Safety protocol for electrical vehicles crash test

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ABSTRACT

During the last few decades, the transportation policies have been stricter to promote more efficient vehicles such as electric and hybrid vehicles due to the environmental impact of the petroleum-based transportation infrastructure along with other factors has increased the climate change.

Electric and hybrid vehicles are assessed as any other transport vehicle of the same category to fulfill with the passive safety standards. Nevertheless, they have a potential danger in specific cases such as severe crashes due to the risk of electric shock, electrolyte spillage or fire from the battery. That is why they are submitted to additional specific extra requirements added to official standards.

The passive safety standards have been extended with amendments for the EV's vehicles. As well, an internal protocol for the EV's in crash tests is used in Applus IDIADA crash test laboratory.

Keywords: PHEV: Plug-in Hybrid Electrical Vehicle, EV: Electrical Vehicle, AFV: Alternative Fuel Vehicle, FMVSS: Federal Motors Vehicle Safety Standard, NCAP: New Car Assessment Programmed, REES: Rechargeable Energy Storage System,

1. INTRODUCTION

PHEV's and EV's have been introduced into the automotive market over the last decade. Their benefits are commonly known as they contribute to reducing emissions and pollution. The latest anti-pollution policies and the automotive industry itself are enhancing the proportion of AFV's (Alternative Fuel Vehicle) against conventional ICE (Internal Combustion Engine) vehicles year by year.

In Europe, the AFV's have to pass Euro NCAP standards in the same way conventional ICE vehicles. Over recent last years, AFV's have been shown to be as safe as conventional vehicles.

Taking this into account, it can be said that AFV's could be as safe as ICEV's or even safer. However, new safety challenges, such as electric shocks due to the HV-system or the risk of fire hazard by battery are present.

The crash tests carried out represent an additional danger as a special attention not only needs to be paid to post-crash battery integrity, but also to the proper functioning of the battery unit following a crash. Live voltage presents a high risk to all workers involved in the crash, as well as to future customers and their first response after a severe accident. That is why the different regulations and protocols, also the passive safety related ones, were adjusted to cover EV's and HEV's. In the following sections, the various worldwide passive safety protocols and regulations amendments are summarized.

2. MATERIALS AND METHODS

2.1 International Regulations

2.1.1 Safety requirements for Electric Vehicles [1] [5]

Scope: Cars, buses, trucks with GVWR of 10,000 lbs (4536kg) or less that use electrical components with working voltages higher than 60 VDC or 30 VAC, and whose attainable speed is more than 40 km/h.

Test conditions:

- *Frontal impact against a rigid barrier ay 48km/h (FMVSS 208)*
- *Rear moving barrier impact at 80 km/h (FMVSS 301)*
- *Side moving deformable barrier impact at 54 km/h (FMVSS 214)*
- *Post-impact test statics rollover in 90-degree steps*

Requirements: Under the test conditions described above:

·Maximum of 5 litres of electrolyte may spill from the batteries.

·There shall be no evidence of electrolyte leakage into the passenger compartments.

·All components of electric energy storage/conversion system must be anchored to the vehicle.

·No battery system component that is located outside the passenger compartment shall enter the passenger compartment.

·Each HV source in the vehicle must meet one of the three following electrical safety requirements:

1. Electrical isolation must be greater than or equal to:
    - 500 ohms/V for all DC high voltage sources without isolation monitoring and for all AC high voltage sources.
    - 100 ohms/V for all DC high voltage sources with continuous monitoring of electrical isolation.
2. The voltage level of the HV source (Vb, V1, V2) must be less than or equal to 30VAC (for AC components) or 60VDC (for DC components).
3. Physical barrier protection against electrical shock shall be demonstrated by meeting the following conditions:
    - The HV source meets protection degree IPXXB [6]
    - Resistance between exposed conductive parts of the Electrical Protection Barrier (EPB) of the HV source and the electrical chassis is < 0.1ohms.
    - Resistance between exposed conductive part of the EPB of the HV source and any other simultaneously reachable exposed conductive parts of EPBs within 2.5meters of it must be 0.2 ohms.
    - Voltage between exposed conductive part of the EPB of the HV source and any other simultaneously reachable exposed conductive parts of EPBs within 2.5 meters of it must be ≤ 30VAC or 60VDC.

2.1.2 Extension of UN Regulations 94/95 Frontal and Lateral Crashes [2][3][5]:

After crash tests according to UN R94 and R95 vehicles with a HV electrical powertrain (> 60VDC or >30VAC) must meet the following requirements:

Protection against electrical shock: At least one of the four criteria specified bellow shall be met.

1. Absence of HV: The voltages Vb, V1 and V2 shall be ≤ 30VAC or 60VDC:
2. Low electrical energy: The total energy (TS) on the high voltage buses shall be < 2.0J. Prior to the impact a switch S_1 and a known discharge resistor R_e is connected in parallel to the relevant capacitance. Not earlier than 5s and not later than 60s after impact S_1 shall be closed while the voltage V_b and the current I_e are recorded.
3. Physical protection: For protection against direct contact with HV live parts, the protection IPXXB shall be provided.

4. Isolation resistance:

- If the AC HV buses and the DC high voltage buses are galvanically isolated from each other, isolation resistance between the HV bus and the electrical chassis shall be ≥ 100Ω/V of the working voltage buses, and ≥ 500Ω/V of the working voltage for AC buses.

- If the AC HV buses and the DC HV buses are galvanically connected isolation resistance between the HV bus and the electrical chassis shall be ≥ 500Ω/V of the working voltage. (if the protection IPXXB is satisfied for all AC HV buses or the AC voltage is <30V after the vehicle impact, the isolation resistance shall be R_i be ≥ 100Ω/V)

Electrolyte spillage:

In the period from the impact until 30minutes after, no electrolyte from the REES shall spill into the passenger compartment and no more than 7% of the electrolyte shall spill from the REES.

REES retention:

REES located inside the passenger compartment shall remain in the location in which they are installed and REES components shall remain inside REES boundaries. No part of any REES that is located outside the passenger compartment for electric safety assessment shall enter the passenger compartment during or after the impact test.

2.1.3 Euro NCAP - Testing of Electric Vehicles technical procedure []:

Pre-test information:

Additional information is required for the safe preparation of AFV's. The location of the service plug; the minimum charge of the RESS, to any state which allows the normal operation of the power train; and how to put the vehicle in neutral drive.

Vehicle preparation:

AFV's will be prepared for the full scale tests exactly the same as any other vehicle. However, before any preparation, the service plug needs to be removed to ensure there is no voltage within the high-voltage circuit other than the batteries.

Additional measurements:

It is already required during Euro NCAP tests to measure the voltage of the battery during the complete test. UN ECE R94 and R95 protection against electrical shock requirements are also adopted by Euro NCAP.

UN ECE R94/95*:*

- Absence of high voltage
- Low electrical energy
- Physical protection (not adopted by Euro NCAP)
- Isolation resistance

For the first two options, on-board measurements are required during test which is the option preferred by Euro NCAP. The other options can be done at any time after test. Euro NCAP does not allow the use of the IPXXB (Physical protection test) and will at least perform the isolation resistance test. To be able to see whether the automatic disconnect has functioned correctly during test an exterior LED indicator light must be mounted to show the status of the switch. The OEM is asked to provide guidance for mounting the LED lights.

Post-test:

After the crash test extreme care needs to be taken to ensure that there is no high voltage exposed before anybody touches the vehicle. Immediately after the test, the ignition is switched off and if possible the service plug is removed. For storage, inspection and viewing the OEM is asked how to discharge the complete high-voltage system so that there is no remaining energy. This methodology is also considered by UN ECE regulation.

2.1.4 Summary of the international regulations:

	FMVSS 305	UN R94/95	Euro NCAP
Tests configuration	Frontal Lateral Rear Rollover	Frontal Lateral	Frontal Full Frontal Lateral Pole
REES retention	Anchoraged Not enter to the passenger c.	Anchoraged Not enter to the p. c.	Anchoraged Not enter to the p. c.
Electrolite Spillage	Max. 5l of electrolyte Not enter to the passenger c.	Max. 7% in 30min Not enter to the p. c.	Max. 7% in 30min Not enter to the p. c.
Electrical Shock			
Isolation (i.) resistance: without i. monitoring with i.monitoring	≥ 500 ohms/V ≥ 100 ohms/V	≥ 500 ohms/V ≥ 100 ohms/V	≥ 500 ohms/V ≥ 100 ohms/V
Absens of high voltage	HV ≤ 30V AC HV ≤ 60V DC	HV ≤ 30V AC HV ≤ 60V DC	HV ≤ 30V AC HV ≤ 60V DC
Phisical protection	One of : *Protection IPXXB *EPB–chasis: <0,1 ohms *EPB–parts: < 0,2 ohms *EPB–part: ≤ 30VAC; ≤ 60VDC	Protection IPXXB	
Low electrial energies		TS ≤ 2,0 J	TS ≤ 2,0 J
Additional			Pretest information Vehicle preparation Post-test

Fig 1. Summary of the international regulations

2.2 IDIADA's Safety Protocol for crash test with AFV's:

Besides the aforementioned special requirements that AFV's need to fulfil, an internal procedure must be implemented to respond to the potential danger inherent to severe crashes with EV/HEV's due their potential electrical and chemical danger.

The Applus IDIADA internal protocol aims to perform those crash tests ensuring safety of their workers, infrastructure and equipment. The protocol is subdivided in before, during, and after crash procedures; involving in case of emergency procedure.

2.2.1 Before test amendments:

Aiming to prepare the vehicle with all the safety requirements, some crucial information must be taken into account. Therefore Applus IDIADA need to know the location of the vehicles SD-switch, the location of the HV battery unit, the HV measurement spots (to record voltage and temperature signals) and additionally the desired percentage of the battery load during the crash event. All this information shall be provided by the OEM.

To prevent workers from misuse situations associated with AFVs, it is necessary to mark vehicles appropriately in order to differentiate them from conventional ICE vehicles. The identification stickers, are usually placed to the front windshield to warn of the vehicle powertrain type and consequently its associated risks. No sticker on the vehicle means that the vehicle is powered by a conventional ICE.

Furthermore, these vehicles are stored in specifically adapted box storages for pre and post-crash analysis in order to ensure shop floor safety. The workers involved in the crash test must be properly protected and so they are equipped with additional personal protective equipment as well as measuring equipment. The personal protective equipment includes: isolating gloves cover gloves, fire-safe clothing, facial screen, isolating boots.

All the HEV and EV are equipped with a SD-switch pre-installed by the OEM, in order to facilitate the electrical disconnection of the powertrain from the battery. As long as the switches are switched off, the electrical circuit is de-energized, and so maintenance and in situ work can be done safely.

IDIADA equips the vehicles with additional emergency switches. Furthermore equips lighting indicators on-board the vehicles in a visible spot in order to see clearly if there are electric derivations; this procedure is mandatory for Euro NCAP and IDIADA has standardized it as an internal procedure for all the electric related crashes. The functioning of the lighting indicators is simple and works as follows:

- Red light: There is more than 60VDC in the vehicle circuit indicating that there is still HV in the vehicle.
- Green light: The voltage is lower than 60VDC, indicating no HV on the vehicle and due to that work can be carried out on the vehicle.

An external measurement box is also mounted on the vehicle, making it possible to measure the voltage more safely, and without getting too close to the HV source after the crash.

2.2.2 During test amendments:

During the test, in order to react in case of emergency, either fire or explosion; a fire-fighter supported by two other trained staff must be present at the crash scene. All of them must be fully equipped with the personal protective equipment described above. Additionally, two fire-hoses must be ready to be used if necessary.

Furthermore, the battery temperature must be monitored in order to detect any anomaly; as chemical batteries increase temperature slowly before burning. This can be used as a signal of danger and if it happens, the emergency protocol must start.

2.2.3 After test amendments:

The after test measures can be listed as a chronological operation sequence, as follows:

1. Air ventilation:_After the crash test the first measure is to open the laboratory outer doors in order to improve air ventilation.

2. Visual inspection:_Then, always with no one touching the vehicle or traction cable, the operator in charge of the measurements must assess the situation of the crashed vehicle. The operator looks for evidence of fire, smoke, loss of fluids from the HV battery or damage in the HV cabling. The lighting indicator previously installed must also be checked to detect if there is HV remaining in the vehicle circuit.

3. Ensure the area*:* Depending on the lighting indicator color, different procedures shall be performed.

    a) Red light: The values of insulation resistance are insufficient, it is crucial that no worker enters the crash area, and so nobody can touch the traction cable or the vehicle itself. Then the person responsible will place the insulation blankets in order to allow the test engineer to safely check the insulation and record the voltages standing on it.

    b) Green light:_The values of insulation allow the engineer to check and record the voltages. Furthermore, the signal acquisition devices can be removed from the vehicle to take the output data. The vehicle can be safely touched, wearing insulating gloves. If measurements need to be taken on the high voltage source, another person must be prepared to pull them away with the instrumented pole.

4. Make the vehicle safe*:* Once the measures are taken, the SD-switch is disconnected. If parts of the vehicle need to be removed, it has to be done by using isolated tools .After the SD- switch disconnection, the vehicle will be completely secure and the regular post-crash analysis can be performed. After obtaining all the necessary documentation and data; the vehicle is moved to a box with fire-fighting equipment systems. Finally when the whole test is finished, the vehicle is transported to an outside area and covered, where it will remain until the battery removal agreed with the client.

5. In case of emergency*:* When an emergency situation occurs, the rescue priority has to be clear. So people will be the first consideration, followed by the measurement equipment and facilities. The emergency protocol covers three main risk situations: electroshock, fire, and chemical fluids spillage. Some of the emergency situations and procedures to react are described below:

    a) Having high voltage (>60VDC) ten minutes after the crash: This indicates that there is a failure in the vehicle safety system and so HV is still present. The correct procedure in that cases, as follows: the test engineer responsible of the crash must remove the SD-switch and the ignition key before opening the doors and taking photographs. Five minutes later, the voltage shall be measured again to ensure that voltage is lower than 60 VDC. Once this is confirmed, the post-crash tasks can proceed as usual.

    b) Leakage or spillage of battery fluids is detected: Avoiding any chemical contamination of facilities and therefore of the filtration system is a must as battery fluids are corrosive and flammable. After performing the test, the battery integrity shall be assessed.

    c) Smoke detection: If smoke is detected, IDIADA’s fire extinguishing team will take extreme precaution and personnel must not approach the vehicle. The on-board equipment shall be extracted by laboratory personnel wearing the agreed anti-fire equipment. It is also important to verify whether the smoke is caused by the airbag deployment, or whether it is a potential risk of fire. In the second case, the correct procedure is to tow the vehicle outside the laboratory.

    d) Fire detection:_In case of fire, fire-fighting team will approach the vehicle, as its main goal is to extinguish the fire, even if it implies damaging the equipment or losing the test data. If the fire cannot be extinguished in the first attempt, the vehicle must be dragged outside before fire propagation.

4. CONCLUSIONS

Alternative fuel vehicles have to pass the same crash test as conventional vehicles. Nevertheless they are dangerous when crashing because of electroshock hazard and chemical fire hazard. Accordingly, in addition of the extra requirements defined in official standards and mentioned in this paper, IDIADA has developed an internal safety procedure to reduce as much as possible any incident and personal damage risk, furthermore in case of incident know how to react safely and quickly to reduce its consequences.

According to the European regulations (R94, R95, Euro NCAP) and American regulations (FMVSS 208, 214 and 301 new, 305), some voltage measurements after crashing should be taken and some calculations have to be made. In IDIADA the internal safety protocol takes the more restrictive safety measure adopted for all cases. Also a display is mounted in vehicle in order to know, without touching the vehicle, if the voltage is higher than allowed (60V). Moreover, an extra switch has to be installed in the vehicle and a temperature recording system has to be installed at the batteries to show if any fire risk exists. Finally specific actions for emergency cases are also clear in case they are needed.

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