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SAFETY RULES FOR USE IN ELECTRIC VEHICLE CHARGING INFRASTRUCTURE

Abstract: *Development trend in automotive industry is based on development of electric vehicles (EV) and supporting infrastructure. To ensure safety of users and user friendly interfaces, complex systems of power electronics, high voltage and current levels, as well as control systems in real time have priority in research and development. This paper presents an overview of technical solutions and standard procedures related to systems infrastructure for EV power charging, protocols for connections and security systems.*

Key words: electric vehicle, charging infrastructure, standards procedures, connections.

INTRODUCTION

The development and use of EV are growing every day in despite of very high investment costs. However, EU directive on energy efficiency with addition to industry problems foreground the problem of energy consumption in transport which makes up to 30% of total energy consumption. Planning of Smart Grids Systems, using of alternative sources and pollution problems are moving the boundaries of research and design of EV system in direction from consumers to vehicles with accent on main problem which is storage and production of energy. All this changes are affecting the technology used in vehicles, so in present day vehicles with ICE engines have significantly improved efficiency, hybrid vehicles are increasingly appearing and domination of EV in future is ensured.

Each development of new technology in engineering (security levels and protection systems) is going through certain stages:

a) *Conceptual stage* – scientific researches with the pioneering research in discovering of new technology.

b) *Prototype testing of limited edition* - phase when development is based on technology closest to prototype technology and already present regulations and safety standards (which to some degree restrict the development of prototype).

c) *Market stage* - competition leads to the selection of the most appropriate solutions adapted to customers. At this stage, new standards are introduced to protect consumers (safety and quality) which directly have influence on the promotion of "severe" manufacturers who have actually contributed the prototype development and new standard definitions.

CHARGING UNITS FOR EV

The purpose of the electric charging units is to ensure a fast charging with compliance of all necessary security measures to avoid any accidents.

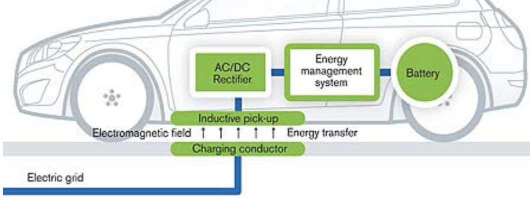
Due to the economic profitability the goal is to provide customers with comfort, safe usage, efficiency and that product is economically viable for investors. Apart from the technical point of EV charging with the electricity, charging unit must ensure the way of payment system.

Types of Charging Station - mode of energy transfer

There are two basic modes of electricity transfer from the Charging Station in EV: *conductive* (using electric cables) and *inductive* (using variable electromagnetic fields, electromagnetic resonance and Faraday law). Each of these modes has its advantages and disadvantages.

Conductive systems have the ability to transfer large amounts of energy in a short time with negligible radiation to the environment. However, there is a big problem with the connection and disconnection, the risk of electric arch (especially problematic for DC current) and the problem of moisture and leakage currents [1].

Inductive systems have a great advantage of comfort because the physical contact between charging stations and vehicles is not required. Today's solutions provide a relatively large transfer of energy in a short time (still under development) but have a major problem with strong electromagnetic radiation which is very unhealthy.



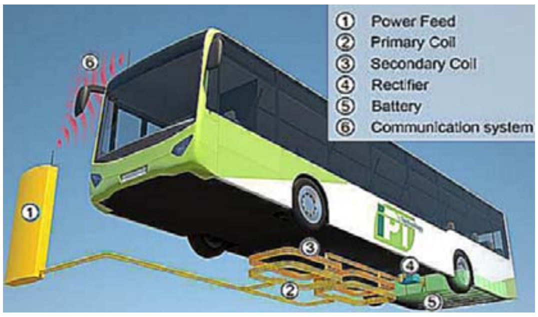


Figure 1. *Display solutions for induction methods for charging electric vehicles [2, 3]*

On today's market criteria's of safety and radiation are more rigorous and significantly tightened in the parts of electrical engineering and telecommunications. This criteria's represent an important obstacle to the development of this mode of energy transfer [2].

Types of charging stations - power of charging

There are several standards of charging levels which main difference is associated with a term called charging speed. Greater speed of charging is ensured by more power from the charging stations. This understands that system in EV is sufficiently prepared to accept the greater amount of energy (faster charging generally includes a high DC voltage and charging current).

Types of charging station - security communication protocol

Standards define number of charging modes between the vehicles and charging stations. Fast charging makes EV more useful because drivers of vehicles are insured that they can quickly recharge an EV. Fast charging is often unnecessary, because the optimum charging rate varies depending on the usage of EV which depends on driver.

EV CONDUCTIVE CHARGING SYSTEMS

There are currently two main standards in the world related to the development of EV: American J1772 SAE (Society of Automotive Engineers) and European IEC 61851 (International Electro technical Commission) standard.

The development of industry related with EV production in different regions of world tries to impose its own technical solutions. Standards for electric vehicles prescribe permissible levels of voltage and current amounts, ways of connection between the charging station and vehicle, communication and protocols of charging. Basically, these two standards are different. The American standard prescribes only charging levels, while European standard prescribes charging levels and safety communication protocols.

According to IEC 61851 (Electric vehicle conductive charging systems) and from it emerged standard IEC 62196 (Plugs, socket-outlets, vehicle couplers and vehicle inlets - Conductive charging of electric vehicles) four different modes of charging EV are defined as [1]:

- Mode 1: slow charging of EV from regular outlet without special protection.
- Mode 2: slow charging of EV from regular outlet, but with built-in protective element.
- Mode 3: slow or fast charging of EV through special outlets with control and protection functions.
- Mode 4: quick charging of EV using a special construction of charging stations.

Mode 1 - Household socket and extension cord

This type of connection is the simplest and it emerges from the initial development phase of the EV. Charging station, in this case a standard household outlet 240V (10A) without any special protective elements, with standard protection systems of in-house installations (grounding system, circuit breaker for overload protection and residual current device (RCD). Connectors used in this mode have no control pins and there is no system of communication between the source and load, neither connecting cable has special protective elements.

Figure 2. *"Mode 1" type connection [1]*

This connection system has many deficiencies that can lead to damage. Very often, users have no idea how in-house installations are performed (neither they have necessary technical knowledge about it). It can easily be seen whether the socket satisfies basic requirements of protective grounding but it is more difficult to know if the corresponding fuse and circuit is a stand-alone circuit or connected in parallel with some other loads. Also, assumption is that cross section of the installation is minimum 2.5mm^2 (which is not always present in practice) and that intensive charging with maximum current will not result with overheating of the installation and possible hazards.

Figure 3. *Different National Domestic Electricity Supply Socket Outlets Available for charging mode 1 (240V, 10A) [4]*

Limitation of home installation wiring is 5,7 kW and charging time is less than 10 hours. Without system of control it is easily possible that those restrictions are to be disregard which will in long-term of use (the assumption is that the user will use the same socket on daily base) potentially increase the risk of failure. Practice shows that this type of potential hazard is the most common cause of fires in homes even for consumers which require less power for EV charging.

Mode 2 - Domestic socket and cable with a protection device

More intensive usage of the home ports for charging EVs and development of protective systems imposed the following technical solution that later becomes adopted as a standard. This solution improved the most accessible part in the chain of supply: household installation - connecting cable - EV. Because it has been not developed and because advanced battery charging system with increased intensity with modifications to house installation has not been practical, standard prescribes the improving of connection cable with protection device built into the cable.

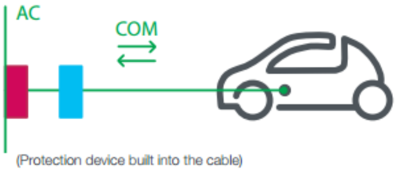


Figure 4. *Mode 2 type connection [1]*

By installing the protection device in connecting cable on the side of the house installation, protected zone is increased. Built-in protective element, according to IEC 61851-1, contains the RCD switch which protects from electric shock and can control and operate the amount of charging current. This also includes built-in fuses for protection from overheating and over current. Such approach mode of protection implies protection of all devices in EV, protection of connecting cable and indirectly protects the house installation by control of the charging current. For this reason, this mode can use a three phase plug (thereby charge current is increased to 32A).

Mode 3 - Specific socket on a dedicated circuit

Numerous deficiencies in high safety requirements which appear in mode 1 and mode 2 are detected simply by requirements of modern life style. Only solution of these problems was complete change of the approach. Existing installation for connection with EV in households is changed to industrial charging station which is designed, implemented and controlled under the supervision of technical staff. Charging stations designed in such way according to existing standards has integrated all necessary management, control systems, fuses for overvoltage and overcurrent protection, as well as the RCD switches.

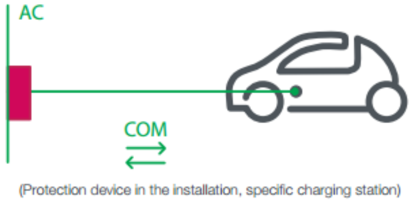


Figure 5. *Mode 3 type connection [1]*

This connection form for EV charging stations ensures complete protection and ensures controlled charging conditions. With Mode 3, the voltages and charging currents in relation to Mode 2 are lifted to a higher level, which ensures shorter charging time of EV. Controlled energy charging system in the EV energy storage can vary the charging currents and extend the battery life, but also can provide a system protection against thermal and overvoltage stress. Safety rules regarding to access of inside parts and IP protection are equal to standards defined in Mode 2.

Mode 4 - Direct current (DC) connection for fast charging

Development of battery energy storage systems (batteries + battery management system) in recent years made it possible that charging of EV occurs with much higher voltages and currents. Observed shortcomings regarding the efficiency of energy conversion (AC to DC) and problems with protection of many (unnecessarily) complicated systems (arc suppression system of the AC current is substantially different from the system for DC currents and thus protective systems must be separated which complicates the management) are detected.

Manufacturers of EV produced a power system in which all complicated systems are transferred to system of charging station, which according to standard mode3, becomes a mini industrial plant with all the necessary technical systems for control and protection. Changes in standard Mode 4 comprehend the changing of connector and connecting cable form which is now designed for the DC current up to 400A and voltages up to 400V.

The systems in the vehicle must be dimensioned for such high power because this provides the charging time of vehicles in less than 20 minutes which is important for the end user of EV.

Communication system in standard Mode 4 is advanced and provides all benefits regarding to the smart grid systems and market of energy. In this way the end user of EV have a very simple system of connection, control of charging and payment of purchased energy. This system even allows the return of energy to electricity system (the last generation of smart grid systems is actively using energy storage in vehicles to balance with electricity system).

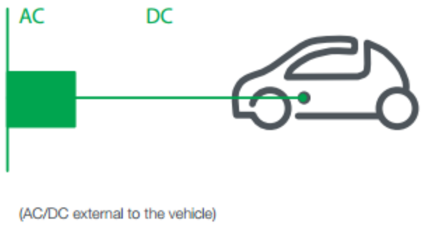


Figure 6. *Mode 4 type connection [1]*

It should be noted that industrial quality and protection systems used in standards in Mode 3 and Mode 4 are not applicable in domestic ports, primarily due to the cost of the system and necessary connection power (charging station power > 50kW).

This implies that industrial systems have a commercial benefit only if they are applicable to a multiple users. The most commonly in use today are power supplies of vehicles in public transport. Cost of personal EV which has the technical possibility to use mentioned charging stations are still priced very high (hence rare time on the road).

EV CHARGING CABLES CONNECTORS

According to previously mentioned standards in practical application AC terminals of different voltage levels and DC terminals are used. Thus, the standard IEC 61851 for system connections of EV was reduced to three basic types shown in Figure 7.

Characteristics	Type 1	Type 2	Type 3
Phase	Single-phase	Single-phase/ 3-phase	Single-phase/ 3-phase
Current	32 A	70 A (single-phase) 63A	32 A
Voltage	250 V	500 V	500 V
No. of prongs	5	7	5 or 7
Shutter	No	No	Yes
Diagram			

Figure 7. *Three types of "electric vehicle" connectors according standards IEC 61851 [1]*

J1772 connector 2009 (Figure 8) has been developed for the US market and later incorporated into the European standard IEC 62196-2 as type 1 connector for use in mode 2 (single phase household installation). Due to market demands, voltage levels of 110V and 240V, up to a maximum current of 32A are provided. As it can be seen in Figure 8, the Type 1 connector have two main pins for power transmission, one pin for protective earth (grounding), and two small signal pins. Protection against direct contact is made by pin isolation in the plug and insuring that there is no power in the socket and pins until connection establishment and insuring that the outlet console has a lid.

Figure 8. *Type 1 connector J1772 2009 and Nissan LEAF connection cable [5]*

In order to provide protection, plug connectors are constructed separated in way to first give command for cutting the power of connecting place. This way of plug construction prevents the phenomena of electric arc on the connection point. The device protection with Mode 2 is on the side of the connector connected to the house installation, while Type 1 connector (J1772 2009) is on the side of power cable that goes into EV.

Connector Type 2 VDE-AR-E 2623-2-2 (popularly called Mennekes connector according to manufacturer who developed the connector) has primary advantage over previous because it have possibility of connection to three-phase power system. On the right side of Figure 9, types of connection to the house installation can be seen. On household side of the cable protection system is made according to Mode 2 standard. Proximity control and pilot pins are included into connector to satisfy safety requirements and to allow communication between the vehicle and charging station. According to data from Figure 9, this type of connection allows almost double charging current, and thus the charging time is significantly reduced. All connection points must have protection against contact (cover).

Figure 9. *Type 2 connector VDE-AR-E 2623-2-2 (Mennekes connector) [6]*

Connector Type 3 - EV Plug Alliance was developed by two French companies Schneider Electric and Legrand and the Italian company Scame. The main feature of this connector was to include a protective cover for protection against direct contact with live parts and supporting power charging through three-phase network with currents up to 32 A. However, the competition development in the EU market has overcome German Mennekes connector which was accepted as standard from 2013. Only France has decided to keep the EV Plug Alliance as standard. Figure 10 shows versions of connecting cables from the side of connector to the charging station for connector Type 3 - EV Plug Alliance (Mode 3 - IEC61851, 32 A, 400 V, 3-phase, <22 kW) and from the side of the vehicle for Mennekes connector. This product is used for electric cars charging in: Mercedes-Benz Vito E-CELL, Renault Zoe, Smart For Two-ED, Tesla Model S.

Figure 10. *Connection cable for EV with connector Type 3-EV Plug Alliance (Mode 3) and according sockets*

Development of DC charging stations demanded terminal connectors which have to be customized for safe connecting and disconnecting because of very large DC currents. This type of connector was developed by the Japanese company Tokyo Electric Power Company - TEPCO (and thus defining the standard). Knowing by the trade name, **CHAdeMO, Type4 connector** (Figure 11), is used for charging EV in Japan. It is specified by Japan Electric Vehicle Standard (JEVS) G105-1993 from the JARI (Japan Automobile Research Institute) and was accepted in Europe under the label IEC 62196 Type4.

Figure 11. *connector CHAdeMO (DC current supply)*

Figure 12. *Nissan LEAF connection combo box for connector CHAdeMO (DC current) and connector J1772 2009 (AC current)*

Advance requirements on standards regarding communication between the vehicles and charging station during development are required. Figure 13 presents sequence circuit of communication for CHAdeMO connector. Communication is insured through the CAN bus system and each signal pin has its own assignment in a certain sequence of procedures for connection, charging and separation from charging station [7].

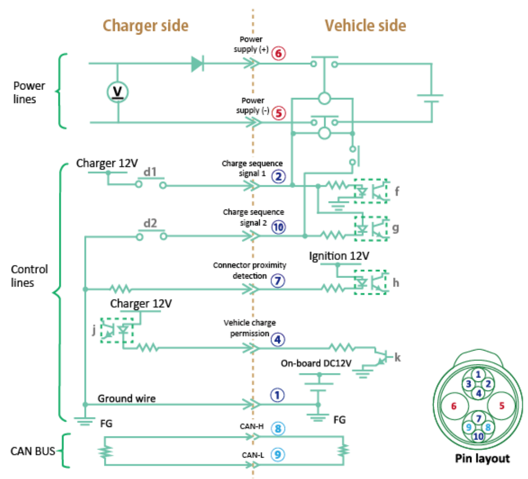


Figure 13. *CHAdeMo sequence circuit [7]*

CHAdeMO connector system provides a full range of safeguards.

a) Protection against electric shock / Conventional method of protection, which is used in this case and in other areas, is using an isolating transformer, whereby input end is grounded (AC). This ensures in case of breakout from grounding to the DC side to avoid possible occurrence of an electric shock. Appearance of leakage current supervision is carried out with a monitoring device which is placed on DC side (Figure 14) and, according to standard IEC60479-1, performing automatic disconnection.

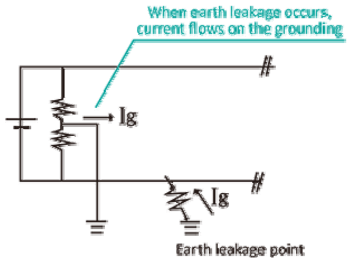


Figure 14. *Electrical shock protection using a leakage current monitoring device*

b) Fail-safe charging of control / Connection systems of EV charging stations must be a user friendly, so technical and physical performance must ensure that the procedure of connecting, charging, as well as disconnecting is carried out in a safe way. Proven method for providing mentioned conditions is a multiple serial connection of possible connecting points in the communication chain, which indicates that circuit is well connected (or not so it is necessary to stop the whole process).

This is also insured by using two communication lines (CAN signal and pilot signal) which will be transmitted by the vehicle charger to the charging station in case of failure detection. In this way, the risk that failure will not be detected by the protection system is reduced.

Another possible scenario of failure is interruption of grounding conductor or power cable. Construction of connectors ensures that communication pins are separated, allowing superior control protection loop to activate and interrupt the power supply from charging station. Clearly, there is always a problem if the vehicle is in the smart grid system used as source, because in this case the charging station has a different topology of the inverter and active time and protective systems are acting in two-way.

c) Protection of battery / Using sophisticated battery management systems put EV in a manager role in the process of charging because it controls charging current. Control Electronic (measurement and control) today works at very high frequencies (typically using CAN communication) that enables operation in real conditions. The system of connectors CHAdeMO prescribes requirements for response time, current and voltage ripple and measurement accuracy from controlled power signal (control voltage and charging current).

SAE Combo Charging System (CCS) - developed and used in BMW, GM, VW, Chrysler, Daimler and others, was created as an attempt of manufacturers to cover both US and EU market segment. The idea was to provide the end user with great flexibility of charging vehicles (combination of modes and types of connectors).

Doing so, this naturally enables the use of AC and DC power supply and power charging. This involves the development of connectors which in itself have all of connectors. The solution (Figure 15) is formed by upgrading the existing J1772 connector in which are added two more power pins for DC fast charging, or the Mennekes connectors.

Figure 15. *Combo Charging System connectors*

SAFETY SYSTEM

Through the last chapters security systems are described on several occasions according to voltage levels and types of connector's connections. The aim was to show that power charging of EV by using EVs charging system must be performed to satisfy several security protocols and to establish the necessary communication with the vehicle during connection and charging process. Figure 16 shows a safety and addition elements in EV fast charging. Two main types of sensors used in security systems must be distinguish: a current sensor (direct current measurement and the reaction to its change) and the feedback signal through one of the connector pins defined by standard IEC62196.

Isolation transformer (described in the previous section) has the function to electrically separate circuit-board energy storage (battery) from distribution network in order to protect users when operating the bottling plant in process of joining with EV.

Battery management system in the vehicle is a very demanding set of power electronics (there are several types of subsystems) and the purpose of the LC filter is to reduce ripple output current station. Voltage disconnector in the case of ground fault is previously disclosed by CHAdeMO type of connectors.

Figure 17 shows block diagram of the subsystems which are installed in standard Mode 2, Mode 3 and Mode 4. Control systems of connection, charging, and protection are superior to control systems of energy flow.

It can be seen in diagrams that substantial difference in the position of sub-conversion AC/DC, which in standard Mode 3 is located in the vehicle, significantly increases the price of performance. Required in the standard Mode 4, most expensive part is placed in a filling station (one charging station = one AC/DC converter for many vehicles) to prevent the possibility of failure in vehicles and to increase the reliability of the entire system.

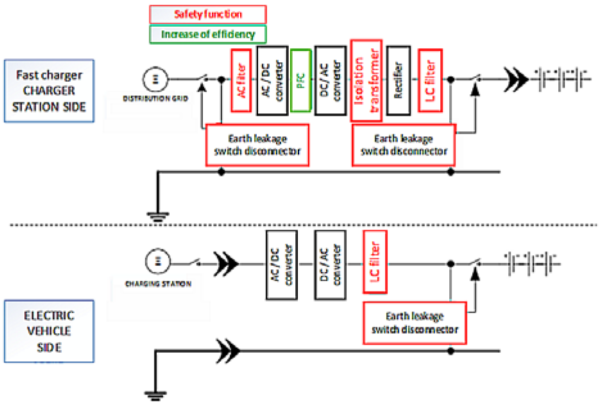


Figure 16. *Safety and addition elements in fast EV charges [8]*

CONCLUSION

High complex systems of electric vehicles required security protocols to be developed in accordance with the available advance technology and special technical equipment. System of EV supply, control systems and drive system of EVs are based on power electronics units that run at very high frequencies. Also, present in EVs are: high voltages, high currents and specific problems of DC circuits. This shows that extreme rapid evolving process of standardization is present in this industry.

Protections systems are based on physical access restriction to parts of electrical circuits to ensure protection from moisture, security sensors that communicate between assembly's parts of charging stations and EV to ensure the quality of connection, transfer of energy and disconnection.

In doing so, exceptional attention is being paid to the user friendly interface and communication panels designed for users to provide conception of events in the process of charging for security reasons.

Area of industry in segment of electric vehicle production will have a big growth and development rate in future.

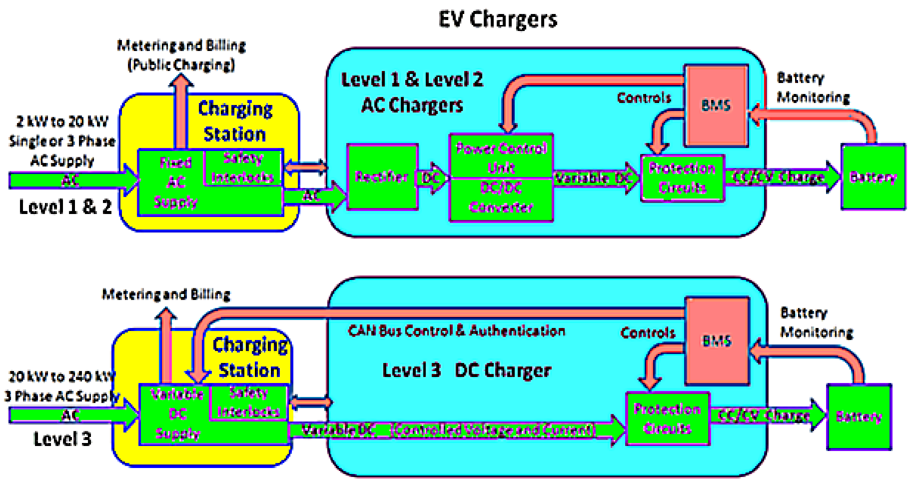


Figure 17. *block diagram of control and power units inside charging station/EV sistem for standard mode 3 (AC) and mode 4 (DC) [4]*

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BIOGRAPHY

Juraj Miličić was born in Zagreb, Republic of Croatia in 1991. BSc in electrical engineering He graduated in field of electromechanical engineering at Undergraduate study from University of Osijek in 2013. Currently he is finishing Graduate university study of Electrical Power Engineering with the master thesis: Design and construction of solar powered vehicles.

SIGURNOSNA PRAVILA ZA KORIŠTENJE U INFRASTRUKTURAMA ZA PUNJENJE ELEKTRIČNIH VOZILA

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Rezime: *Trend u automobilskoj industriji je razvoj EV i prateće infrastrukture. Kompleksni sustavi energetske elektronike, visokim naponskim i strujnim razinama, kao i kontrolni sustavi u realnom vremenu - sve to zajedno ima prioritet da se osigura sigurnost korisnika i interfejz prilagođen laganom korištenju. Ovaj rad predstavlja pregled tehničkih rješenja i standarda koji se odnose na sustave infrastrukture za napajanje EV električnom energijom, protokole za priključak, kao i sigurnosne sustave.*

Ključne reči: električna vozila, infrastruktura za punjenje, standarde procedure, konektori.