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# Electrical Vehicles Safety protocol for Testing

**Alba Fornells1, Núria Parera1**

*Applus IDIADA, Santa Oliva, Spain*

*Email:Nuria.Parera@idiada.com*

**Abstract:** Over recent decades climate change and air pollution have become an increasingly important issue and so the transportation policies of many countries aim to make vehicles more efficient and promote the development and use of electric vehicles. According to the European Automotive Manufacturers Association, the registration of electric vehicles showed a substantial increase of 160.5%, that makes stakeholders assume a realistic market share for new electrically chargeable vehicles to be in the range of 2 to 8% by 2020 to 2025, based on today's market.

Electric and hybrid vehicles are submitted to the same passive and active safety standards as fossil fuel engine vehicles and so they have to pass crash tests defined by homologation regulations or other consumer standards such as Euro NCAP. Electric and hybrid vehicles only have to fulfil a few specific extra requirements added to official standards; however they have a potential danger after severe crashes due to the risk of electric shock from the battery. Therefore, Applus IDIADA has defined a new internal protocol, to be applied during electric vehicle crash tests, in order to ensure the safety of workers and the infrastructure.

In this paper the internal safety protocol applied for EV crash tests that is used at Applus IDIADA crash test laboratory, is described and related with the principal risks of testing electrical vehicles. Moreover, an overview of the principal amendments of passive safety standards regarding EV's is presented.

## 1 Introduction

Nowadays, to ensure a high safety level to the vehicles, thousands of crash tests are performed to assess their crashworthiness. The series for testing fully electric vehicles started in 2011, when the Euro NCAP published the results of the Mitsubishi i-MiEV. The achieved four-star rating proved that consumers can expect the same safety standards as in conventional vehicles [1]. However, special attention needs to be paid to the post-crash battery integrity, but also to the proper functioning of the battery unit cut-off switch following a crash, as live voltage presents a high risk to all involved workers on the crash, as well as to the future customer and their first responders after a severe accident.

Already more than one million electric and hybrid vehicles have been on the worldwide markets in 2015. However, this trend in technology goes along with new safety challenges, such as electric shocks due to the HV-system or the risk of fire hazard by the lithium-ion battery [2]. There are already defined procedures for the type approval of new electric and hybrid vehicles by means of national and international regulations. However, these regulations do not cover the procedure on how to work safely on the crash side to avoid accidents, as their main content only determines the necessary state of the vehicle after the crash in order to gain approval to sell them on certain markets. For this reason, Applus IDIADA has defined a new internal protocol, to be applied during electric vehicle crash tests, in order to ensure the safety of workers and the infrastructure.

## 2 General Testing Requirements for Electric and Hybrid Vehicles According To National and International Regulations

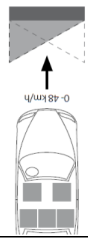
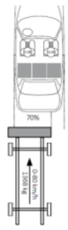
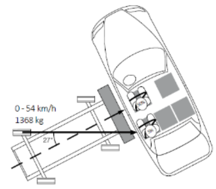
All current crash-tests are built upon national and international laws and regulations, which both conventional fuel systems as well as electric and hybrid vehicles need to fulfill. Most countries conform to the regulations from the Inland Transport Division of the United Nations Economic Commission for Europe (UNECE), called UN Regulations. Only the United States (FMVSS Regulations) and Canada (CMVSS Regulations) are the two significant exceptions, while the Canadian arrangement is broadly similar to the US FMVSS.

### 2.1 FMVSS 305 US Regulation

As for vehicles sold in the United States, the Federal Motor Vehicle Safety Standards (FMVSS) needs to be fulfilled. The FMVSS 305 regulation covers the post-crash survivability on electric-powered vehicles on electrolyte spillage and electrical shock protection. This standard is applicable to passenger cars, multipurpose passenger vehicles, trucks and buses with a GVWR (cross vehicle weight rating) up to 4,536 kg [3]. The electric propulsion power components shall exceed

60VDC (direct current) or 30VAC (alternating current) with a minimum speed of 40km/h. It applies to the following three barrier tests:

**Table1.Crash Tests according to FMVSS 305**

| Frontal Rigid Barrier | Rear deformable Barrier | Side Moving Deformable Barrier |
|---|---|---|
| Any speed between 0-48 km/h.Any barrier angle between 0 ° and ±30 °, according to FMVSS 208 | Any speed between 0-80 km/h with a 70% overlap, according to FMVSS 301 | Any single moving deformable barrier crash at any speed up to 54 km/h side impact, according to FMVSS 214 |
|  |  |  |





The main requirements for the vehicle in the post-crash analysis are as follows: the vehicle shall not spill more than 5 liters of propulsion battery electrolyte (Propulsion battery= Rechargeable energy storage system (REESS), which provides the electrical energy for propulsion) outside the passenger's compartment within 30 minutes after the vehicles crash and throughout its following static rollover. Moreover, there shall be no signs of electrolyte spillage inside the passenger's compartment. It has to be checked, that the propulsion battery system remains at its position, when mounted inside the passengers compartment. If mounted outside, it has to be verified that the high-voltage components do not enter into the passenger's compartment. Another requirement is for the vehicle to maintain its electrical isolation between the propulsion battery system and the vehicle's electricity-conducting structure. The isolation shall not fall below a value of 500 ohms/volt for AC voltage sources and DC voltage sources without isolation monitoring and 100 ohms/volt for DC voltage sources with an isolation monitoring system [5].

## 2.2 ECE R94 – European Regulation

The UN Regulations (UN ECE – United Nations Economic Commission for Europe) for vehicle design depict the counterpart of the American FMVSS regulation. The ECE Regulation 94/95 covers the protection of the occupants in the event of a frontal/lateral crash and its extension involves the safety requirement for electric vehicles. The regulation is composed of three sections, namely the protection against electrical shock, the electrolyte spillage and the propulsion battery systems retention.

To fulfill the requirements against electrical shock, at least one of the following criteria needs to be met:

1. Absence of high voltage within Vb, V1 and V2, see Figure 1 – shall be less than 30 VAC or 60VDC.

2. Low electrical energy (less than 2 Joule), as to be measured between 5 and 60 seconds after the crash by means of the switch S1 and the resistor Re. The obtained values Vb and Ie can be used to determine the energy TE as follows:

$$TE = \int_{tc}^{th} V_b \times I_e dt \qquad (1)$$

With tc= the moment when the switch S1 is closed

and th= the moment the voltage Vb falls below the high voltage of 60VDC

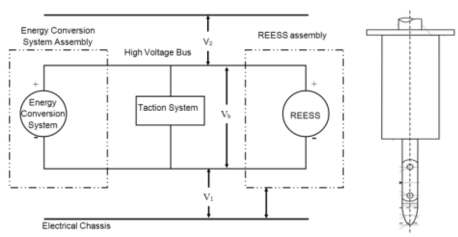




**Figure1.Measurement of Vb, V1, V2 (left), Jointed Test Finger IPXXB (right)**

3. A physical protection against direct contact with high voltage live parts, using the protection IPXXB jointed test finger.

4. Isolation Resistance

As for galvanically isolated AC / DC voltage buses, the isolation resistance shall have a minimum value of 100 ohms/volt for DC buses and a minimum of 500 ohms/volt for AC buses. When the AC / DC voltage buses are galvanically connected, the isolation resistance between the high voltage bus and the electrical chassis shall be a minimum of 500 ohms/volt. However, in case the protection IPXXB is guaranteed or the AC voltage is less than 30 volts, an isolation resistance of 100 ohms/volt is also adequate.

Referring to the electrolyte spillage, within 30 minutes after the impact, there shall be no electrolyte within the passengers' compartment and there shall be no more than 7% electrolyte spillage from the propulsion battery. All spillage from the propulsion battery will be considered as electrolyte, unless the manufacturer provides means to differentiate between the leakages of different liquids.

The requirements regarding the propulsion battery retention are very similar to the ones mentioned in the FMVSS 305 regulations: based on a visual inspection, it has to be ensured, that the battery unit remains at its position, when mounted inside the passengers compartment. Also when mounted outside, no component of the high voltage system shall enter the passengers' compartment [6] [7].

## 2.3 Euro NCAP assessment

Euro NCAP tests for electric vehicles are taken additional preparations and precautions to ensure safety before, during and after testing. However, Euro NCAP assesses Electric and Hybrid vehicles equally than any other vehicle.

Euro NCAP protocol requires additional information for safe preparation of Plug-In vehicles regarding the location of the service plug and the minimum charge of the Rechargeable Energy Storage Systems.

The vehicle preparation will be exactly the same as any other vehicle but before the service plug need to be removed. Besides of this, the protection against electrical shock have to be verified through four different test options: the absence of high voltage and the low electrical energy, which are required to be onboard measured during test, and the physical protection and the isolation resistance, which can be done at any time after the test. Moreover, to be able to see whether the automatic disconnect has functioned correctly during test an exterior LED indicator light will be mounted to show the status of the switch.2.4E-mail address of contact person

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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 test, the ignition is switched off and if possible the service plug is removed.

# 3 Crash laboratory internal protocol for testing of electric vehicles

As for the aforementioned requirements that electric and hybrid vehicles need to fulfil, there is still a potential danger after severe crashes due to the risk of electric shock and fire from the propulsion battery unit, as the main purpose of these tests is to prove the proper functioning of the vehicles security systems (voltage cut-off function). By means of the newly defined internal protocol, Applus IDIADA ensures the safety of their workers and the infrastructure for crash-tests of electric vehicles. The protocol is structured for best practice procedures before and after the crash, as well as in a case of emergency.

## 3.1 EV amendments before testing

In order to safely prepare a hybrid or electric vehicle crash test, it requires gathering as much information as possible about the vehicle and its safety functions. Therefore, Applus IDIADA prepared a list with necessary documentations which is sent to the manufacturer of the crashed vehicle. The information required is about the location of the vehicles SD-switch as well as the location of the HV battery unit, measurement spots to measure voltage and temperature and the desired percentage of battery load during the crash.

To inform all workers that are associated with the crash-test about the on-board electricpower train, it is necessary to mark the vehicle appropriately. The identification stickers can be observed in Figure 2 and they are usually attached to the front windshield.


**Figure 2. IDIADA identification stickers for hybrid and electric vehicles**

To ensure the safety inside the shop floor, the vehicles are stored in specifically adopted box storages for pre and post-crash analysis. The workers associated with the crash are equipped with additional measuring equipment (voltage, insulation and temperature) and specific safety equipment like high voltage insulating defined in Table 2. Each activity will require a part or all of the safety equipment.

**Table 2. Personal Protective Equipment**

| | |
|---|---|
| Isolating gloves |  |
| Cover globes |  |
| Fire-safe clothing |  |
| Facial screen |  |
| Isolation boots |  |

Every hybrid and electric vehicle is equipped with an SD-switch (SD-switch= service disconnect, used to ensure that the electrical circuit is completely de-energized for service or maintenance ), which is preinstalled by the OEM and can be found either within the engine block or close the high-voltage propulsion battery unit (dependent on the manufacturer). As long as these switches are not connected, the electrical circuit is completely de-energized while work is conducted to the battery unit or the vehicle itself. In Figure 3 and schema of the electric circuit and the SD-switch can be observed.

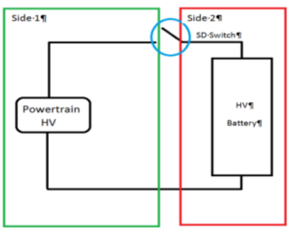


**Figure 3.Location of the SD-switch on a Chevrolet Volt**

For the ease of use and due to the reason, that the accessibility of the manufacturers SD-switch is limited, IDIADA instruments the tested vehicles with additional emergency switches and lightning indicators for high voltage outside the vehicles on a visible spot. The lightning indicators work in that way, that when there is more than 60 VDC on the vehicle circuit, the light will be red and indicates that there is still high voltage on the vehicle. If the voltage is lower than 60 VDC, the light turns green and shows that work can be carried out on the vehicle.

Also, to perform the measurements required by different standards, it has been designed a measurement box connected to the vehicle high voltage system that allows doing the measurements quickly and without accessing to the vehicle. Via this external measurement box, it is possible to measure the voltage on the vehicle in a safe manner and without getting to close after the crash. The additional instrumentation can be observed in Figure 4.

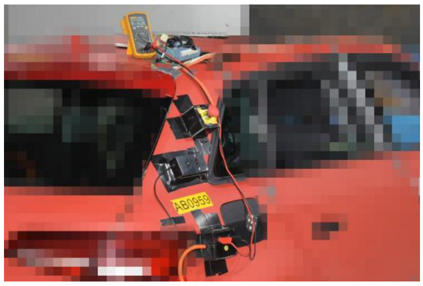

**Figure 4.Vehicle Safety Instrumentation (IDIADA)**

Moreover, one of the main characteristics of a high voltage battery is the increment of temperature before they are starting to burn and as a prevention measure, it is realized a measurement and recording of temperature in real time at any important point of the battery. Therefore a temperature displayed of the battery is stored on an easy and visible location. The temperature is measured with thermocouples connected to a wireless transmitter.

When the vehicle is ready to be crashed, the test engineer authorizes the technician to connect the SD-switch and to record the voltages and the resistance of the insulation. Then the regular crash procedure can be initiated.

## 3.2 EV amendments during the test

During the test, and to increase the safety on the crash scene, a fire-fighter and two other prepared staff to give support will be ready to act in case of fire or explosion. All of them have to be equipped with the full personal protective equipment (Table 2). Moreover, two fire-hose will be prepared to be use if necessary.

## 3.3 EV amendments after testing

After the crash test the laboratory outer doors will be opened to improve the air ventilation.

1. Visual inspection

Without anyone touching the vehicle or traction cable, the operator responsible for the measurements will assess the situation on existence of smoke or fire, loss of fluids from the high-voltage battery unit or the deterioration of the systems elements or cables of the high-voltage battery.

2. Ensure the area

If the lightning indicator installed (Figure 4) is red, the values of the insulation resistance are insufficient, it is important that no worker gets in contact with the traction cable or the vehicle itself. Insulation blankets (Figure 5) will be set on the working area where test engineer will safely check the insulation and will record the voltages standing on it.

If the lightning indicator is green, the voltages can be safely checked and the signal acquisition devices can be removed from the vehicle to take the data. Right after the voltage measurements, the test photographers record all necessary vehicle documentation and download the film. The vehicle can be touched but using the insulating glove. In case of the measurement technician contacts with the high-voltage source another person have to be prepared to pull them away with an insulated pole (Figure 5).

At any case the voltage to be recorded is defined at European standards (R94, R95, Euro NCAP) and American standards (FMVSS 208, 214 and 301 new).. In case of being necessary to record the voltages, there are high voltage sensors inside the vehicle. Its main characteristics are their high input impedance which allows measurement with a non-intrusive method regarding the internal system of the vehicle. Furthermore, as they are connected with the data acquisition system, it allows doing online measurements.

**Figure 5.Insolation banquet (left) and insulated pole to secure the measurement technician (right)**

3. Make the vehicle safe

Then, the SD-switch will be disconnected. If it is necessary to dismount any vehicle piece, it has to be done with isolated tools (Figure 7). With the SD-switch disconnected, the vehicle will be completely sure and the regular post-crash analysis can begin: opening doors, inner vehicle photographs, dummy and on-board equipment extraction. When all the necessary documentation has been obtained, the vehicle can be transported to a box with fire-fighting equipment systems. There, more post-crash analysis can be carried out. Finally the car will be transported to an outside area and covered with a camouflage cover, where it remains until the battery removal has been agreed with the client.

**Figure 6. Specified high-voltage tools**

4. In case of emergency

As for the case of emergency, the rescue priority lays first at the people, then the facilities, followed by the measurement equipment. IDIADAS internal protocols covers emergency cases like the existence of high voltage after the crash, the loss of HV battery fluids and the appearance of smoke and fire.

a) If 10 minutes after the crash, the voltage is higher than 60 VDC, it indicates that the vehicles security system did not work well and that there is still HV on the system. In that case the test engineer is responsible of removing the SD-switch and the ignition key before opening the doors and taking photographs. After waiting another 5 minutes, the voltage of the battery will be measured again to confirm that the voltage is below 60 VDC. Once this is confirmed, it can be preceded to all the relevant tasks.

b) When the vehicle is loosing HV battery fluids, it is necessary to avoid any contamination to the facility and the filtration system, as the battery fluids can be corrosive and flammable. Before proceeding with the test the battery should be assessed if it is viable.

c) In case of smoke appearance, IDIADAs fire extinguishing team will take extreme precautions and the personnel will not approach to the vehicle. The on-board equipment will be extracted by the laboratory personnel with the necessary fire equipment. If the smoke appears due to the exploding airbags the scenario does not have to be necessarily dangerous. If the smoke is not caused by the airbags, the vehicle will be towed outside.

d) In case of fire, only IDIADAs fire team will approach to the vehicle as its main goal is to extinguish the fire even if it compromises obtaining the test data. If it is not possible to extinguish the fire, the vehicle will be dragged outside.

## 4 Conclusions

Electric vehicles have to be as safe as the other ones and so they have to pass the same crash tests. However they are dangerous when crashing because of battery liquid sink or electroshock. Therefore, a part of the extra requirements for electric and hybrid vehicles

defined at official standards, IDIADA has developed an internal safety protocol to reduce as much as possible any incident and personal damage risk.

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

Besides of this the crash laboratory protocol defines each step after the crash test: first of all a visual inspection is required; secondly the actions to ensure the area have to be carried out followed by all the post-crash activities to be performed once the vehicle is safe. Finally specific actions for emergency cases are also clear.

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