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Definition and implementation of a global EV charging infrastructure

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Part I: General descriptions

Contents

1 Project goals (abstract)

It is a proven basic requirement to recharge an EV at the existing infrastructure. Considering the given power limits and the different national standards defining of an improved and international solution seems to be an essential step towards promoting the growth and the acceptance of the EV.

The purpose of this project was to develop and to demonstrate the feasability of a cost effective and comprehensive EV-infrastructure system in three steps:

- **Definition of the architecture**

  The definition of a particular solution, based on existing international standards and agreements. This part was close related to standardisation work.

- **Implementing of the system in the test market place of Mendrisio**

  The major issue was the proof of concept under real conditions. This field test started in 1997 and provided the experience on which the improvements of the components were based.

- **Commercialising of the system**

  The success of a system in the longer run depends highly on stable products with an industrial background and their reliability. To achieve that is still the most sensitive part, because it requires active influence in the standardisation process as well as partnership to relevant industrial partners.

  The value and the relevance of this project depends therefore on the continuity and the support in the coming years.

Since the beginning of 1999 a commercial AC charging station is available, compliant to the recent standard proposals and already installed in several european countries.

2 Project motivations

2.1 General situation

The EV charging system contains parts on board the EV as well as specific off board equipment. They have to adopt the existing power supply infrastructure to provide energy to the vehicle, regardless of the transfer technology.

Defining a globally agreed implementation of existing infrastructure, special charging stations and on board chargers, is a great challenge. One of the major difficulties is the variety of energy distribution systems with it´s different voltages and safety concepts around the world.

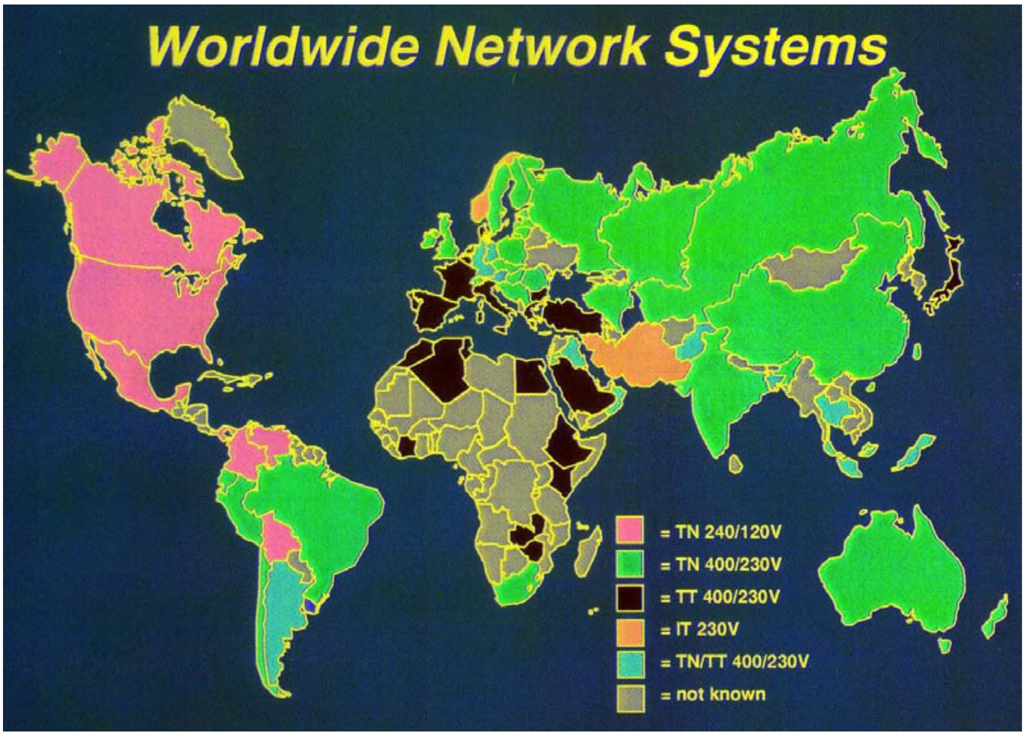


Figure 1: worldwide network systems

Both means of electricity transfer, conductive and inductive, are presently used and supported by car manufacturers. While the inductive charging system is basically represented by a single solution, the definition of a sustainable worldwide conductive charging system is still under consideration.

2.2 Implementing charging systems - considerations

2.2.1 Experience from test markets

There have been a lot of discussions about which charging system should be implemented. Such a system should meet local test market demands, but also represent a sustainable soluti-on for a non restricted niche market situation.

- **Safety**: It should be possible to recharge an EV at the existing infrastructure anywhere, at any time and at the highest possible safety level.
- **Econimical feasability**: A lower-cost approach, which is tailored to the present niche market situation, but also has the potential to grow according to demand, is the favourite for third parties, who have to invest in infrastructure.
- **Technical potential**: Any charging system, which exclusively relies in the existing infra-structure is seriously limited both in it´s technical as well in it´s market potential. But any system which don´t utilise the benefit of the omnipresent AC-sources would require a tremendous initial effort and is therefore commercially not feasable.
- **Standardisation**: A major obstacle in implementing enhanced charging facilities is the necessity of a common and international agreement on the specifications of the interface and the power source. For others than standard AC sources, the communication protocole, the power and the voltage range have to be specified carefully.
- **Internationality**: Any commercial implementation must be based on an international consensious of all involved parties.

Recently some major steps were taken toward a common agreement. The awareness of the following statements contributed the major share to the positive development:

2.2.2 Technical considerations

In most cases the charging system consists of the stages, displayed in the figure below. Some of them are located off board, some on board. The electrical place of the link determines the specification of the interface.

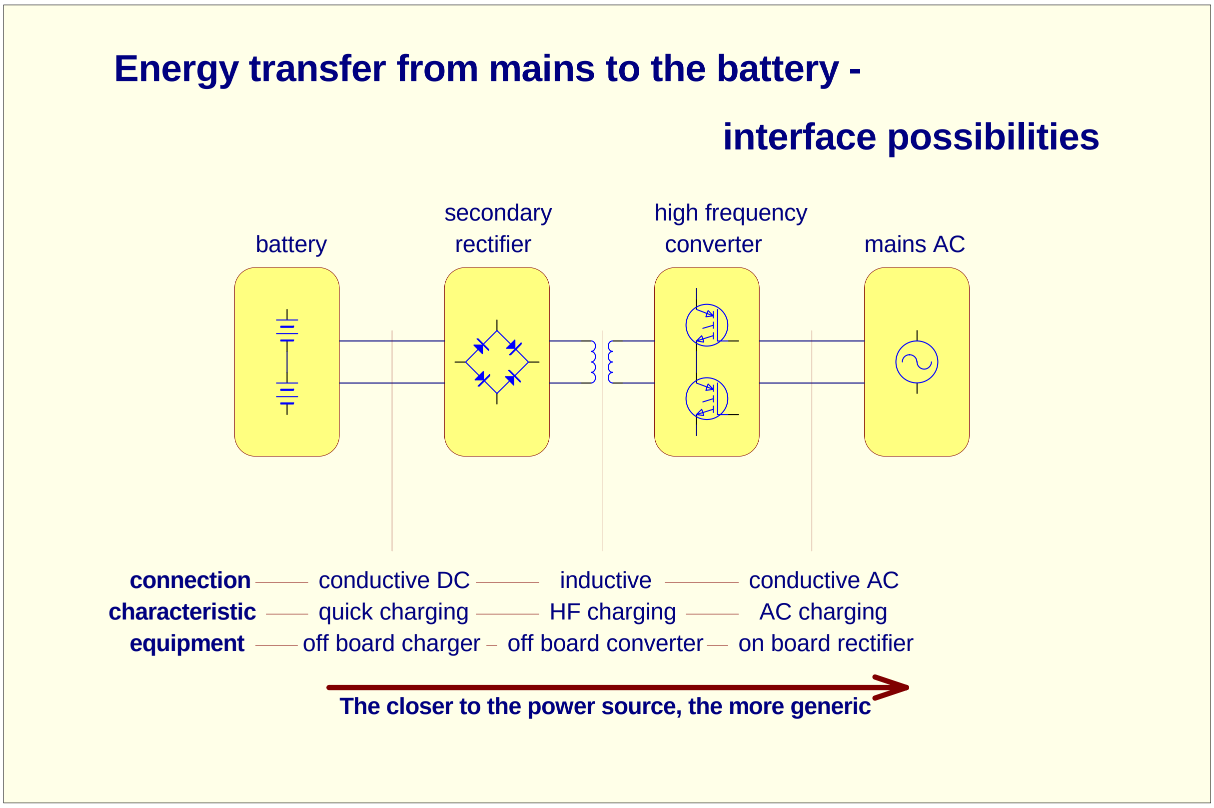


Figure 2: possible interface locations

- The closer the interface is located to the battery, the more varietys of vehicle layout have to be covered by the fixed equipment.

  Consequence:

  An interface at the DC side has to cover all present and reasonable future EV-demands. It should also allow home charging at common AC sources and be based on an international agreement about the physical and functional design.

- Supplying AC to the vehicle requires all conversion stages on board. The charging system is entirely part of the vehicle´s design.

  Consequences:

  An exclusively AC interface at the vehicle prevents it from quick charging. An inter-face at the fixed part of the supply could be tailored to the demand, without restricting vehicle designs.

  An international agreement on the physical and the functional design is required.

2.2.3 Characterisation of the charging systems

- **DC charging (mode 4 - conductive quick charging)**

DC charging allowes almost unlimited power, therefore it is so far the favourite concept for quick charging implementation. The specifications of the off board power source are quite challenging, exspecially if it is not dedicated to a certain EV-type.

- **Inductive charging (via an inductive coupler)**

An inductive coupling is a sort of a high frequency transformer. Therefore there are possibilities to adopt different battery voltages in some discrete steps. The limitation comes from the operating point. At low power rates efficiency decreases, which makes the system inadequate to top up batteries.

- **Mains AC conductive charging**

Direct connection to mains provides the most freedom to the vehicle design but is restricted to a certain power level. The on board charging equipment is very cost sensitive. On the other hand, there is a very low initial effort to develop infrastructure.

However, amendments are necessary to provide a practical and competitive charging facility.

- **High power AC charging**

Powerful AC sources could also be used to charge a traction battery via the traction inverter. In this case the voltage adaption is realised by an off board mains transformer. A broad introduction would severely restrict the possibilities of the vehicle design. Therefore it is used for special applications

2.3 The release of an IEC committee draft on conductive charging

The standardisation organisations refer for classification to the physical interface. There are seperate standards for conductive and inductive charging in preparation.

On the conductive part, the classification derives from the level of safety as well as from the both cases AC and DC delivery.

2.3.1 Energy transfer from mains to the battery – charging modes

Mode 1: domestic and unspecific industrial outlets without communication at standard safety level

Mode 2: the same sources with additional safety features, located at the vehicle-specific charging equipment

Mode 3: AC charging stations and AC sources with communication and additional safety features

Mode 4: DC charging, regardless of the power level. It is mainly intended for quick charging utilising up to 400A DC charging current.

2.3.2 Table of agreement on functionality, safety and power levels

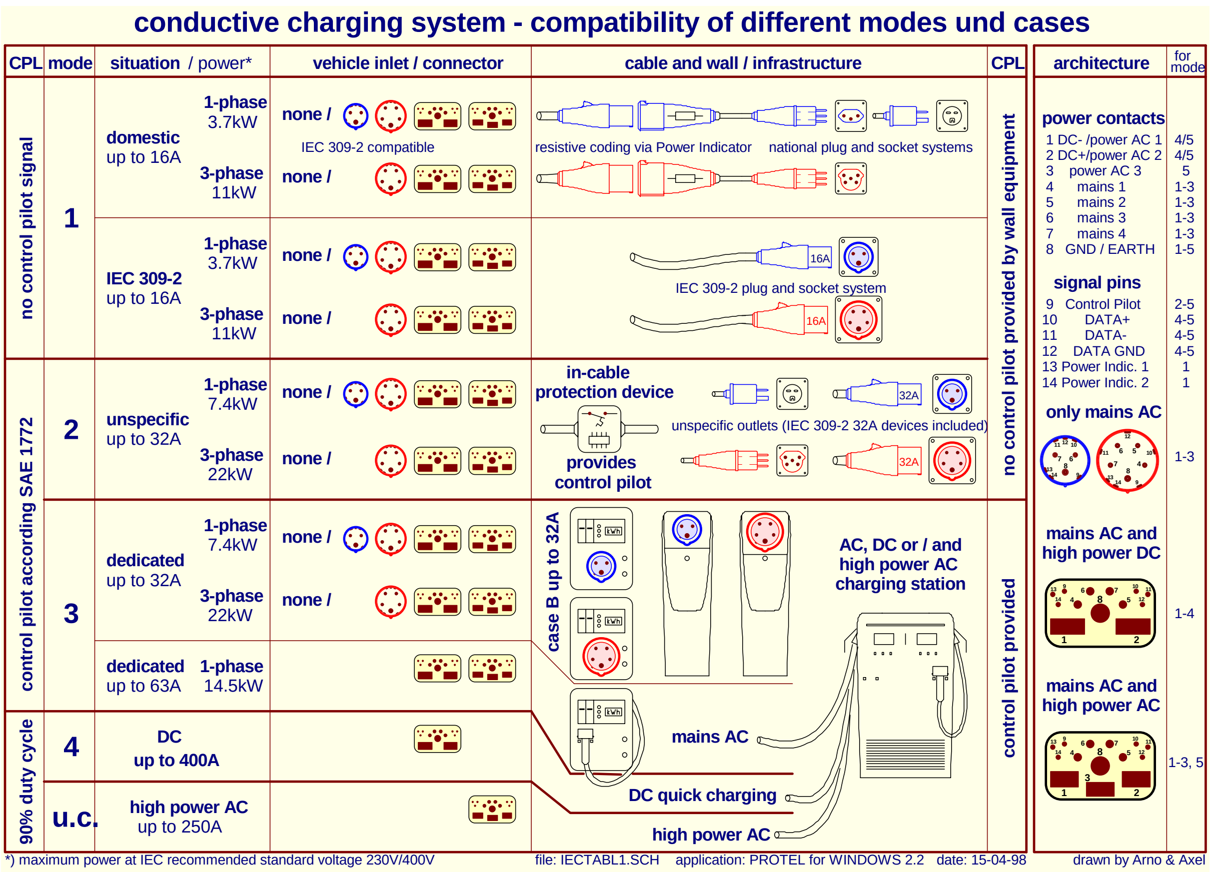


Figure 3: informative annex to the future IEC 61851-1

2.4 The interface issue

2.4.1 Vehicle interface

There has been (and still is) a long discussion about the standardisation of an unique vehicle interface. This is quite an important issue, because the interface determines and limits the number of possible solutions. Moreover, an interface which fits to all modes mentioned above will become quite complex - and, therefore, expensive.

As long as there is lack of an international agreement, any sustainable conductive charging concept should not relay on a certain vehicle interface, because a significant number of e-xisting solutions would be prevented from sharing the system.

However, a practical charging solution would focuse the discussion on the real needed pro-perties of the interface and therfore contribute to the agreement process.

2.4.2 Mains connectors

A mains connector for EV applications is necessary to implement a sustainable AC charging concept. It should cover some additional requirements, layed down in the standard proposals. The specification partially exceed the functionality of standard devices:

- Devices should be based on an agreed worldwide standard, such as IEC60309-2
- The connection must provide industrial durability
- The implementation of specific additional safety means must be possible
- Communication and safety contacts should not affect mechanical intermateability with standard devices

Recently CENELEC, the European standardisation body, started to work out a standard pro-posal based on IEC 60309 „industrial plugs and sockets“

3 Architecture requirements

3.1 Requirements on part of the user

The nearest step is to decide, which charging system should be implemented at first. This is useful to demonstrate perspectives and to meet at least the known demands, which arose previously in the test market situation.

In a real market situation, there will be room for different systems similar as we are used to have different types of fuels available. Initially concentration is necessary and it should be provided:

- **Open architecture** to integrate very high power facilities in a later period
- **High availability** of public charging facilities
- Save **home charging** with minor adaptions of the infrastructure
- At least **50km range gain per hour**
- Guaranteed **full charge over night.**

Mains AC charging meets all theese requirements and is chosen to be the base.

3.2 Power ratings

Test market experience showes, that with an enhanced on board charging system a very attractive charging time is attainable. Such a more powerful on board charger cover a wide range of customer demands in terms of charging time, accommodates the existing infrastructure and will be economical by skale.

The following diagrams show the significant improvement of accelerated charging. The first one demonstrates, how it is possible to change a 2 hour into a typical short term charging and the second one, how an overnight stop turnes to the lunch brake situation. Both cases are based on a modern high energy battery.

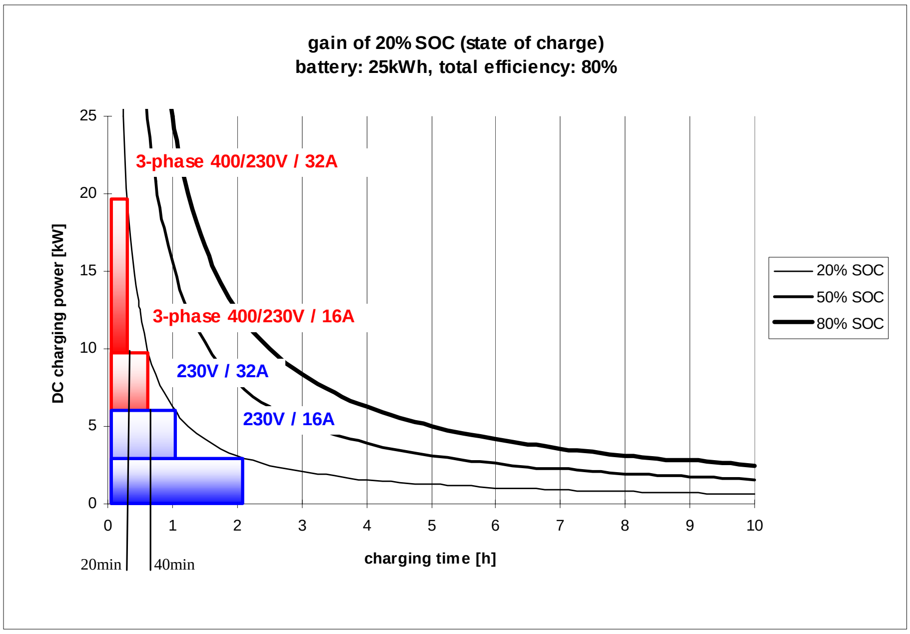


Figure 4a: 30km range gain at different AC power levels

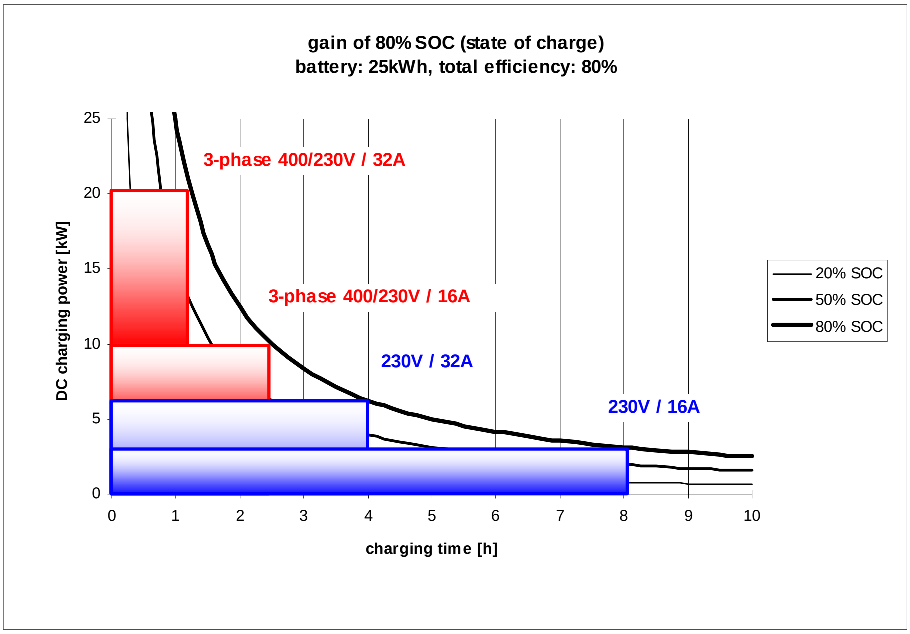


FIGURE 4b: 120km range gain at different AC charging power levels

Obviously it is possible to cover most demands on a charging system only by mains AC charging. In many countries, including U.S. and Japan, the phasecurrent of 32A is available. (It may require minor adaptions in some other countries.)

3.3 Charger specifications

Besides power conversion, an on board charger should also provide system management functions:

- **full adaption of unspecific or domestic infrastructure** at the given limits at the highest possible safety level – automatical downrating
- **accomodation of enhanced AC infrastructure** equipment, if any
- **communication to DC power boosting** off board charging stations, if needed

In case of lack of communication the charger should default to a safe level, where this is allowed (mode 1). The mains current under this condition will be 16A, which is the rated current of the unspecific IEC 60309-2 connector.

	DC-Power	Mains ratings
Single Phase	7kW	230V / 32A
Three phase	21kW	400V/230V / 32A phase current

Tab. 1: Preferred ratingsTable 1: Preferred ratings

The design power should be 7kW for each phase (32A single phase).

Based on 7kW power units, a 21kW three phase on board charging system, which still complies to common outlets, becomes possible.

3.4 Mains socket outlet / connecting devices

They should be capable of delivering significantly more power than domestic outlets, but not exclude any existing solution with a standard low power charger. To cover the whole power range at reasonable cost, a single phase connection has been developed, which is fully compatible to the well known IEC 60309-2 industrial plug and socket system.

With the cross section of an unspecific 16A connection the pins are designed to carry a maximum current of 32A. This will provide mains power depending on the system voltage:

7.7kW @ 240V/32A in the U. S.

7.3kW @ 230V/32A in the European Community and in Switzerland

7.0kW @ 220V/32A in other European Countries Russia

6.4kW @ 200V/32A in Japan.

The IEC standard defines basic interface, which does only provide AC, safety and communication contacts. This is exactly, what is needed here.

The specifications of the basic interface is as follows:

Position N°	basic		Functions*2
	single phase	three phase.	
1			high power d.c./a.c.
2			high power d.c./a.c.
3			high power a.c.
4		400 V 32 A*4	L1
5		400 V 32 A	L2
6	400 V 32 A	400 V 32 A	L3
7	400 V 32 A	400 V 32 A	Neutral
8	Rated for fault	Rated for fault	PE
9	30 V 2 A	30 V 2 A	Control pilot*3
10			Communication 1 (+)
11			Communication 2 (-)
12			Clean data earth
13	30 V 2 A	30 V 2 A	Power Indicator
14	30 V 2 A	30 V 2 A	Power Indicator
Note 2: For contacts 9, 13 and 14, environmental conditions may demand larger conductor cross-sections. Note 3: In the absence of the control pilot circuit pin 9 may be used for other purposes Note 4: In some countries the branch circuit overcurrent protection is based upon 125% of the device rating			

Source: IEC/TC69/CDV „conductive charging system; part 1: general requirements“

Table 2: Requirements for conductive charging interfaces

4 The solution - system specifications

4.1 Overview

The hereby proposed mains AC conductive charging system is based the previous considerations and compies to the recent standard proposals.

The basic intention is, that any combination mains AC charging components, fully or partially compatible to the OMNICHARGE architecture, can be used at the maximum possible power and safety level.

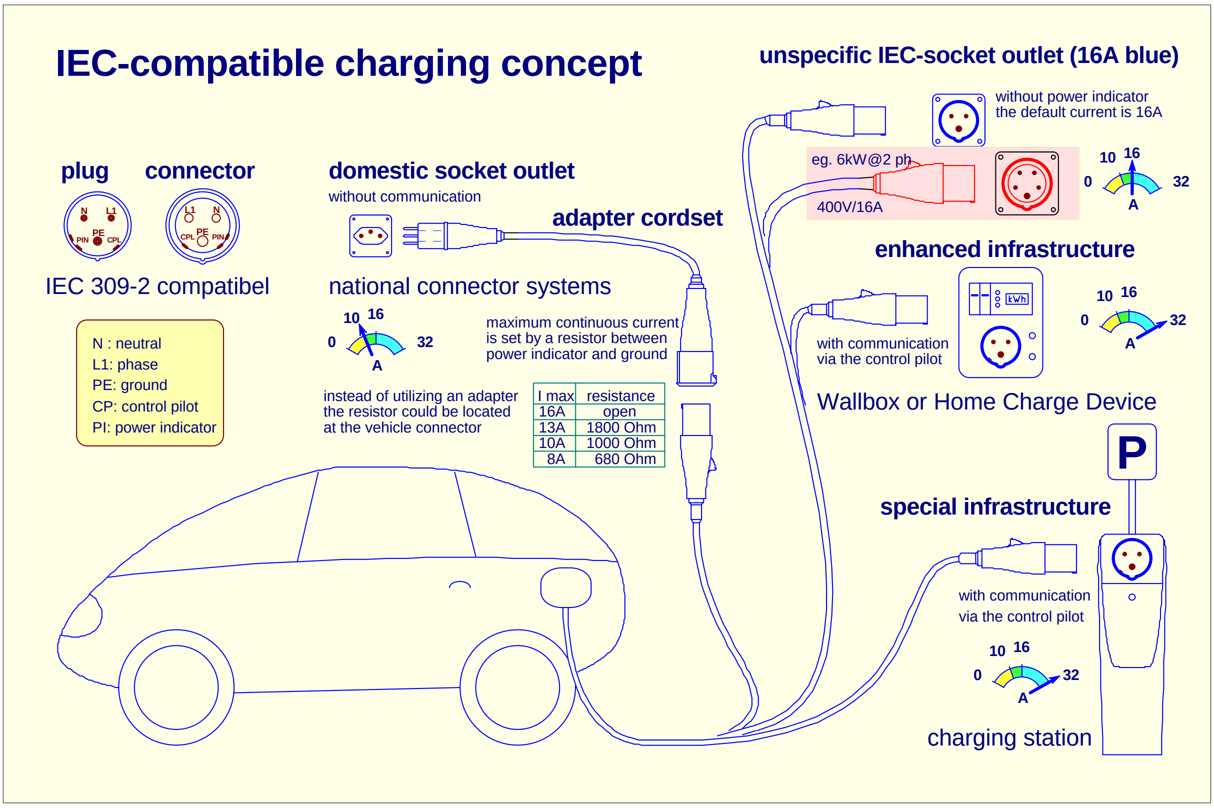


Figure 5: Implementation of the downwardly compatible OMNICHARGE architecture

4.2 Degrees of compliance

4.2.1 On board chargers

Any existing on board charging equipment, designed for mains operation will partially comply to the system.

At the part of the vehicle, on board chargers are to be seperated into three groups:

charger	additional safety features	means to provide
Group 1 unadjustable	none	
Group 2 adjustable	recognition of domestic plug rating	Power Indicator
Group 3 Full compliance to mode 3	recognition of domestic plug rating adjustment of real time available load current energisation and deenergisation at supply point indication of ventilation requirement of the charging area	Power Indicator Control Pilot

Table 3: Additional features of on board chargers

4.2.2 Vehicle interface

The vehicle interface, if any, must provide the corresponding power and communication paths according the specification table given in the previous section.

In case of lack of additional pins, as it would be the case with the AVCON™ Interface for the Power Indicator, the information must be translated into the Control Pilot signal, which is mandatory by the standard proposal.

4.2.3 Socket outlet

Regardless of the type of socket outlet, the basic protection against direct and indirect contact must be provided at the infrastructure side.

Three groups of sockret outlets could be defined:

Outlets	additional safety features	means to provide
domestic	none, insufficient durability	none
industrial	none	none
Omnicharge	Electromechanical verification of proper insertion Verification that the vehicle is properly connected Continuous protective earth conductor integrity checking Energization of the system De-energization of the system Determination of ventilation requirements Adjustment of the real time available load current	Microswitch Control Pilot

Table 4: outlet possibilities

4.3 Performance of the combinations

Each power level is the result of the actual link of components and their safety features and complies to the limitations given in the IEC standard proposal.

	Domestic outlet*	**Industrial outlet**	**OMNICHARGE**
Unad-justable charger	230V/400V, 10A	230V/400V, 16A	230/400V, 16A
Adjustable charger	230V/400V 16A	230V/400V, 16A	230/400V, 16A
Full compli-ant charger	230V/400V 16A	230V/400V, 16A	230V/400V, 32A

*) depends on the rating of the socket outlet

Table 5: performance of combinations of partial or full compliant components

The safety features are also a result of the actual combination. According to the IEC standard proposal, only the specific outlet, combined with a full compliant charger, is classified as mode 3. **All other combinations are mode 1** and are not suited for public charging areas.

	Domestic outlet	**Industrial outlet**	**specific outlet**
Unad-justable charger	insufficient durability		verification of proper connection deenergisation at the supply point
Adjustable charger	recognition of plug ratings	recognition of plug ratings	verification of proper connection deenergisation at the supply point
Full compli-ant charger	recognition of plug ratings	recognition of plug ratings	verification of proper connection energisation and deenergisation at supply point continuous protective earth checking adjustment of real time available load current determination of ventilation requirements of the charging area

Table 6: additional safety as a result of the actual combination

4.4 Means to provide additional safety

4.4.1 Control Pilot

The Control Pilot (former called Safety Pilot) is an additional means to increase safety and reliability of the charging process of an EV.

Features and functions:

- Electrical verification that the vehicle is properly connected
- Continuous protective earth conductor integrity checking
- Energization of the system
- De-energization of the system
- Supply rating recognition by the vehicle
- Determination of ventilation requirements of the charging area
- Detection/adjustment of the real time available load current of the supply equipment.

Technical realisation, compatible to SAE1772

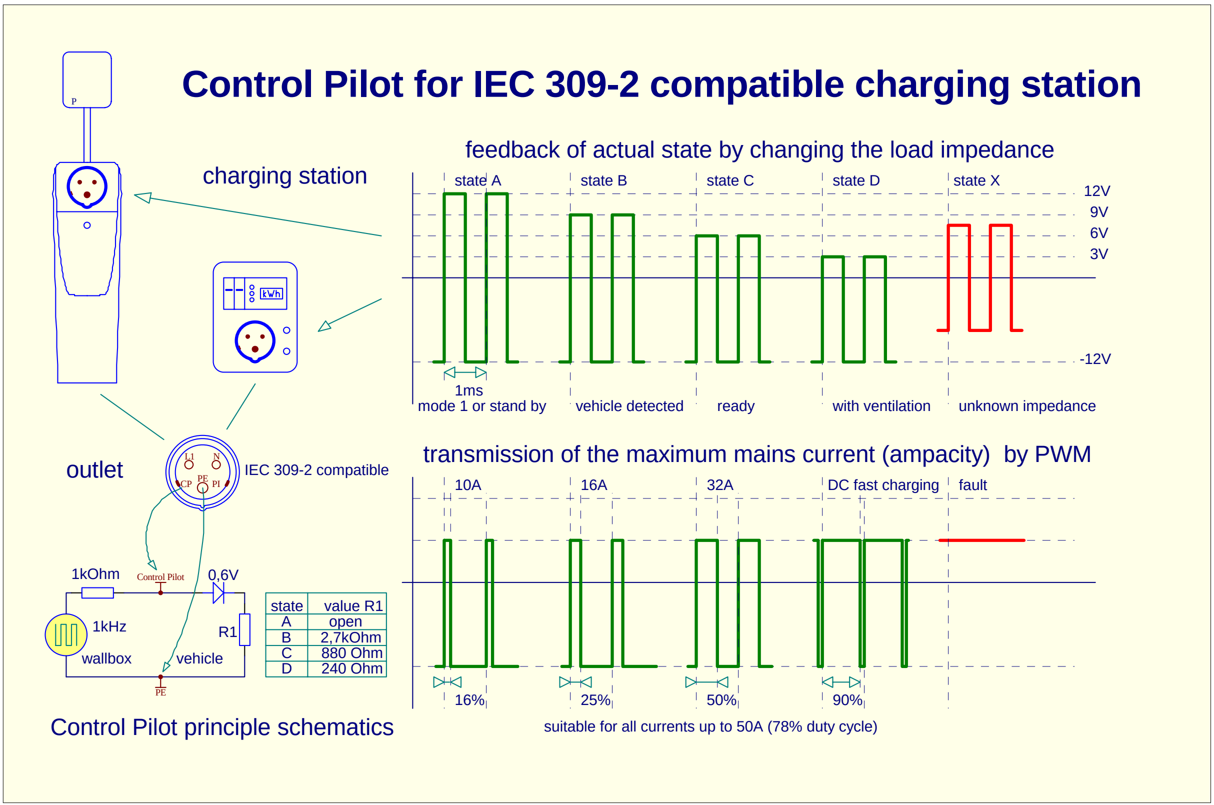


Figure 6: Control Pilot communication according SAE 1772

Vehicle detection

The load impedance on the vehicle side consists of a resistor, connected in series with a diode. The negative half wave of the control pilot signal remains unloaded. Therefore the wall box can distinguish between the presence of a vehicle and an unintended turn on request e.g. caused by a wet finger.

Information from the vehicle to the wallbox

Communication from the on board charger to the wallbox is provided by changing of the load impedance. Totally four operating states (A, B, C and D) one idle state (I) and one error state (X) are possible.

(refer to the following table)

Information from the wallbox to the vehicle

The maximum allowed mains current is indicated by the duty cycle of the control pilot signal.

In the US the duty cycle of the control pilot signal indicates the rated current of the actual connection including socket outlet (if any), cable and vehicle inlet. It prevents the on board charging system from recharging at an insufficient source.

For domestic charging at common outlets the control pilot generating unit is attached with the charging cable (mode 2).

For Europe it is intended to use a modified IEC connector at the wall side both for domestic and public charging stations capable of delivering 32A. This connector has the same mechanical dimensions as the already existing single phase 16A device (coloured blue) but one of its 7 additional contacts is dedicated for the control pilot.

Although the same signal forms are implemented to provide control pilot functionality, the information of the maximum current is used to adjust the on board charging system according to the given limit.

A decrease of the default value of 32A will be an exception:

- for a short period, to avoid undesired peak loads (the vehicle is used to balance mains load)
- programmed by the user to gain low tariff facilities
- permanently if the supply is rated for a lower than the default current e.g. domestic places

Both approaches are compatible to each other. The US 60Hz 240V/208V source is basically compatible to the European single phase 50Hz 230V source.

A car designed for the US market could be operated in Europe without any major changes of the on board charging system.

Coding of the standard current values (IEC 38)

current [A]	6	10	16	25	32
duty cycle	25/256	5/32	1/4	25/64	1/2

US ratings are different for continuous and short term operation. The duty cycle will cause slightly different values in the OMNICHARGE system:

duty cycle	**SAE1772**	**OMNICHARGE**
0,5	30A cont. / 36A peak	32A
0,4	24A cont. / 30A peak	25,5A
0,3	18A cont. / 22A peak	19A
0,25	15A cont. / 20A peak	16A

Table 7: duty cycle to mains current characteristic

State chart of the OMNICHARGE charging station (compatible to SAE1772)

state	load	condition	Reaction of the station	control pilot signal
O		nothing plugged in	stand by	-12V static
trans 0		plugging in	mechanical switch produces master reset	-12V static
I	any load	An IEC 309-2 connector was plugged in; detection by a microswitch	No energization, Reset of the control unit	-12V static
trans 1 unidirect	any load	Start signal detected 1. no impedance at the control pilot 2. all other defined impedances a wrong impedance	The impedance of the control pilot circuit is measured. transition to state A1 (mode 1 with the 16A path energized) will cause immediate transition to the corresponding state leads to state X	1kHz, duty cycle depends on ampacity positive 12V, pulse
A1	open	no Control Pilot communication, open end	Line current limited to 16A. **Mode 1 charging** still waiting for response	1kHz, duty cycle depends on ampacity positive 12V, pulse
B	2.7kΩ +diode	A mode 3 compatible vehicle has been connected but is not ready for energy delivery.	The vehicle is detected and the charging station waits for transition to C.	1kHz, PWM, 1kΩ internal resistance positive 9V, pulse
trans 2		vehicle changes impedance from 2.7kΩ to 880Ω (240Ω)	Releasing of the 32A path	transition from positive 9V pulse to positive 6V (3V) pulse
C	880Ω +diode	A mode 3 compatible vehicle is connected and ready for energy delivery. The direct transition from A to C without the intermediate step B is also allowed.	Mains will be delivered to the socket outlet protected by a 32A line fuse The continous current is equal to the ratet value	1kHz, PWM, 1kΩ internal resistance positive 6V, pulse negative -12V, any state

D	240Ω +diode	Same as C with the requirement that ventilation of the charging place must be switched on.	Outdoor same as C. If no sufficient vent. could be guaranteed, no energy delivery is allowed.	1kHz, PWM, 1kΩ internal resistance positive 3V, pulse
trans 3 bidi rect.		interruption of the control pilot	32 A path will be deenergized immediately or remain deenergized (from state B)	transition from positive 9V (6V or 3V) pulse to positive 12V pulse
A0	open end	A mode 3 compatible vehicle has been detected previously and is still connected with interrupted pilot.	stand by state. A reestablishment of the control pilot circuit is accepted at any time.	1kHz, duty cycle depends on ampacity positive 12V, pulse
X	any value	The diode is missing.	no energy, no reset.	negative less than -12V, pulse
trans 4		unplugging	transition to state O	-12V static

Table 8: state chart for control pilot communication

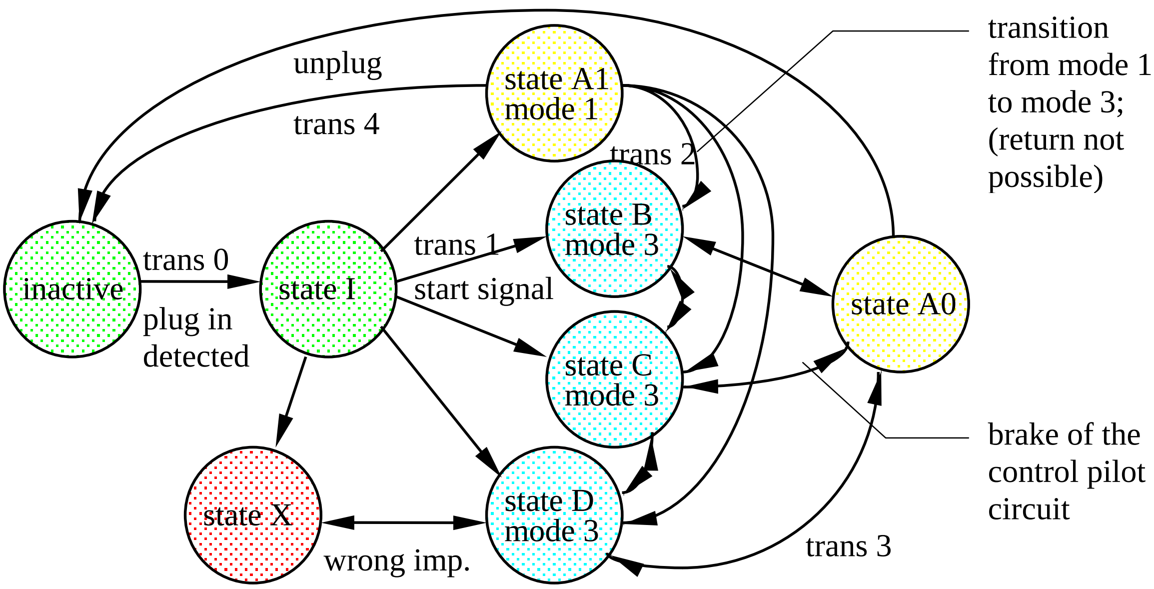


Figure 7:State event diagram of the control pilot communication

4.4.2 Power Indicator

Purpose of the power indicator

Due to the necessity to allow mode 1 charging in some countries, a Power Indicator is to be defined to prevent the on board charger from drawing more current as the unspecific socket outlet is able to deliver.

- connection rating recognition by the vehicle

By indicating the actual rated current either safety as well as convenience of mode 1 charging is improved.

How the Power Indicator works

Mode 1 charging occours in domestic areas but however it requires a relieable connection to mains. Therefore the usage of IEC 309-2 / 16A devices is highly recommended.

Without any information, the on board charging system should default to 16A, whatever its rated power would be. In this case the presence of a IEC 309-2 connection is assumed.

National plug and socket systems may have lower ratings. The Power Indicator is intended to accomodate even these charging facilities at the maximum possible safety level.

The indication of the actual ampacity is realised by a resistor built in the AC charging cordset. This resistor could either be sensed directly by the on board charging system or by an in cable protection device, if any. The latter is necessery if the power indicator is used in connection with a vehicle inlet, not providing additional pins for the power indicator circuitry.

Specifications of the Power Indicator

The actual ampacity of the particular plug and socket system is coded in a ratio of two resistors. One is fixed at 1kOhm and located at the receiver which is either the on board charger or the in cable protection device. The other one is located somewhere between the receiver and the plug. The voltage at the center tap of both resistors with respect to the supply voltage provides the information. The characteristic between voltage ratio and ampacity is linearly.

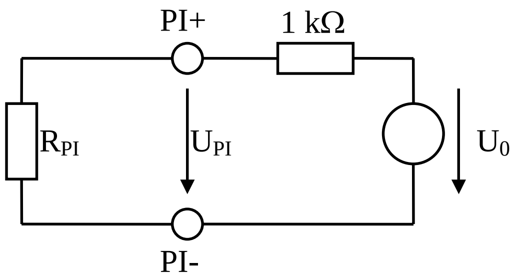


Figure 8: Power indicator schematics

To ensure a minimum measuring current, the maximum mains current is coded at 80% and above of the supply voltage:

$$I_{mainsAC} = 20\frac{U_{PI}}{U_0}, \qquad I_{\max} = 16A\text{, } U_0 = \text{open circuit voltage}$$

Special functions of the Power Indicator

In some cases it may be required to enable an AC current exceeding the 16A limit. This feature could be achieved by adding an additional component to the external resistor and to process the impedance:

The internal voltage source becomes a symmetrical bipolar 1kHz square wave generator as it is used for the Control Pilot. Both the positive and the negative voltage at the PI+ is sensed. The corresponding mains current is to be calculated as follows:

$$I_{mainsAC} = 20 \cdot \frac{2U_{positive} - U_{negative}}{U_0}\ \text{[A]}, \qquad \text{, } U_0 = \text{open circuit voltage}$$

With a simple resistor, the formula reproduces the same result as the previosly described solution. By adding a diode, the characteristic will change. There are two possibilities:

characteristic #1: diode in parallel to the indicating resistor

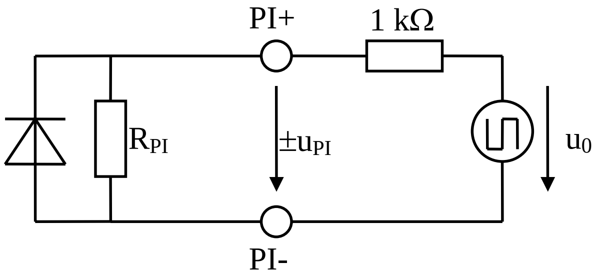


Figure 9: Power indicator with enhanced indicating range

The diode will double the proportional factor. This will result in the formula:

$$I_{mainsAC} = 40 \cdot \frac{U_{PI}}{U_0} \text{ [A]}, \qquad I_{\min} = 0A,\; I_{\max} = 32A$$

characteristic #2: diode in series to the indicating resistor

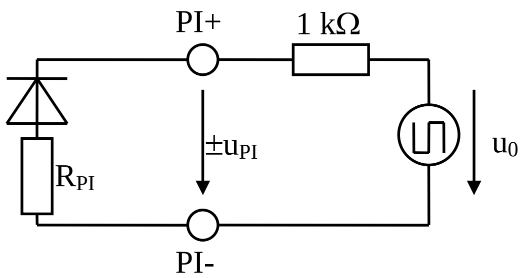


Figure 10: Power indicator with shifted indicating range

In this case the diode causes an offset of 32A. The proportional factor changes its sign:

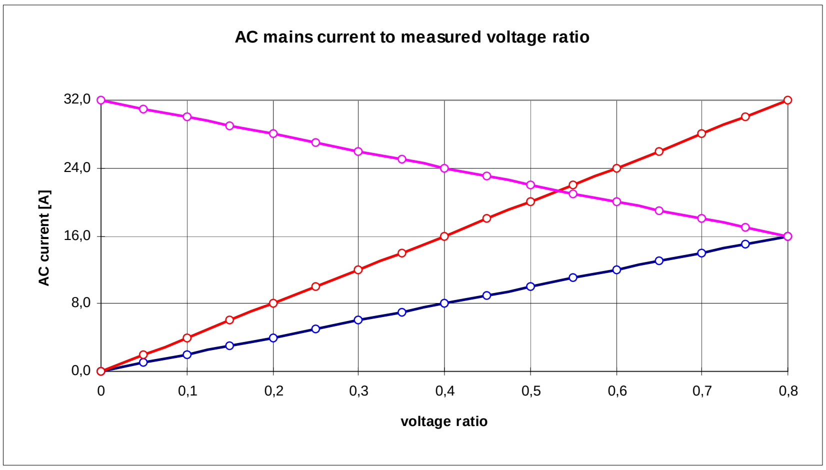
$$I_{mainsAC} = 32 - 20 \cdot \frac{U_{negative}}{U_0} \text{ [A]}, \qquad I_{\min} = 16A,\; I_{\max} = 32A$$

Resistor values

voltage ratio	$R_{Power\ Indicator}$ [kOhm]	I_{ac} standard. [A]	I_{ac} char.#1 [A]	I_{ac} char.#2 [A]	R (E24) [kOhm]
0	0,000	0,0	0,0	32,0	
0,1	0,111	2,0	4,0	30,0	0,110
0,2	0,250	4,0	8,0	28,0	0,249
0,3	0,429	6,0	12,0	26,0	0,430
0,4	0,667	8,0	16,0	24,0	0,680
0,5	1,000	10,0	20,0	22,0	1,000
0,6	1,500	12,0	24,0	20,0	1,500
0,7	2,333	14,0	28,0	18,0	2,400
0,8	4,000	16,0	32,0	16,0	
0,9	9,000	16,0	32,0	16,0	
1,0	open	16,0	32,0	16,0	

Note: The diode must show a very low forward voltage.

Table 9: Power indicator resistor values for connection rating recognition



Legend: standard characteristic diode in parallel diode in series

Figure 11: Characteristics

4.4.3 Full insertion sensor (FIS)

description

To prevent the power contacts from plugging and unplugging under load, the wallbox-contactor is also controlled by a sensor, which detects the full insertion of the plug into the socket outlet.

realisation

Unplugging will release the switch, before the power circuit is interrupted mechanically. To achieve this with IEC 60309-2 devices, the switch must be operated between 4 mm and 7mm distance from the full insertion point.

This electreomechanical measurement provides additional safety, where no control pilot is applicable.

4.5 Connecting devices

IEC 60309-2 compatible plug and socket system

The mechanical outline of the hereby described devices is fully compatible to the 16A IEC 60309-2 plug and socket system (well known as 1Φ/230V/16A „camping“ und 3Φ/230V|400V/16A „red three phase plug“). Therefore they can be connected to unspecific standard devices in any case.

Both special devices connected to each other provide additional signal and pilot paths. Due to the guaranteed no load plugging, the contacts are rated for 32A continuous current. For conductive charging above the 16A level an additional means of safety and communication provided by an intelligent control pilot is highly recommendet and mandatory in the USA (SAE 1772).

Presently these devices are not subject of an industrial production. However, they are available for small quantities and already utilized in the Swiss test market project, established in Mendrisio.

Function of the additional pins

Nr.	contact	functions	sc.
1	Control Pilot	Vehicle detection, ground continuity checking, shut off at the point of supply, transmission of the maximum current, detection of ventilation requirement;	CPL
2	Drive train interlock	If the device is used as a vehicle interface, driving should be disabled, if a charging cable is engaged.	DTI
3	Data (hi)	In symmetrical systems e.g. CAN-bus it will be CANH, in other cases (e.g. RS232, SAE1850) the single data path.	DHI
4	Data (gnd)	Not used with the CAN-Bus or RS 485, else signal ground	DGD
5	Data (lo)	Only utilized with symmetrical Systems (e.g. CAN-bus, RS485)	DLO
6	Power Indicator	The Power Inticator provides ampacity information for the on board charger in case of mode 1 charging (no pilot provided). If it is left open, the default current will be 16A.	PIN
7	Power Indicator	Ground path of the Power Indicator (ELV, near to PE)	PI0

Table 10: Additional auxilary contacts and their function

Position of the auxilary pins

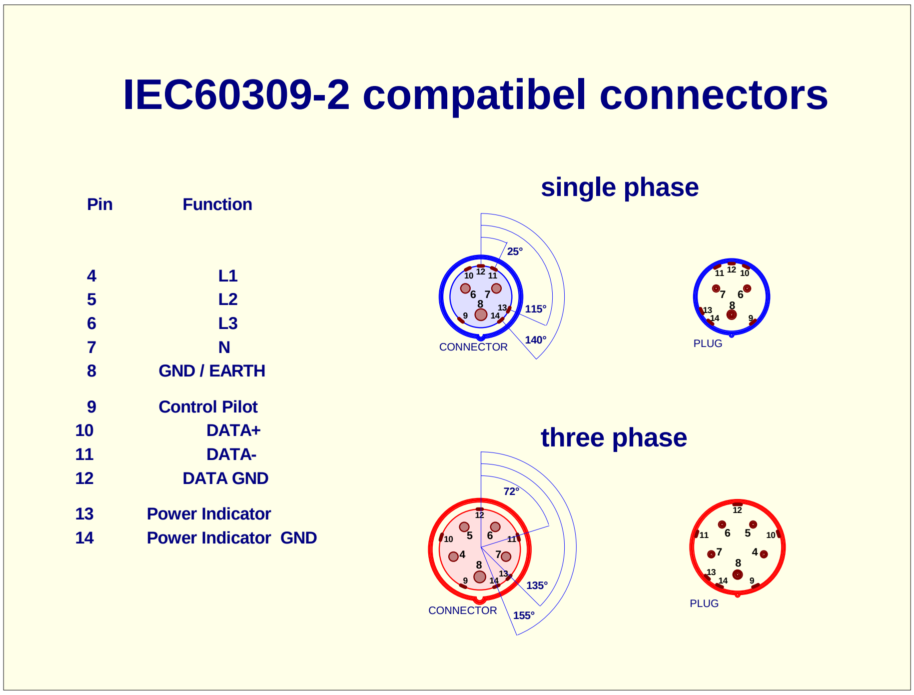


Figure 12: Position of additional contacts

4.6 Wiring examples

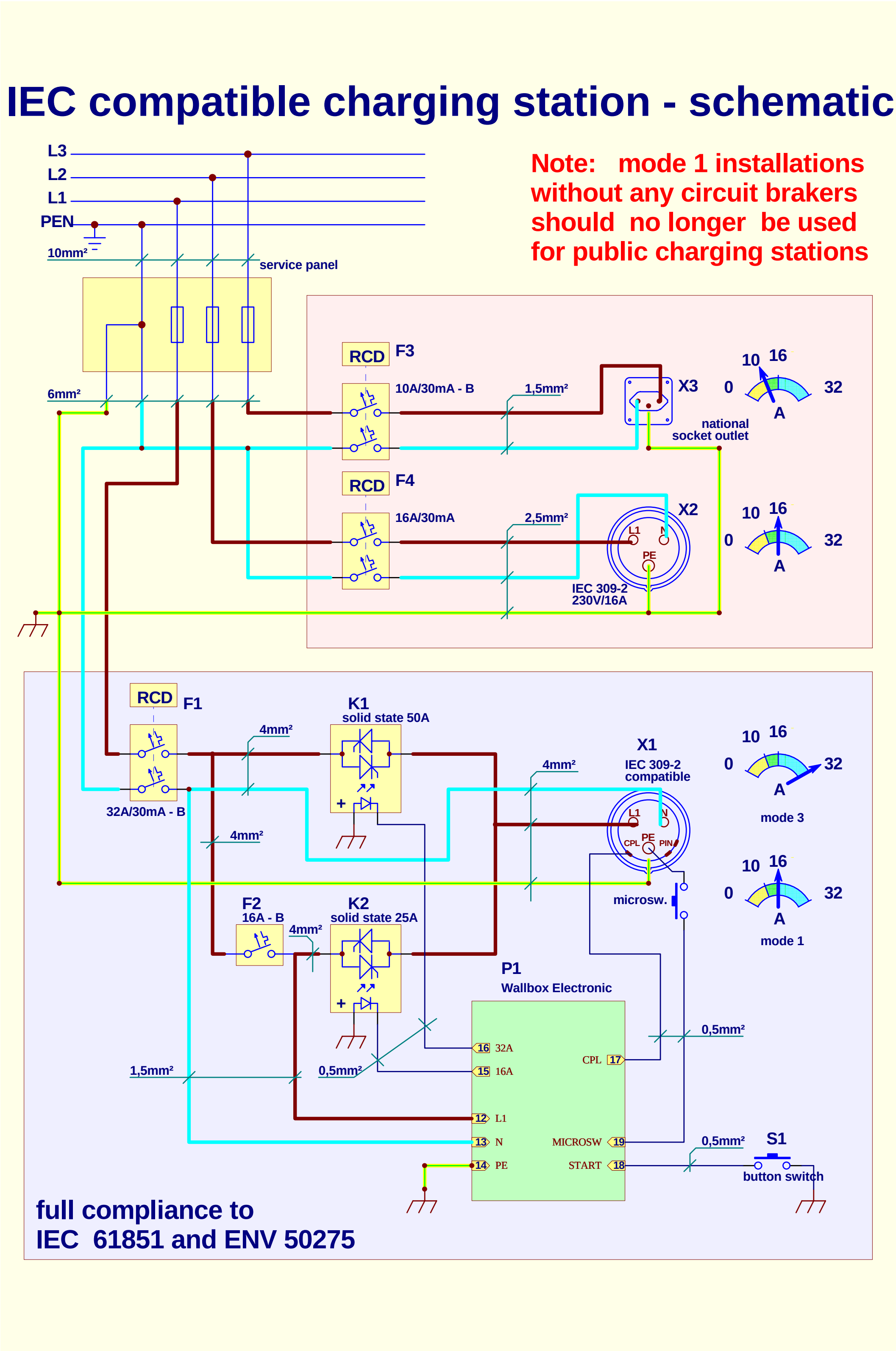


Figure 13: Wiring schematics for a full compatible charging station

4.7 State chart of a full compatible vehicle

state	**mains**	**condition**	**state of vehicle**	**set input current**
P	no	no connector at inlet	ready for drive state	charger inactive
trans 0		connecting connector	drive train interlock activated	charger activated
A0	no	no control pilot detected no energization	measuring impedance on Power Indicator	according PIN, 16A maximum
trans 1	no	control pilot detected		
B	no	control pilot communikation present	prepearing to charge if source is compatible	set according the given limit
trans 2	no	control pilot communication present	vehicle requests state C or D	set according the given limit
C or D	yes	station energizes connector	mode 3 charging	set according the given limit
2.1	no	CPL communication present, connector deenergized without request	vehicle detects forced charging break or mains fault	set according the given limit
C0 (D0)	no	charging request still valid	vehicle waits for mains	set according the given limit
2.2	no	CPL interrupt, connector is not energized	vehicle detects mains break down. Actual state of charge stored, default to 2.7kΩ, waiting for CPL, default to A0	default to: according PI, 16A maximum
trans 1.1	yes	connector gets energized no CPL communication	vehicle recognizes mode 1 connection	according PI, 16A maximum
A1	yes	connector energized, no CPL communication	measuring impedance on Power Indicator, charging at mode 1	according PI, 16A maximum
trans 1.2	yes	CPL detected during charging at mode 1	unsafe charging station alert	shut down to 0
trans	yes	connector is energized,	unsafe charging station	shut down to 0

2.3		when R_{CPL}= 2,7kΩ	alert	
F	yes	connector energized	charging withdrawn	shut down to 0
trans 3		connector unplugged	end of charge period, data saving, transition to state D	

Table 11: state chart at the vehicle side

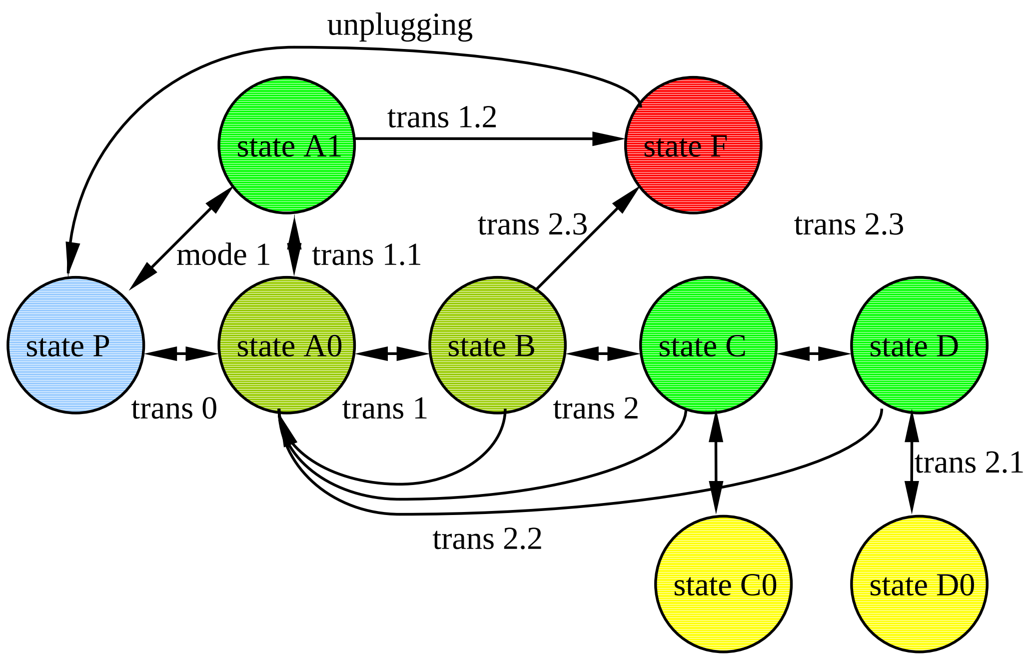


Figure 14:state event diagram at the vehicle side

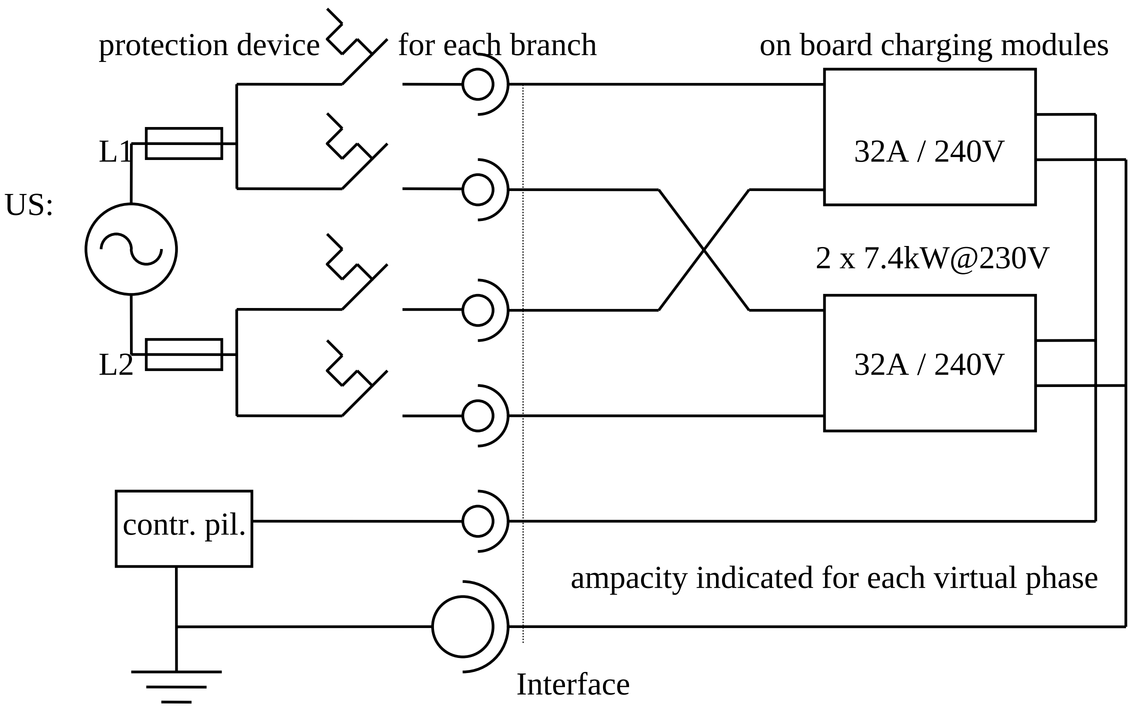
5 Compatibility to the US conductive charging system

In the U.S. there is a significant number of existing conductive charging stations. Therefore any new conductive charging standard should at least be compatible to the U.S. standard SAE1772

5.1 virtual 2-phase system to get 15kW from the 240V US infrastructure

Many countries in Europe have a three phase distribution system. Such a powerful on board charging system could also work at the U.S. infrastructure.

The suggestion is applicable for interfaces, which provide 4 contacts for AC to accommodate also the 3-phase system. If all contacts are specified for 32A (continuous) current, a real 60A architecture utilizing all 4 pins becomes feasable:



advantages:

- all four AC pins are rated only for 32A
- no change on control pilot specification needed
- the charging cable consists of more wires at the same cross section which leads to a smoother appearance of the device

- the control pilot has 50% duty cycle for 32A each virtual phase which will be the same for a 2-phase 208V-connection and the same for an european 2-phase connection.
- All protection devices needed could be the same all over the world and the AVCON is utilized optimally.
- Increasing the phase current to 50A will still be possible and provide space for future development.
- very easy upgrading of charging station and vehicle from 32A to 63A possible

5.2 modifying the control pilot signal specification to achieve higher power

As long as SAE 1772 is presently used only below 32A, the upper region of the duty cycle-could be defined to provide more indicating range.

The problem is the „lack of duty cycle“ for more than 50A continuous phase current. On the other hand existing equipment is already utilizing the SAE 1772 progression (see the next chapter) and needs a compareable high resolution at lower currents.

The suggestion would be to have a higher progression at duty cycles above 50% as follows:

- for low power 0.25A / digit of an 8-bit counter which leads to 32A at 50% duty cycle
- for higher power 0.5A / digit for more than 50% duty cycle which would lead to 64A continuous @ 75% duty cycle

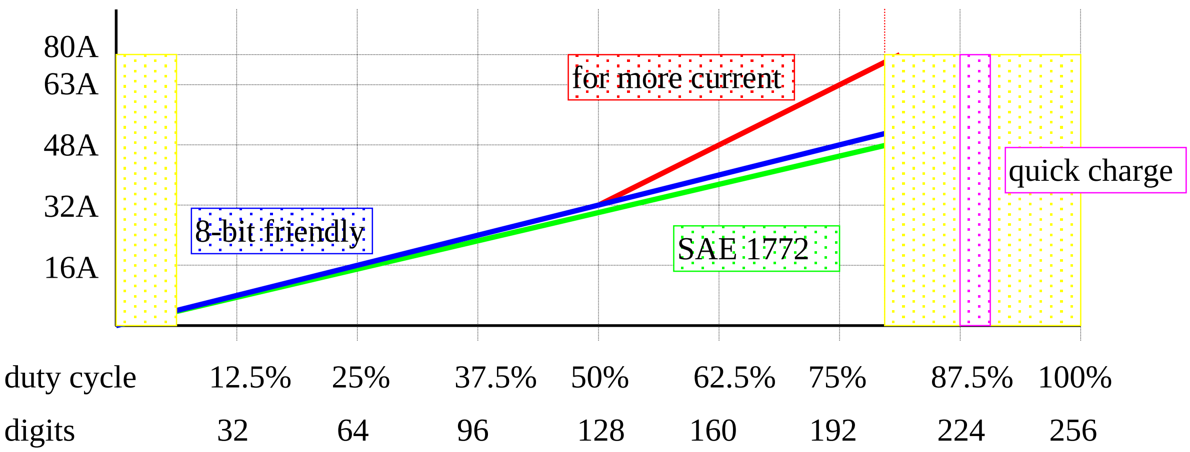
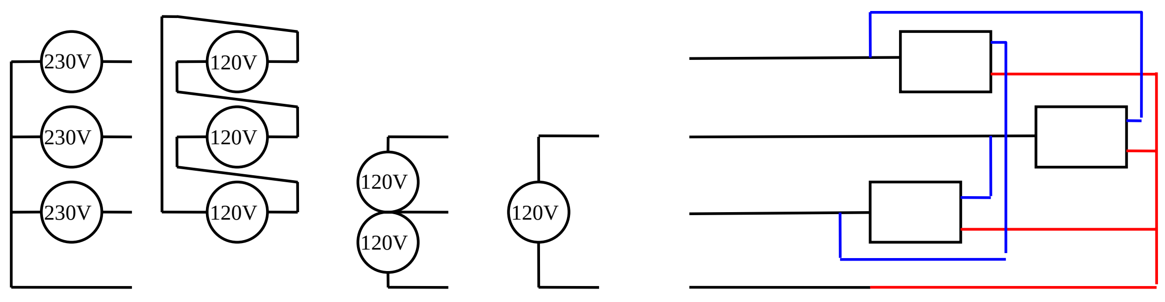


Figure 15: proposal for alternative control pilot characteristics to increase the current range

5.3 considering the 208V system for US public charging stations

If this is desired, it could make sense to design the vehicle inlet to up to 50A phasecurrent:



EU 3-phase US 3-phase   US 240V   US 120V   EU: red wiring, US: blue

For the US 3-phase the charging modules have to be wired in Δ, for european 3-phase in Y