local traditions. As the successful introduction of electric vehicles is greatly dependent on the availability of a suitable charging infrastructure, the comparative assessment of conductive charging technologies standardization is of paramount significance for the promotion of the electric vehicle as a vital factor for improvement of traffic and more particularly for a healthier living environment.

A. EV Power Systems (Motors and controllers)

The power system of an electric vehicle consists of just two components: the motor that provides the power and the controller that controls the application of this power. In comparison, the power system of gasoline-powered vehicles consists of a number of components, such as the engine, carburetor, oil pump, water pump, cooling system, starter, exhaust system, etc. Electric motors convert electrical energy into mechanical energy. Two types of electric motors are used in electric vehicles to provide power to the wheels: the direct current (DC) motor and the alternating current (AC) motor. The DC electric motors have three main components, a set of coils (field) that creates the magnetic forces which provide torque, a rotor or armature mounted on bearings that turns inside the field and a commutating device that reverses the magnetic forces and makes the armature turn, thereby providing horsepower.

As in the DC motor, an AC motor also has a set of coils (field) and a rotor or armature; however, since there is a continuous current reversal, a commutating device is not needed. Both types of electric motors are used in electric vehicles and have advantages and disadvantages, as shown here. While the AC motor is less expensive and lighter weight, the DC motor has a simpler controller, making the DC motor/controller combination less expensive. The main disadvantage of the AC motor is the cost of the electronics package needed to convert (invert) the battery‘s direct current to alternating current for the motor. Past generations of electric vehicles used the DC motor/controller system because they operate off the battery current without complex electronics. The DC motor/controller system is still used today on some electric vehicles to keep the cost down. However, with the advent of better and less expensive electronics, a large number of today’s electric vehicles are using AC motor/controller systems because of their improved motor efficiency and lighter weight. These AC motors resemble motors commonly used in home appliances and machine tools, and are relatively inexpensive and robust. These motors are very reliable, and since they have only one moving part, the shaft, they should last the life of the vehicle with little or no maintenance.

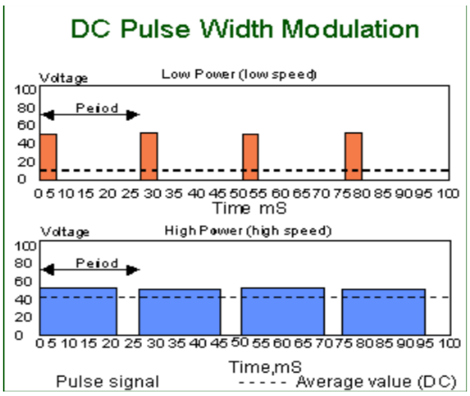
Electric Motor Comparison	
AC Motor	DC Motor
Single - speed transmission	Multi-speed transmission
Light weight	Heavier for same power
Less expensive	More expensive
95% efficiency at full load	85-95% efficiency at full load
More expensive controller	Simple controller
Motor/Controller/Inverter more expensive	Motor/controller less expensive

Picture 1 Advanced Vehicle Testing Activity (AVTA) by the Idaho National Laboratory [1]

The controller of electric vehicle is the electronics package that operates between the batteries and the motor to control the electric vehicle‘s speed and acceleration much like a carburetor does in a gasoline powered vehicle. The controller transforms the battery's direct current into alternating current (for AC motors only) and regulates the energy flow from the battery. Unlike the carburetor, the controller will also reverse the motor rotation (so the vehicle can go in reverse), and convert the motor to a generator (so that the kinetic energy of motion can be used to recharge the battery when the brake is applied) (Picture 5).

In the early electric vehicles with DC motors, a simple variable-resistor-type controller controlled the acceleration and speed of the vehicle. With this type of controller, full current and power was drawn from the battery all of the time. At slow speeds, when full power was not needed, a high resistance was used to reduce the current to the motor. With this type of system, a large percentage of the energy from the battery was wasted as an energy loss in the resistor. The only time that all of the available power was used was at high speeds.

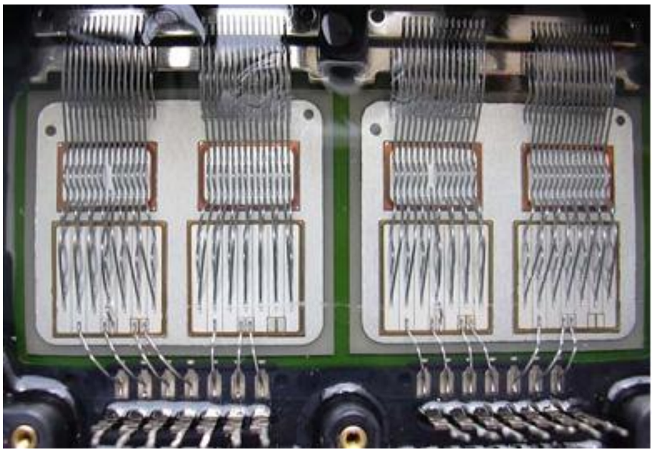
Modern controllers adjust speed and acceleration by an electronic process called pulse width modulation. Switching devices such as silicone-controlled rectifiers rapidly interrupt the electricity flow to the motor. High power (high speed and/or acceleration) is achieved when the intervals (when the current is turned off) are short. Low power (low speed and/or acceleration) occurs when the intervals are longer.



Picture 2 Pulse Width Modulation Controller

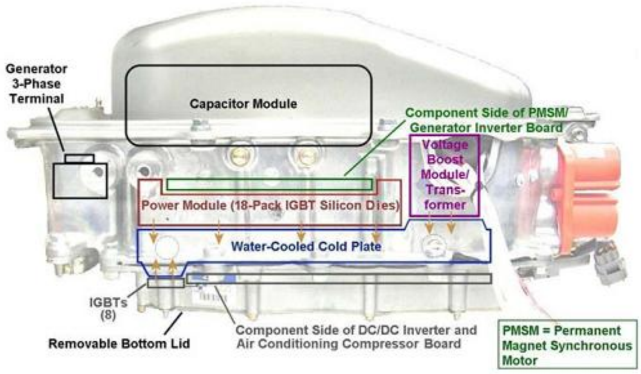
In the specific case of a Toyota Prius, the inverter package contains several important circuits that include the motor inverter, the generator inverter, the buck/boost converter and an AC-to-DC inverter.

Picture 3 shows how these circuits are packaged in the inverter casing. The PMSM inverter and generator inverter driver circuitry is contained on a circuit board mounted below the inverter capacitor module and above the power module that contains the IGBTs and diodes for both inverter circuits. The power module contains 6 IGBTs and 6 diodes for the generator inverter and 12 IGBTs and 12 diodes for the PMSM inverter to support its higher power rating (6 pairs of IGBTs are wired in parallel).



Picture 3 Prius New Car Features 2004 [2]

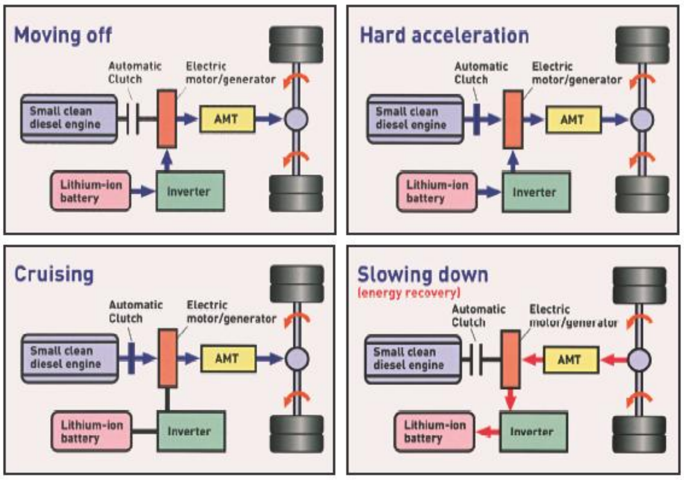
The power module is mounted on a water-cooled cold plate for cooling. Adjacent to the inverter circuitry is the buck/boost converter (500V clamp on the boost) and it's associated IGBTs. The voltage is boosted from 51200V to 200–500V for motor operation and bucked from the same 200–500V range for charging the 200V battery.



Picture 4 Prius New Car Features 2004 [2]

The controllers on most vehicles also have a system for regenerative braking. Regenerative braking is a process by which the motor is used as a generator to recharge the batteries when the vehicle is slowing down. During regenerative braking, some of the kinetic energy normally absorbed by the brakes and turned into heat is converted to electricity by the motor/controller and is used to re-charge the batteries.

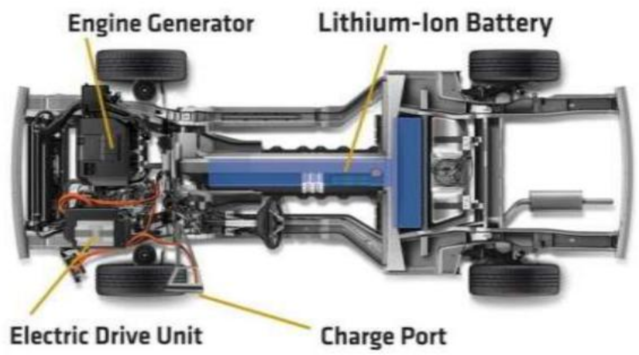
Regenerative braking (Picture 5) not only increases the range of an electric vehicle by 5 - 10%, it also decreases brake wear and reduces maintenance cost.



Picture 5 Regenerative Brake System for an Electric Car [2]

B. Batteries

Electric vehicles (EVs), hybrid electric vehicles (HEVs), and plug-in hybrid electric vehicles (PHEVs) are bringing new test and validation challenges to the automotive industry as the electronic and software content of the vehicles grow. We will discuss the basics of EV and the comparison of then. The battery pack designs for Electric Vehicles are complex and vary widely by manufacturer and specific application. However, they all incorporate a combination of several simple mechanical and electrical component systems which perform the basic required functions of the pack.



Picture 6 Example of a battery pack in a EV [2]

The actual battery cells can have different chemistry, physical shapes, and sizes as preferred by various pack manufacturers. Battery pack will always incorporate many discrete cells connected in series and parallel to achieve the total voltage and current requirements of the pack. Battery packs for all electric drive EVs can contain several hundred individual cells. To assist in manufacturing and assembly, the large stack of cells is typically grouped into smaller stacks called modules. Several of these modules will be placed into a single pack. Within each module the cells are welded together to complete the electrical path for current flow. Modules can also incorporate cooling mechanisms, temperature monitors, and other devices. In most cases, modules also allow for monitoring the voltage produced by each battery cell in the stack by the Battery Management System (BMS). The battery cell stack has a main fuse which limits the current of the pack under a short circuit condition. A “service plug” or “service disconnect” can be removed to split the battery stack into two electrically isolated halves. With the service plug removed, the exposed main terminals of the battery present no high potential electrical danger to service technicians.

1) *Types of batteries*.

Lead Acid Batteries are the most tried and tested battery for EV applications, the low upfront cost and their resistance to abuse means they are the battery of choice for most EV conversions. For use in any EV the only lead acid battery that should be considered is a deep cycle.*A beginner’s guide to Lead Acid batteries for use in EV's*.

Picture 7 Lead Acid Battery [2]

Flooded wet cell battery is perhaps the most common battery type for use in most roads going EV's. The most common brands being Trojan, US battery, although several others exist. These are typically used in marine, RV, golf cart, and forklift applications. Flooded wet cell batteries are composed of thick lead plates submerged in a sulfuric acid/distilled water mixture. they come in 6V, 8V, and 12V, and, some industrial units are available in 24V or 36V.Flooded wet cell batteries typically have the highest AH (amp hour) rating, meaning they can go the furthest distance, but are somewhat limited at how fast they can release their energy. Since they are specifically made for deep cycling applications they tend to have a long cycle life compared to other batteries that focus more on producing current. This makes them better suited to commuting than competition and is easy to recharge.

The AGM battery type is typically not of quite as high of an amp hour rating, as the flooded type, but has many advantages, that make it a very desirable battery as well.

The AGM is by its design very resistant to vibration, and even if broken open cannot leak its acid mixture because it is held within the fiberglass mat like a sponge, that is below its saturation point, so it will not drip.

The AGM can be charged, and discharged at very high current without damage to the battery. This makes the AGM well suited for competition use, as well as being suitable for commuter use. The AGM is a truly maintenance free battery, requiring nothing but proper charging for the life of the battery.

Technology	Density				Cycle life to 80% DOD	self discharge %/month	maturity	cost			Range* +-50%	unique features
	energy		power					current	future	environmental		
	Wh/kg	Wh/l	W/kg	W/l				$/kWh	$/kWh		km	
Flooded lead acid					600	20	mature	100	100	low with recycling	96	modest performance lead
Advanced lead acid	35	71	412	955	500	5	production	150	100?	low with recycling	160	high performance lead
Nickel Cadmium	50	150			2000?	100	mature	300	300	high cadmium	200	
Nickel Metal Hydride	80	200	220	600	600+		production	1000	200	low	320	
Nickel Zinc	60	100	500		600		laboratory?			low	250	
Lithium Ion	100	300			1200		laboratory			low		
Lithium Polymer (3M)	155	220	315	445	600+	1000	protoype			low		pack in body panels saving space!
Lithium Polymer (Electrofuel)	183	470					production			low		pack in body panels saving space!
Lithium Polymer Potential	400	500	1000		600+		laboratory			low		pack in body panels saving space!
Sodium Nickel Chloride	90	150	100	200		400	prototype		300			
Zinc Air	200	200	100	30			prototype	300	100	low		Recharged by Zn electrode replacement
Flywheel							laboratory			low		Mechanical!
Ultra Capacitor	12	5		10**8	10**8		laboratory			low		
Vanadium Redox							laboratory					electrical or mechanical recharge by replacing electrolyte

Picture 8 Generic battery technology comparison [2]

Lithium (Li)

The Technology Lithium batteries are planned for all the commercial EVs in design. They are known for their high power to weight density, long cycle life and relatively high power output. They are currently at high cost, and have a reputation for safety issues. (Picture 9).

Picture 9 Lithium (Li) Based Battery Technology [2]

Lithium Iron Phosphate (LiFePo4)

Good for EV apps. Phosphate based technology possesses superior thermal and chemical stability which provides better safety characteristics than those of Lithium-ion technology made with other cathode materials. Lithium phosphate cells are incombustible in the event of mishandling during charge or discharge, they are more stable under overcharge or short circuit conditions and they can withstand high temperatures without decomposing. When abuse does occur, the phosphate based cathode material will not burn and is not prone to thermal runaway. [5]

Lithium Titanate

This type battery probably is a Future promising technology. This seems to a promising technology that has been proposed by EnerDel with some successful testing. No near term production plans. [6]

Picture 10 The Lithium Titanate Battery[3]

C. Battery Management Systems (BMS)

Virtually all types of batteries can be damaged by excessively high or low voltages, and in some cases the results can be catastrophic. Battery Management Systems can provide battery charge protections, discharge protections, state-of-charge monitoring.

In general, using flooded lead-acid batteries in series in EV applications can work without a BMS. A good charger can provide a float or equalization charge cycle that can effectively balance the batteries. Occasional checking and manual equalization is still required, but not on a daily basis.

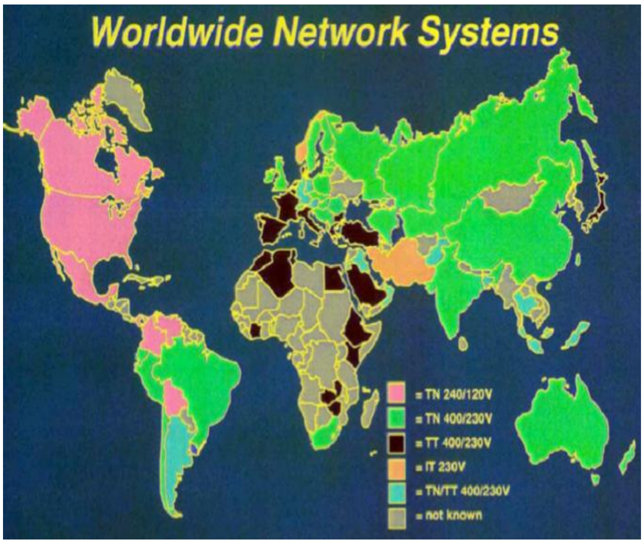
Alternative battery technologies such as Lithium and NiMh are more sensitive to over-charging and over discharging on a cell-by-cell basis. When the cells are used in a series, these battery technologies are generally implemented with a BMS. Batteries perform differently due to different processes used by different manufacturers and different models from the same manufacturer will perform differently depending on what they are optimized for. The actual application will dramatically affect a battery's performance and the choice of battery.

III. CHARGING EVS

A. *European EV & PHEV Conductive Charging Infrastructure*

The reason why there is no common EU agreement on charging standards for EVs, basically is for technical reasons, in Europe, unfortunately Europe has several grid systems. The main 2 systems are TN (Terra-Neutral) e.g. in the German speaking countries TT (Terra-Terra) in the countries, where homes are typically supplied by gas (for cooking and heating – e.g. Italy, Spain, France, Benelux).

Those grid systems are characterized by a different quantity of phases typically delivered to a household and different levels of current typically delivered per phase.

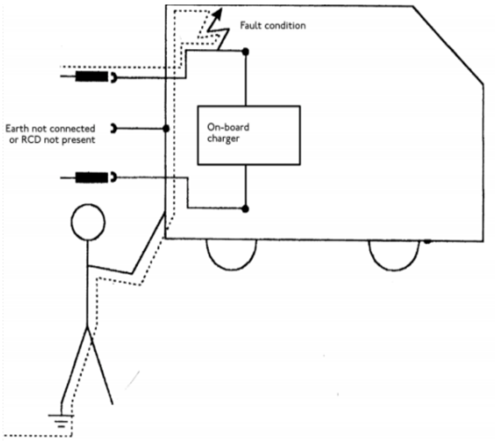


Picture 11 Europe grid systems

In TN Countries, user over-proportionally own a garage or private parking spot (50%-70%), compared to TT countries, where this percentage can shrink down to about 20%. www.protoscar.comStolz E., *Park&Charge* There is no one point of view from an "*EU power utility*" perspective, instead there are (at least) two points of view from a EU power utility perspective, both points of view are equally legitimate, and should both be considered.

B. *Safety Aspects*

According vehicle-charging infrastructure standard IEC 61851-1, during charging of an EV, a double electric safety has to be guaranteed (since vehicles are totally insulated sitting on their rubber tires). Typically those two systems are the FI and the fuse. In case of a TT grid, the FI assumes the function of the fuse, and therefore a second safety system has to be provided (e.g. by a PLC).



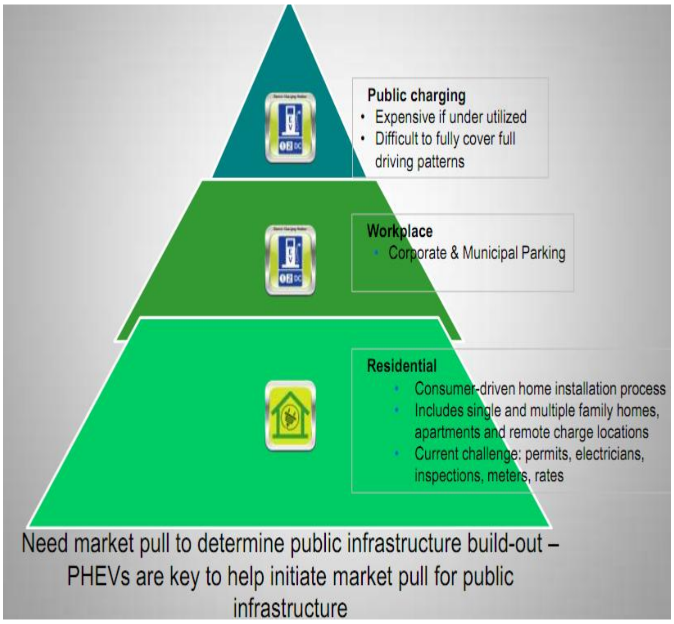
Picture 12 Dangerous condition without an earth link

In the TN grid the fuse would be the second safety device, although because of the insulated cars sitting on its rubber wheels does it not really work until a short circuit is caused between ground and car body. The IEC standard IEC 61851-1 also defines higher security options that check for the continuity of the earth line. This method is imposed in the USA and requires a fourth wire as defined in the SAE standard J1772. The present option in the USA is to use a cable that is permanently wired to the wall thus avoiding the need to define a wall mounted socket that has a fourth pin. This solution does not seem to be acceptable for most of Europe unless the charging spot is under surveillance or in protected private property. The car owner will normally supply the cord set under all circumstances, both at home and on the curbside. Sockets with pilot wire pins are proposed however it is considered that basic charging for two wheelers and low cost vehicles should be compatible with readily available plugs and sockets. Using such four-pin sockets could seriously impede the introduction of electric vehicles, as it would require specific installations that would also be more expensive.

C. *Home-Charging from an Energy Provider point of view*

Home charging (or/and at the work place) will be the main and crucial charging mode for all European EVs and PHEVs. Smart charging will be necessary in terms of load optimization/peak sawing In TN-countries, 2 or 3-phase is available in most of the households. A typical value for current assured is 25 - 40A. This is sufficient for heating, cooking, washing and even charging an EV with a power of up to 3x32A=22kW. In TT countries, 1-phase only is available in most household. Typical range for current assured is 16-20A. In the best case (if no other appliances are used in the meantime), max. Charging power of up to 3.7kW is available for charging EVs/PHEVs for being charged, EVs/PHEVs need an additional safety function, such as a PLC protection or pilot-contact. In a TN-countries can support up to 3x16A (11 kW), or 1x32A (7.4 kW) chargers. Higher power s -in some cases- technically feasible but related to VERY HIGH cost for network connection (see

EKZ sample: cost over CHF 19'000 to connect a new household with 100A compared to 3’000 CHF for a common 3x16A). www.protoscar.comStolz E., *Park&Charge* In TT-countries can generally not support more than up to 3.7kW chargers, at least not in the next decades. For EVs charging in those countries, the only alternative to up to 3.7kW home charge is public fast charging. To avoid 3.7kW on board chargers (with possibility to further limit the current) will be the only EU standard for EV-home charger. Higher, and multiphase, will if the market pays for the service- be offered only as an option (eventually by companies installing “big batteries”, such as TESLA or Daimler). More than 11 kW (16A on three phases) or 7.4 kW (32A on a single phase, Mode 3) will not make sense even for optional on-board charger. For home charge, 3,7kW (1 phase) shall be the maximum power supplied. Wiring is nationally and even locally different in terms of quantity and size of cables and cannot be standardized.**[7] [8]**



Picture 13 Charging Infrastructure

D. *Charging an EV*

When we charging a EV, there are important aspects to observe, the maximum charging current, the state of battery at charging start, which type of charging needs the EV, the state of battery at charging start , the required charging time, the charging mode need a surveillance of the charging process sequence and charging cost.

1. *The norms associated to the EV´S´ and EV´S´ chargers*

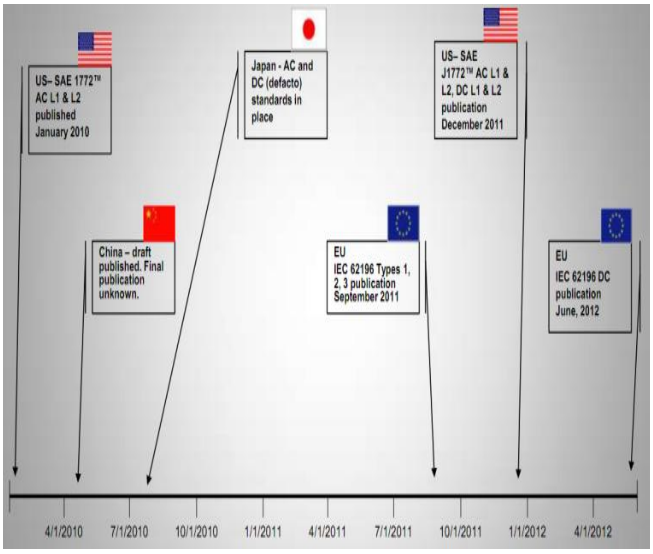
The norm **IEC 62196-1** contains the general requirements for the charging system, while **IEC 62196-2** standardizes three types of grid (mains) connecting systems, known as Types 1, 2 and 3:

- Type 1: single-phase vehicle coupler (vehicle connector and inlet), for example Yazaki or SAE J1772 (Japan, North America)
- Type 2: single- and three-phase vehicle coupler and mains plug and socket-outlet without shutters, for example VDE-AR-E 2623-2-2
- Type 3: single- and three-phase vehicle coupler and mains plug and socket-outlet with shutters, for example SCAME plug developed by the EV Plug Alliance.

Which of these is appropriate depends largely on the electrical infrastructure and regulatory conditions in each country. The above standards build on **IEC 61851-1**, which defines the four modes of charging an EV from a power source:

- Mode 1 (AC): slow charging from a standard household-type socket-outlet
- Mode 2 (AC): slow charging from a standard household-type socket-outlet with an in-cable protection device
- Mode 3 (AC): slow or fast charging using a specific EV socket-outlet and plug with control and protection function permanently installed
- Mode 4 (DC): fast charging using an external charger

Modes 1 to 3 are estimated to allow an EV to be fully charged in between three and ten hours through direct connection to a mains supply. Mode 4 could fully charge an EV in under ten minutes, but as it uses off-grid batteries it is the most expensive to implement. The IEC 61851 applies to both, the electric vehicle (EV) as well as to the charging station to charge at A.C. supply voltages up to 1000V and at D.C. supply voltages up to 1500V, and for providing electrical power to the vehicle when connected to the supply network. EV in this case means all electric road vehicles, including plug in hybrid vehicles (PHEV), that derive all or part of their energy from hybrid vehicles (PHEV), that derive all or part of their energy from onboard batteries running for a larger distance (e.g. 50 km) poorly electric and hence without local emissions. It describes the characteristics and operation conditions of the Electric Vehicle Supply Element (charging station, EVSE) and its connection to the electric vehicle (EV), the operators and third parties electrical safety, and the characteristics to be complied with by the vehicle with respect to the A.C. / D.C. EVSE, when the vehicle is earthed.



Picture 14 The publications (Charger) Standards Timing [9]

It is necessary that there are charging stations that are conform and certify because the EVs come from independent companies and the EVs will use multiple charging stations, the charging stations are in the public and need to be proven for safety and the charging stations are according to the state of technology IEC 62196-1 applies to all four of these modes while IEC 62196-2 applies only to mains charging (Modes 1 to 3). A third standard (IEC 62196-3) is being developed to standardize DC charging (Mode 4). In addition, IEC 61851-1 also defines three cables and plug setups which can be used to charge EVs:

- Case A, where the cable is permanently attached to the EV
- Case B, where the cable is not permanently attached to anything
- Case C where the cable is permanently attached to the charging station

Taken together, these Types, Modes and Cases allow manufacturers to work to common standards within which they can meet the regulatory requirements across differing markets. For example, Italy and the United States have limited Mode 1 charging on safety grounds, while Mode 3 is receiving a lot of interest in the United States and Europe for public charging points and Mode 4 is favored in Japan. Furthermore, technical constraints mean that all Mode 4 cables need to be permanently attached to the charging station (Case C) and United States regulations demand that Mode 3 charging stations also have Case C cables.

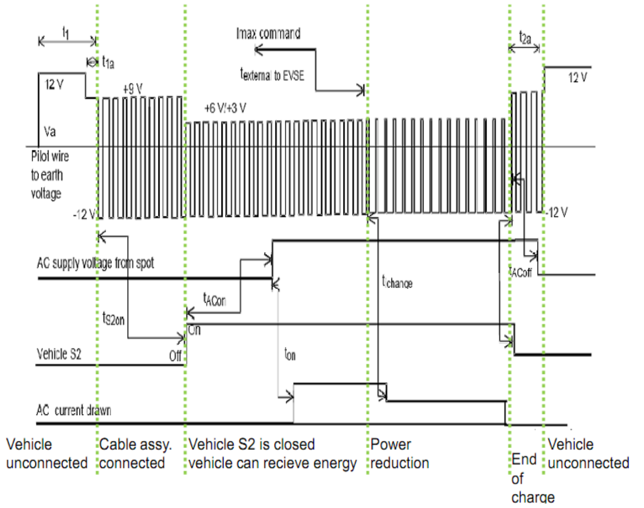
2. *Technologies*

Mode 1 charging.

"Mode 1 charging" stands for the connection of the EV to the AC supply network utilizing standardized socket-outlets at the supply side, single-phase or three-phase, and utilizing phase(s), neutral and protective earth conductors. This means that the electric vehicle is directly connected to a standard socket-outlet. This is currently the most frequent way of electric vehicle charging in Europe. The standard European socket-outlet provides up to 16A at 230V. This power level corresponds with normal charging for small and medium sized vehicles. An outlet of this power level can be installed at extremely low cost. The standard American outlet however gives only 15A at120V, a bit puny output to charge a automobile-sized vehicle. This output power is referred to as "Level 1" charging in the USA, and stands for "cord and plug connected portable EV supply equipment (EVSE) that can be transported with the EV and is intended for emergency use". Most EVs introduced in America are not designed for this type of charging, using instead "Level 2" charging, which is a dedicated 240 V 40 A charging circuit. However, Mode 1 charging has raised a number of safety concerns: its safe use depends on the presence of a residual current device (RCD) on the supply side. The installation of such device is now enforced by national codes in most countries; however, many older installations continue to exist without RCD, or even without protective earth conductor connection. In such cases, hazardous conditions may occur after a fault. Thus, without RCD, mode 1 charging is not permissible. While as some countries leave this responsibility to the user, mode 1 is prohibited in a number of countries, or limited to private environments (closed garages) with controlled access. Where the presence of an RCD on the supply side cannot be ensured by national codes, mode 1 charging is not permissible. In some countries, mode 1 charging may be prohibited by national codes, or limited to private environments with controlled access. Although Mode 1 charging is considered by many a transitional solution, pending the development of dedicated electric vehicle charging infrastructure, it is sure that Mode 1 will be with us, at least in the countries where it is not prohibited, for a long time, particularly for private home charging and fleet vehicle charging in controlled-access environments In some countries (Switzerland) Mode 1 charging is used for public charging stations additional protection is provided by the RCD and by mechanical means (key-locked flap preventing unauthorized access to plugs and socket-outlets). For greater safety and reliability, the use of industrial plugs and sockets-outlets according to IEC 309-2 becomes increasingly popular. These are of a heavier build then standard "domestic" plugs and more suitable for harsh environments, repeated disconnection under load and prolonged operation at high current rates. Mode 1 connectors do not require any control pins from IEC 61851-1.**[3].**

Mode 2 charging

The safety concerns with Mode 1 charging in certain countries (particularly the USA) has lead to the definition of Mode 2: the connection of the EV to the a.c. supply network utilizing standardized socket-outlets, single-phase or three-phase, and utilizing phase(s), neutral, and protective earth conductors together with a control pilot conductor between the EV and the plug or in-cable control box. Mode 2 allows additional protection of the cable and the vehicle, whilst using standard, non-dedicated socket outlets. It uses a special plug (or an in-cable device) holding an RCD and additional protection devices (control pilot conductor; see below). In Europe, it is used very rarely. This solution can be considered as transitional. The introduction of Mode 2 charging in the USA reflects the American infrastructure process which developed electrical standards and code language that was adopted by the National Electrical Code (NEC 625), this ensured that personnel protection and other safety considerations were implemented in all charging systems utilized (inductive or conductive).



Picture 15 Communication during the Charging Process through PWM Signals (according to SAE J 1772)[10]

Mode 3 charging

Mode 3 charging refers to specific electric vehicle charging stations, with the direct connection of the EV to the AC supply network utilizing dedicated EV supply equipment. Where the control pilot conductor extends to equipment permanently connected to the AC. supply. It concerns dedicated infrastructure: equipment specially designed and reserved for EV use, whether intended for public access or not. The control pilot is a device which controls the integrity of the protective (earth) conductor (by adding a control pilot conductor which forms a loop with the protective earth conductor), and which is able to perform additional safety functions, such as ensuring the socket outlet is dead when no vehicle is present, as well as basic communication functions. This is particularly interesting for charging stations located in public locations. Mode 3 charging stations come in different power levels, 16A, 230V corresponding to standard socket-outlet but with enhanced safety features. This configuration will be typical for on-street charging stations, and is being deployed in several European countries. For the socket-outlet and plug combination, several options are being considered: A Mode 3 socket outlet with fourth pin for the control pilot, with a matching plug which is compatible with a standard (Mode 1) socket outlet, enabling vehicles to charge both at a private garage (albeit in Mode 1, without control pilot protection) and at public charging stations (in Mode 3). This system is under operation in France (over 200 public charging stations in Paris alone). However, the special plugs used are very expensive, leading to a number of charging stations being fitted with mechanical safety devices (locking trap door) instead, allowing the use of “domestic” plugs. The control pilot function is then lost however, a new type of plug and socket-outlet specially reserved for EV use. Such a solution is being proposed for the Italian market, as a lightweight 4-prong plug (including control pilot) which may be feasible for lightweight vehicles such as scooters and electric bicycles. The 32 A, 230V power represents a higher level (7kW) for semi-fast charging. This power level is readily available at most places. This option has been developed into an multifunctional charging solution, with a common plug design, compatible with existing IEC 309-2 plugs, but fitted with additional contacts for control pilot and “power indicator”. This implies an “intelligent charger” however, which can adjust its input current according to its needs. This equipment, already being deployed in Switzerland, can be used in different ways:

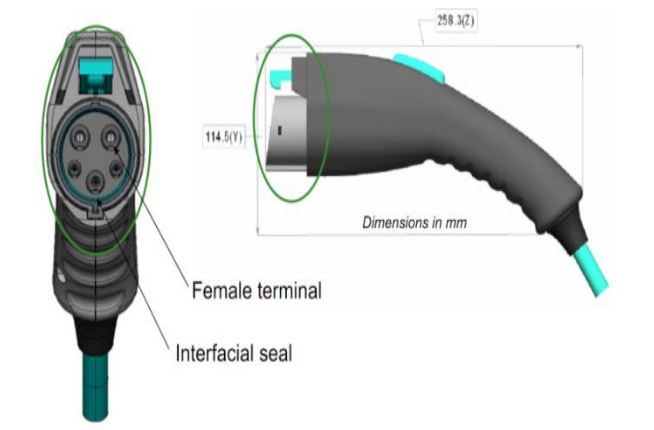
- Connected to a public charging station. The charger detects the presence of the charging station (through the control pilot) and sets its input current to 32 A. High power level is chosen. Control pilot provides additional protection: when no vehicle is present, the socket outlets are dead.

- Connected to a private charging station, i.e. a wall box with suitable socket-outlet and control pilot circuitry. The charger operates at 32 A, and control pilot protection is provided. This solution is aimed at corporate vehicle depots which need a higher rate of charge, as well as to discerning private vehicle owners.

- Connected to a private socket-outlet (standard IEC 309-2 16A outlet, i.e. Mode 1). The charger does not detect the control pilot and defaults to 16A.

- Connected to a standard “domestic” socket-outlet (Mode 1) using a suitable adapter cord set. The power-indicator function (a resistive circuit) can be used to adjust the charging current to a level lower than 16A when desired (e.g. rated outlets of 10A or 13A in some countries).

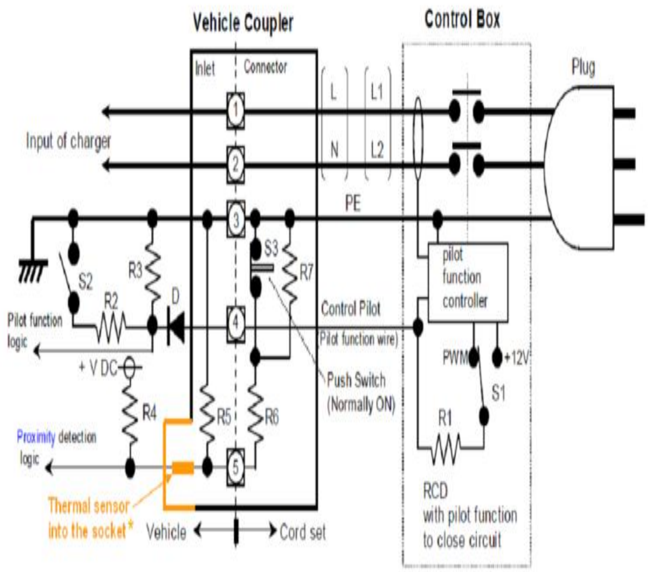
The development of three-phase drives on electric vehicles has opened the opportunity of using these devices for charging the batteries through direct connection to a three-phase distribution network. Such a network can be made available quite easily, and attainable power levels are very high, up to several dozens of kilowatts. This way, really fast charging becomes possible without the necessity of heavy and expensive fixed chargers like in Mode 4. It has even been proposed to use the batteries of vehicles such connected to the grid for peak-shaving purposes. The development of such an infrastructure however raises specific standardization issues. Since the three-phase inverters used on the vehicle may not have a galvanic separation in their circuits. This means that the vehicle traction circuits, including the battery, will become connected to the grid, and part of an electric appliance, which may rise the need for specific protection measures. Thus, standardization of these issues may become the competence of IEC, while as the vehicle and its traction equipment has traditionally being covered by ISO.



Picture 16 Interface conform to J1772 standard charge connector 16/32A [11]

Mode 4 charging

The mode 4, fast charging, uses an external charger. It needs a stationary charger D.C. is a connection heavy and has an expensive infrastructure. In Mode 4 (the indirect connection of the EV to the AC supply network utilizing an off-board charger where the control pilot conductor extends to equipment permanently connected to the AC supply), the vehicle is charged with a DC current provided by an off-board charger. Vehicles in captive areas like industrial vehicles are mostly charged with off-board chargers; for road-going vehicles, this solution is most often used for fast charging stations which require a very heavy infrastructure. This infrastructure being very expensive, its usage has been largely limited to public charging stations for “emergency” charging.



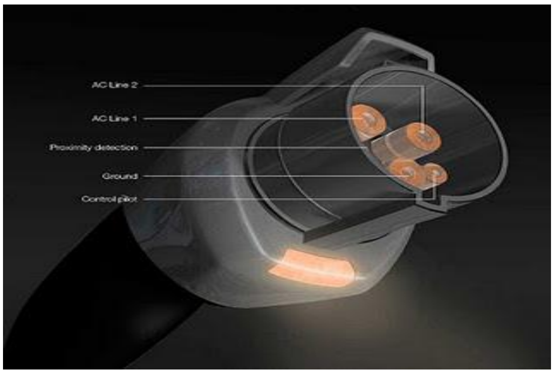
Picture 17 Charge connector 16/32A [11]

3. Plugs Interfaces

SAE J1772 or Yazaki

Picture 18 SAE J1772 or Yazaki [11]

This connector is proposed by the Society of American Engineers, SAE and it’s the standard in USA. It encompasses not only physical but the device itself and the communication protocols used. It’s based on a 43 mm (1.7 inches) round shape and it’s composed by 5 pins: 2 for AC line (same size), one protective earth and one for proximity control (prevents the car from moving when connected) and one for control purposes. The control connector uses a square wave (+ -12 V) of 1 kHz frequency that controls the vehicle's presence, regulates the maximum permissible current intensity and the whole process. The position of these pins on the connector is shown in the following Picture 19.



Picture 19 Position the pins [11]

It is designed for several levels of AC power:

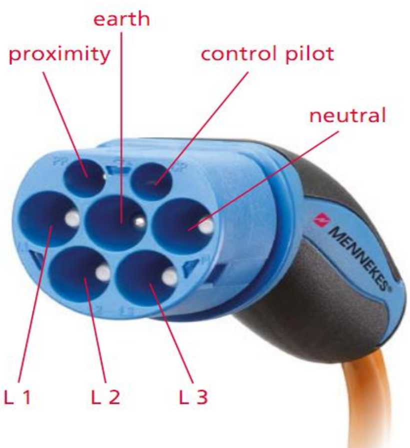
- •Level 1: 120V single phase supply and up to 16A (up to2kW);
- •Level 2: Split-phase 240V systems and up to 80A (up to 19 kW).

This system can be used in mode 2 or mode 3. Later, a different configuration with additional DC current and protective earth pins is introduced. It can provide 36 kW of power at 200-450VDC at the first level and up to 90 kW with 200Ampère DC for level 2.

MENNEKES

Picture 20 Mennekes plug [12]

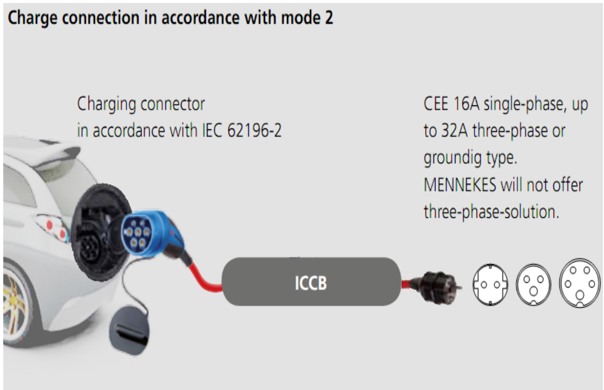
What does the plug used both by the Mini D project by Vattenfall al and BMW and the "e-mobility" project by RWE and Smart look like? Just like the one pictured above, which is a creation of a company called Mennekes. Getting all the interested parties to agree on a standard plug isn't an easy thing, so some initiatives had been taken to make the Mennekes plug the standard model, at least in Europe. This formed the basis for the agreement of the European energy suppliers and car manufacturers on the key points for the charging connection on electric vehicles. The plug works both for single phase 230V connections, the vast majority of European outlets, as well as three-phasing up to 63A and 400V, which results in a much shorter recharging time. It includes not only a connector, but also communication interfaces. A "plug present" contact, for example, turns on the immobilizer and a "Pilot Control" contact facilitates the exchange of data between the vehicle and charging station. In the U.S., the J1772 connector will likely be the new standard for plug-in vehicles. The VDE has awarded its test seal for the first electric mobility charging plug system. The developer of the international draft standard, Mennekes Elektrotechnik GmbH & Co. KG, has successfully submitted a charging cable as well as the infrastructure socket for testing.**[13]**



Picture 21 Close up at a Mennekes Plug [12]

4. Basic communication with the vehicle

Before the charging process starts, PWM communication with the vehicle is established via the CP cables in charging modes 2 and 3. Several parameters are transmitted and adapted. Charging does not start until all safety prompts clearly meet the specifications and until the maximum admissible charging current is transmitted. The charging station (in mode 2 the control device in the charging cable) checks the connection of the earthed conductor to the vehicle and transmits the available charging current. The vehicle adjusts the charger accordingly. The vehicle interlocks the charging connector and requests the start of charging.



Picture 22 Charge connection in accordance with mode 2.[12]

The charging station interlocks with the infrastructure charging connector. If all other requirements are fulfilled, the charging station activates the charging socket. The earthed conductor is monitored for the duration of charging via the PWM communication and the vehicle can communicate with the charging station to cut power supply. A stop device (in the vehicle) terminates the charging process and unlocks the connectors. These signals are transmitted to the charging station via the CP conductor. The vehicle charger defines the charging process. To prevent the vehicle charger from exceeding the capacity of the charging station or the charging cable, the capacity data of the systems is identified and adapted to each other. The CP box reads the capacity data of the charging cable from the cable. The capacity data of the charging station is recorded in the CP box. Prior to starting the charging process, the CP box transmits the capacity data via PWM signal to the vehicle. The charger of the vehicle is adapted accordingly and the charging process can start without risking an overload.

SCAME or EV Plug Alliance

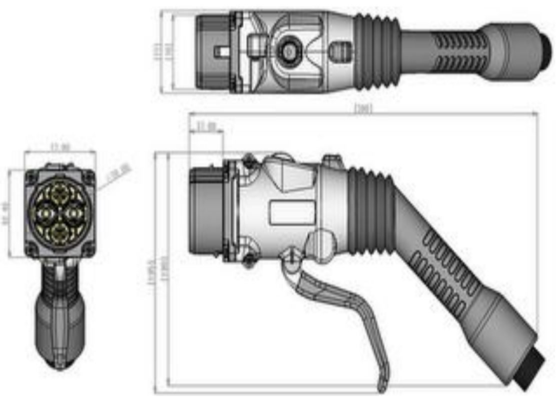
This connector (Picture 23) is created by the EV Plug Alliance, a group formed by Schneider, Legrand and SCAME, and it's also known as SCAME connector. This is another strong bet to implement electro mobility in the European market.

Picture 23 SCAME connector [15]

It can provide single-phase charge at 220V or three phase at 380V up to 22.2 kW (up to 32A at 400V three-phase).It can include 5 or 7 contacts in the connector, consisting of the 3 phases, neutral, protective earth and 2 pins to communicate with the docking station. This connector is designed mainly for mode 3.

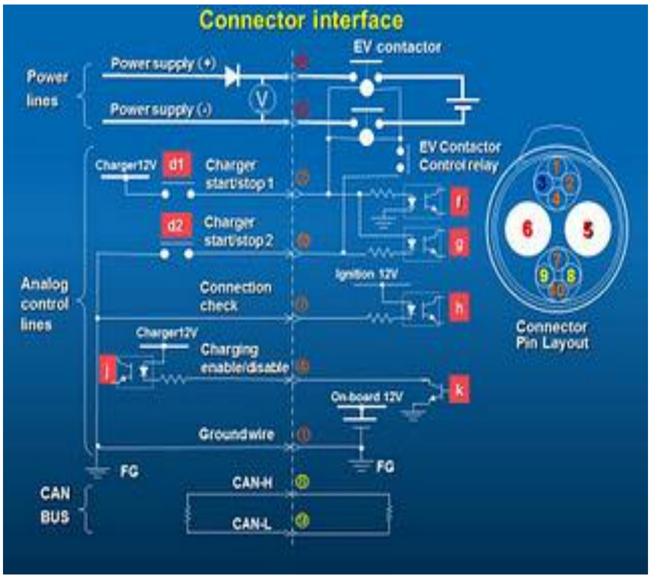
TEPCO – Jari - CHAdeMo

CHAdeMO is an association formed by Tepco, Nissan, Mitsubishi, Fuji Heavy Industries (maker of Subaru) and Toyota. The standard CHAdeMO allows fast charge with direct current, so, it moves the conversion and rectification of current outside the vehicle and provides DC power directly to batteries. This system achieves the fastest charging and it's an international technology for this kind of process. The connector used is shown below and it's also called Jari or TEPCO, as it has been established by the Tokyo Electric Power Company.



Picture 25: Jari or TEPCO Connector [16]

The connector has 10 contacts. The two with a larger diameter are the positive and negative poles that provide DC current and the other 8 are a combination of analog and digital communications for charging management and control. The most important physical connections in this system are shown in the image below:

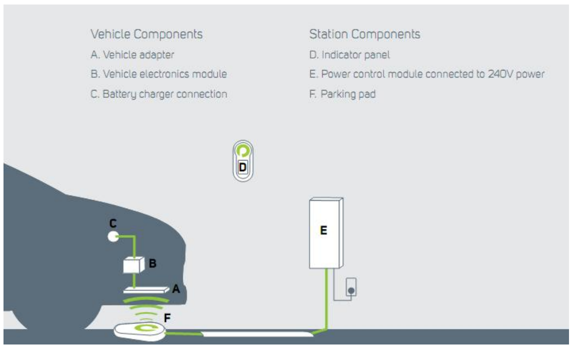


Picture 26:Jari or TEPCO Connections Pins [16]

This system is a mode 4 and provides a maximum current of 100A at 500VDC, which means up to 50 kW. This high power requires the charging station to be connected to the high voltage grid, usually with a dedicated transformer. These are the main systems that are now on the market. Probably, in the future, some of them will become standard and others will disappear, but now they are doomed to coexist.

Plugless

Plugless Power uses inductive power transfer to replenish to EV's battery, the same process used by common household devices like electric toothbrushes. Originally discovered in 1831, electromagnetic induction does not transfer live power across an air gap. Instead, the system leverages magnetic fields to safely transfer power between two coils – one in the Plugless Power parking pad on the floor and one that's installed in an adapter on the EV.



Picture 30: Plugless Power Parking Example [17]

The Plugless Power system recognizes the EV from approximately 50 feet away. As it enters the alignment zone, the last five to 10 feet, the system provides parking guidance. When the EV is optimally positioned over the parking pad, it will receive confirmation that the system is ready to charge car. Using a communication system based off the SAE J1772 protocol used in corded systems, the vehicle wirelessly communicates it is ready to charge. After it receives this signal, the Plugless Power system begins charging automatically. The indicator panel communicates charging status. When the vehicle is fully charged, the system stops charging. And if there is the need to leave before charging is finished, simply by backing up the system will turn off. There's never any exposed electricity, so the system is completely safe.

IV. CONCLUSION

The success of the electric vehicles industry is the charging process that takes place between electric vehicles and charge spots has to be coordinated, taking electricity grid and electricity generation capacities into account. Normal power charging, already available in domestic settings (home and work), should be the dominant charging method – not only due to the possibility of integrating into the existing electrical system, but also as a means of stabilizing the grid through "smart", i.e. Controlled, charging processes. This will also minimize the costs for rolling out additional infrastructure and provide a user friendly solution. Provided that electric vehicles are charged in a smart, controlled way, we see no reason to doubt that the functioning of market forces will turn electric vehicles into a competitive transport technology. Over time, the market will signal which charging functionalities and facilities EV customers' desire and are willing to pay for.

The electric vehicle, in order to have a chance to achieve a significant penetration of the market, particularly the private vehicle market, must be able to charge at different locations away from its home base, as to allow its operation in a wider area. Plugs and sockets must be interchangeable. This highlights the problem of creating a "universal" infrastructure, taking into account on one hand the specific needs of different applications and on the other hand the existing differences in electrical infrastructure in different countries. This aspect is particularly striking in Europe, where nearly every country has its own type of plug and socket-outlet, with different ratings, and where international trips with electric vehicles are a quite realistic option due to the intense trans-border traffic in a number of populated regions. A common interface will be relatively easy to realize for the vehicle inlet/connector interface. For the plug/socket outlet side, dedicated EV infrastructures (i.e. charging stations) can be fitted with a common interface. Connection of electric vehicles to existing infrastructure (i.e. Mode 1 or Mode 2 charging) can be done with material compatible with IEC 309-2 plugs, or by using suitable adapter cord sets, which may allow charging at the correct rating. These adapter cord sets however shall be of a design which does not compromise safety. A number of issues remain to be resolved however, based mainly on specific properties and traditions of each operating theatre.

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