SAFETY CONSIDERATIONS FOR ELECTRIC VEHICLES

P. Van den Bossche
CITELEC
Pleinlaan 2
1050 Brussels
Belgium

Abstract

Electric vehicles represent a complete different technology compared with internal combustion engines. This means that new safety hazards, mainly related to the characteristics of high-power electric equipment, may be present.
The electric vehicle system shall be designed to operate safely in all conditions; a number of specific problems will be treated, concentrating on aspects of vehicle behaviour which are typical for electric vehicles. At this moment the standards and official regulations concerning electric road vehicles are not very clearly defined. The existing documents and standards are far from harmonised, and they cover a vehicle in full technological evolution. Another aspect is the psychological awareness of these “new” risks: the presence of high voltages or of battery chemicals may used as an argument against electric vehicles; the fact that internal-combustion-engined vehicles present large risks too is often overlooked, people having get used to the danger.

Introduction

In urban traffic, due to their beneficial effect on environment, electric vehicles are an important factor for improvement of traffic and more particularly for a healthier living environment.
The electric vehicle represents a “new” technology, introducing electric power components on board road vehicles.
The different risks associated with this technology must be carefully assessed.
The risk levels however should not be overestimated by fear of the unknown.
Different aspects of electric safety can be considered on electric vehicles:

- electric system safety
- functional system safety
- battery charging safety
- vehicle maintenance, operation and training

Regulatory aspects

There is no specific European legislation covering electric vehicles.
Standards and regulations for electric vehicles are still under development.
The rapid technological evolution of the matter makes strict normative standards less recommendable at this moment.
The current situation of unadapted and often contradictory directives, standards and regulations makes harmonisation however necessary.

Several international standardisation committees are active on electric vehicle standards:

- IEC TC 69
- CENELEC TC 69X
- ISO TC22/SC21
- CEN TC 301

Electric system safety: Protection against electric shocks

Voltage levels on board electric vehicles

Typical voltage levels on electric vehicles are as follows:

- 48-120 V for cars and small vans
- 96-240 V for large vans
- 300-600 V for buses

For AC drives, which are gaining an increasing popularity, higher voltage levels are used; 200 V or more may be encountered even on small vehicles.
These voltage levels are to be compared with the safety voltage levels: in a typical electric vehicle environment, characterised by a low skin resistance (wet skin likely) (BB2) and a contact with conductive bodies (BC3), the security extra low voltage level is 25 V for AC and 60 V for DC.
The voltages used on electric vehicles are thus potentially dangerous and measures should be taken to prevent electrocution through direct or indirect contact.

Protection against direct contact

Live parts of the electric traction system should be protected against direct contact by persons in or outside the vehicle, through insulation or inaccessible position.
Insulation such as varnish, enamel, coatings,… are not considered to be insulation as required for protection against direct contact.
Removal of protective devices and opening of doors, lids, and bonnets permitting access to live electrical equipment shall only be possible with tools or keys..
The conventional protection degrees (IPXXB or IPXXD) should be enforced:

Protection against indirect contact

The problem of indirect contacts is closely related to the problem of frame faults. Any spurious connection between the traction circuit and the vehicle frame is regarded as a fault. Frame faults can lead to several hazards:

- short circuits
- electrocution
- uncontrolled operation

Following measures should be taken to avoid these hazards:

- a fuse shall be built inside the battery pack, preferably in the electrical centre of the battery
- the vehicle frame shall be isolated from the traction circuit and shall not form any part of the power electrical circuit
- all conductive parts of the vehicle, particularly accessible parts or parts adjacent to electrical equipment shall be connected with an equipotential connection.
- frame fault leakage detection shall be included in routine maintenance; permanent frame fault monitoring is mandatory for certain vehicles.

Functional system safety

The electric vehicle traction system must ensure a reliable and safe operation of the vehicle.
The topology of the traction system in an electric vehicle is fundamentally different from IC-engined vehicles and specific measures should be taken to avoid or prevent unsafe operations.

System activation warning

An electric vehicle standing still is in most cases completely silent. To prevent movement through unintentional actuating of the traction circuit, a warning device shall be present.

Power on procedure

To avoid possible damage through excessive torque, overcurrent or fierce accelerations, the power on procedure must be adequately organised: it shall be impossible to activate the controller with the accelerator depressed. Any unintentional movement of the vehicle during start-up shall be avoided.

Driving backwards - Prevention of fierce reverse braking

The change of driving direction in an electric vehicle can be done mechanically or electrically

In the latter case, the actuation of the reversing shall be obtained by two different; consecutive movements or an electrical safety device which only allows reverse to be engaged when the vehicle speed is lower than 1 m/s, in which case actuation of the control unit shall be indicated obviously.

Emergency disconnect device

This problem is approached in a different way by car manufacturers and electricians:

- vehicle manufacturers do not consider emergency switches as a necessity and want to avoid them (they are in fact not present on thermal vehicles)

- electrical manufacturers consider emergency switches as essential (they are in fact present on any industrial electric device)

Emergency switches come in different versions:

- battery connectors
- direct-acting emergency buttons
- indirect-acting emergency buttons

It is recommendable that the disconnect action is direct.
Furthermore, its operation shall not be detrimental to the controller.

Fail-safe operation- Power surge prevention

Unintentional acceleration due to failures in electronic traction controllers must be prevented by the use of power surge control fail-safe circuitry. In particular, any failure shall not cause more than 0,1 m movement of a standing, unbraked vehicle.

Fail-safe operation - Frame faults

Frame faults and stray currents can also cause uncontrolled operation: a fault current of a few μA in a controller can release hundreds of Amps in the motor!

Traction and auxiliary circuits shall be galvanically isolated.
Infiltration and condensation of water shall be avoided.

Fail-safe operation - Electromagnetic compatibility

Electromagnetic interference, generated externally or by the controller itself, must not adversely affect controller operation.
The controller must be designed in conjunction with the rest of the vehicle in such a way that no unwanted radiations are generated.

The auxiliary network

The auxiliary network is used for lighting, windscreen wipers and other similar loads.
It is fed by the traction battery through a DC/DC converter; this should be designed with galvanic isolation.
In most vehicles, an auxiliary battery is also present. The auxiliary battery can be dispensed with if the DC/DC converter is powerful and reliable to ensure safe operation of the auxiliary loads (particularly lighting) in all conditions.

Electrical regenerative braking

Some particular safety considerations are to be put forward on this item:
- regenerative braking works through the drive train, on one axle only
- regenerative braking does not work at very low speeds or at standstill
- in most cases, the rate of deceleration is limited and not sufficient for an emergency stop
- on slippery surfaces, high levels of regenerative braking may cause loss of adhesion
- torque inversions add wear and tear to the mechanical drive system
- the effect of regenerative braking may be impaired when the battery is fully charged; the latter may even be overcharged.

The primary friction brake system should be able to stop the vehicle in all circumstances.
To ensure safe operation and maximum efficiency, the braking torque should be controllable gradually and coasting must remain possible. This last feature is particularly important considering energy efficient driving.

Overspeeding

Electric motors, particularly direct-current motors, can be liable to overspeeding damage.
Overspeeding is mostly caused by excessive downhill speed, but can also be caused by excitation failure.

Battery safety

The battery is the most critical item on board the electric vehicle. It represents several potential hazards:
- electrical
- mechanical
- chemical
- explosion hazard

Electrical aspects

- Protection against electrocution: the conventional enclosures shall be enforced as needed.
- Protection against short-circuits: traction batteries have usually a very high short-circuit current. Protective devices (fuse links) shall be foreseen, preferably at the electrical centre of the battery.
  When multiple battery packs are used, additional fuse links shall be provided.
  The type and location of these fuse links shall be carefully determined to avoid any risk of explosion.
- Furthermore, the layout of the battery compartment shall be sensibly designed to avoid any unintentional direct contact or short-circuit.
- To minimise leakage currents, particularly when vented batteries are used, creepage distances between live parts must be observed.

Mechanical aspects

The traction battery is a heavy item (particularly the Lead-Acid battery); its location on board the vehicle shall be determined to avoid instability of the vehicle. The battery must be constrained to avoid injury in case of an accident.
The battery location should be particularly observed when existing thermal vehicles are converted to electric traction; an adequate battery compartment is usually not available in this case.

Chemical aspects

Lead-Acid batteries. The main chemical hazard in the Lead-Acid battery is the electrolyte (sulphuric acid).
Precautions should be taken during maintenance.
In case of an accident, care must be taken to avoid electrolyte to be spilled on the vehicle's occupants or on third parties.
The lead metal in the battery is only released during the disposal and recycling process.

Nickel-Cadmium batteries. The electrolyte is a lye solution (potassium hydroxide). The same precautions apply as for sulphuric acid.
When Lead-Acid and Nickel-Cadmium batteries are used in one fleet, handling and maintenance tools shall be carefully separated.
The cadmium metal present in the battery is only released during the disposal and recycling process.

Sodium-Sulphur batteries. This are completely sealed batteries. The thermal envelope safely encloses the reagents (molten sodium and sulphur). Furthermore, the battery contains a multitude of small cells so that the amount of active material released in an accident is limited.
Early prototypes of this battery have faced problems of thermal runaway.

Sodium-Nickel Chloride batteries. These are similar to sodium-sulphur, but the nickel chloride is a salt which is less reactive than sulphur.

Zinc-Bromine batteries. The inherent safety of this battery is rather high; the bromine complex solution in the battery is toxic but shows a low reactivity.
The main hazard of this battery is the inhalation of bromine and bromine compounds which are released in case of fire.

Explosion hazards

Batteries with an aqueous electrolyte emit hydrogen due to the electrolysis of this electrolyte. This is particularly the case at the end of charge.
Particular measures should be taken to avoid explosion hazards:

- hydrogen concentration anywhere in the vehicle must never exceed 0,8 % in normal operation and 3,5 % in case of a failure (the explosion limit being 4 %).
- devices which are liable to produce heat or sparks (contactors, switches, connectors, lighting bulbs, brake paths,…) shall not be located where potentially explosive air/gas mixtures can occur.
- battery fumes shall be ventilated and shall never be allowed to enter the passenger compartment
- when valve-regulated lead-acid batteries are used (these are commonly known as “sealed” or “maintenance-free” batteries), one must take into account that in case of overcharging these batteries can also emit hydrogen gas.

Battery charging safety

During the battery recharging process, the electric vehicle is connected to the mains distribution network and the necessary safety measures should be taken to avoid electrocution danger. Several cases can be observed:

Off-board battery chargers

Off-board battery chargers are mostly used with large vehicles and for rapid charging. With off-board chargers, it is essential to connect the vehicle body to the earth while charging. Otherwise dangerous situations can occur in the case of a fault.

On-board battery chargers

With on-board battery chargers, the vehicle body must be connected to the earth during charging, except when using Class II (double insulated) equipment.
It is recommended to check the soundness of the earth using an earth-loop monitor.
When the charger has no electrical separation, isolation monitoring is essential, and the traction battery must be isolated from the vehicle body.

Partially on-board battery chargers

Partially on-board chargers are based on inductive energy transfer. Since they involve no electrical contact between the vehicle and the mains network, their electrical safety is very high.
The absence of a cable also reduces the mechanical risks.
The characteristics of the electromagnetic environment of these chargers are under consideration.

Maintenance

First-line maintenance: by the user

Example: vehicle washing, windscreen top-up
The ordinary user is not a trained electrician, and must be protected against all risks of direct contact.

Second-line maintenance: in the workshop

Example: battery top-up, routine mechanical maintenance, controller replacement.
The servicemen must be thoroughly trained for safe maintenance action when servicing electric vehicles. The battery should be disconnected before any intervention is done.

Third-line maintenance: in the manufacturer's workshop

Example: major electrical repairs. This is to be done by trained personnel only.

Maintenance for safe operation

Besides the maintenance of mechanical parts, some electrical routine maintenance is necessary for safe operation and shall be done at regular service intervals:
- test of insulation resistance and earth leakage
- controller operation
- battery condition, maintenance and cleaning

The verification of these points could become a part of legal vehicle testing.

Driver training

An electric vehicle is not petrol, not diesel, not even LPG or CNG. It's electric!
The electric motor has torque and power characteristics which are quite different from IC engines. Safe and energy-efficient driving of an electric requires proper

skills. In the electric vehicle world there is no place for the casual driving style so often encountered with petrol vehicles.
In particular battery charging should be done properly and with the necessary discipline.
Purchasers of electric vehicles shall be provided with the necessary information through the dealer network.

Conclusion

The introduction of electric vehicles will necessitate the observance of the safety rules inherent to electric traction. Proper risk assessment and common sense should prevail in this matter; the electric vehicle will thus become a safe and reliable means of transport which will allow the improvement of traffic and environmental conditions in tomorrow's cities.

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