Journal of the Society of Automotive Engineers Malaysia
Volume 3, Issue 2, pp 112-122, May 2019
e-ISSN 2550-2239 & ISSN 2600-8092

# Safety Protocols for Electric Vehicles Crash Tests

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**REVIEW** *Open Access*

**Article History:**

Received
*18 Oct 2018*

Received in revised form
*25 Feb 2019*

Accepted
*28 Feb 2019*

Available online
*1 May 2019*

**Abstract** – *Climate change and air pollution in the recent decade have become an increasingly important issue. This has led to the introduction of transportation policies in many countries to make vehicles more efficient by promoting the development and use of Electric Vehicles (EVs). According to the European Automotive Manufacturers Association, the registration of EVs has shown a substantial increase of 160.5%, prompting stakeholders to assume a realistic market share for new electrically chargeable vehicles to be in the range of two to eight percent by 2020 to 2025, based on today's market. Electric and hybrid vehicles are subject 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 also have to fulfil a few specific extra requirements added to the official standards; as they pose a potential danger after severe crashes due to the risk of electric shock from the battery. 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 EVs. Moreover, an overview of the principal amendments of passive safety standards regarding EVs is presented.*

**Keywords:** Electric vehicles (EV), crash tests, passive safety


*Journal homepage: www.jsaem.saemalaysia.org.my*

## 1.0 INTRODUCTION

Over the last decade, Plug-in Hybrid Electric Vehicle (PHEV) and Electric Vehicle (EV) have been introduced into the automotive market. Their benefits are well recognised as they significantly contribute to reducing emissions and pollution. The latest anti-pollution policies and the automotive industry itself are increasing the proportion of Alternative Fuel Vehicle (AFV) against conventional Internal Combustion Engine Vehicle (ICEV) year by year.

Looking at the Asian market, approximately 375,000 EVs were manufactured by China's OEMs in 2016, marking an impressive 43 percent of EV production worldwide (Hertzke et al., 2017). Previously, in 2015, Chinese OEMs had also achieved a 40 percent global share. OEMs from around the world (Chinese manufacturers included) also produced approximately 332,000 EVs within China in 2016, and the country now has the largest number of EVs on the road – overtaking the number of EVs in the United States for the first time (Hertzke et al., 2017). China's lithium-ion battery-cell players currently account for about 25 percent of global supply. Approximately 25 new EV models were introduced to the China market in 2016. Hence, consumers in China can now choose from around 75 EV models, which is more than in any other country in the world (Hertzke et al., 2017).

In Europe, the AFVs have to pass Euro NCAP standards in the same way as the conventional ICE vehicles. In recent years, AFVs have been proven to be as safe as conventional vehicles. This includes the Toyota Prius (2009), Toyota C-HR (2017), Chevrolet Volt (2011), Nissan Leaf (2012), Renault Zoe (2013) and Tesla Model S (2014). All of them are examples of AFVs which were able to achieve Euro NCAP five-star safety rating (Euro NCAP, 2018). Taking this into consideration, it can be said that AFVs could be as safe as ICEVs or even safer. However, AFVs pose different safety challenges such as electric shocks due to the high voltage (HV) system or the risk of fire hazard by battery.

The crash tests carried out present an additional danger as special attention not only needs to be given 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 the personnel involved in the crash testing as well as to future customers following their immediate response after a severe accident. That is why different regulations and protocols including those related the passive safety have been adjusted to cover EVs and HEVs. In this paper, the various worldwide passive safety protocols and regulations amendments are summarized.

## 2.0 INTERNATIONAL REGULATIONS ON EV CRASH TEST

Four sources of international regulations are considered in this review, namely the United States' Federal Motor Vehicle Safety Standards (FMVSS) 305, the United Nations' Regulations No. 94 (UN R94 for frontal impact) and No. 95 (UN R95 for lateral impact), European New Car Assessment Programme (Euro NCAP) Assessment Protocol, as well as IDIADA's Safety Protocol.

### 2.1 FMVSS 305 Safety Requirements for Electric Vehicles

The scope under FMVSS is for cars, buses, trucks with gross vehicle weight rating (GVWR) of 10,000 lbs (4,536 kg) or less that use electrical components with working voltages over 60 VDC or 30 VAC, and whose attainable speed is above 40 km/h (NHTSA, 2008).

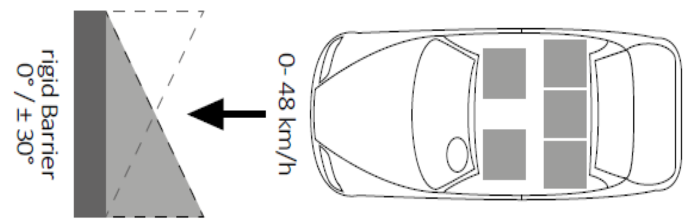
#### *2.1.1 Test Conditions*

There are four test conditions considered in FMVSS as presented in Table 1 (Carhs, 2018). The requirements of the test conditions include (NHTSA, 2008):

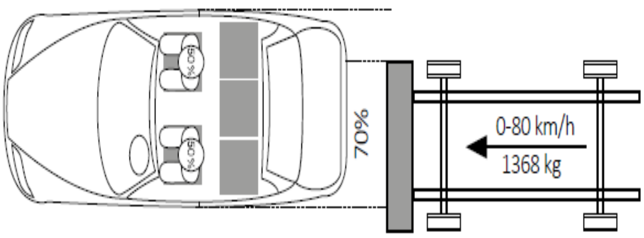
i. Only a maximum of five litres of electrolyte may spill from the batteries.
ii. There shall be no evidence of electrolyte leakage into the passenger compartments.
iii. All components of electric energy storage/conversion system must be anchored to the vehicle.
iv. No battery system component that is located outside the passenger compartment shall enter the passenger compartment.
v. Each HV source in the vehicle must meet one of the three following electrical safety requirements in Table 2 (NHTSA, 2008).

**Table 1:** FMVSS test conditions (Carhs, 2018)

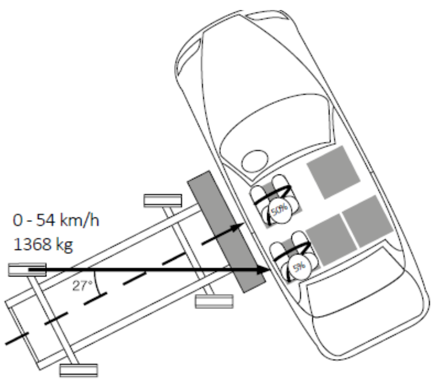
**FMVSS 208**: Frontal impact against a rigid barrier at 48km/h




**FMVSS 301**: Rear moving barrier impact at 80 km/h




**FMVSS 214**: Side moving deformable barrier impact at 54 km/h




Post-impact test statics rollover in 90-degree steps

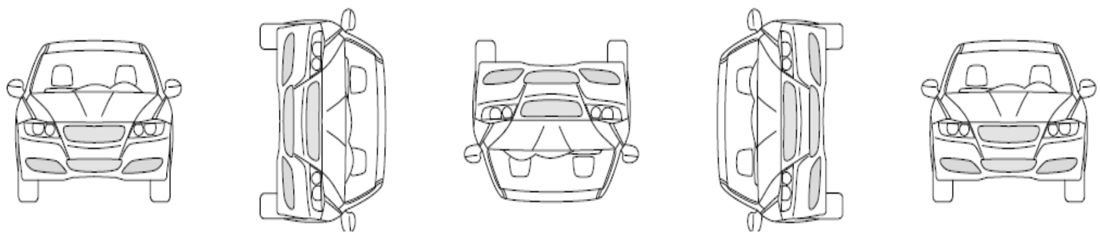


**Table 2:** Electrical safety requirements (NHTSA, 2008)

| **Electrical Safety Requirements** |
|---|
| 1. Electrical isolation must be greater than or equal to:<br>• 500 ohms/V for all DC high voltage sources without isolation monitoring and for all AC high voltage sources.<br>• 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:<br>• The HV source meets protection degree IPXXB.<br>• Resistance between exposed conductive parts of the EPB of the HV source and the electrical chassis is < 0.1 ohms.<br>• 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.<br>• 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. |

## 2.2 Extension of UN Regulations for Frontal (UN R94) and Lateral Crashes (UN R95)

According to UN R94 and R95, vehicles with a HV electrical powertrain (>60 VDC or >30 VAC) must meet the following requirements after crash tests (UN, n.d.; UN, 2011):

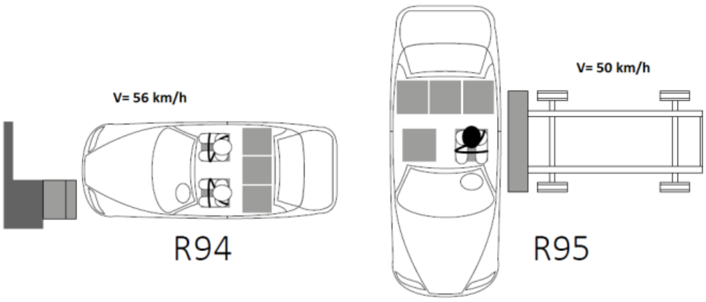



**Figure 1**: UN R94 and R95 test conditions (Carhs, 2018)

For protection against electrical shock, at least one of the four criteria specified below must be met:

i. *Absence of HV*: The voltages Vb, V1 and V2 shall be ≤ 30 VAC or 60V DC (Figure 2).

ii. *Low electrical energy*: The total energy (TS) on the high voltage buses shall be less than 2.0 J. Prior to the impact a switch S1 and a known discharge resistor Re is connected in parallel to the relevant capacitance. Not earlier than 5 second and not later than 60 seconds after impact, S1 shall be closed while the voltage Vb and the current Ie are recorded (Figure 3).

From this, TE is calculated as follows:

$$TE = \int_{tc}^{th} V_b \cdot I_e \, dt$$

With: tc = time of closing S1

th = time when voltage drops below 60 VDC

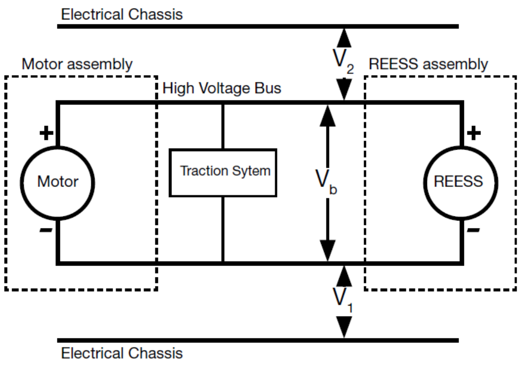



**Figure 2**: Electric simplified scheme of electrified vehicles

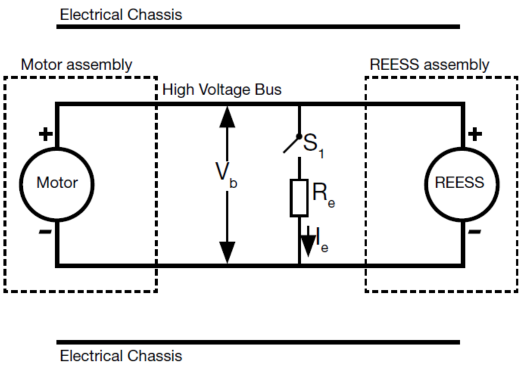



**Figure 3**: Electric simplified scheme with SD switch and discharge resistor

iii. *Physical protection*: For protection against direct contact with HV live parts, the protection IPXXB shall be provided.
iv. *Isolation resistance*: Which is calculated using the following formula:

$$Ri = Ro * (Vb/V2' - Vb/V2) \text{ or } Ri = Ro * Vb * (1/V2' - 1/V2)$$

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 ≥ 100 Ω/V of the working voltage buses, and ≥ 500 Ω/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 ≥ 500 Ω/V of the working voltage (if the protection IPXXB is satisfied for all AC HV buses or the AC voltage is < 30 V after the vehicle impact, the isolation resistance shall be Ri be ≥ 100 Ω/V).

In addition, there are two other concerns in regard to electrolyte spillage and REES retention, namely:

i. *Electrolyte spillage*: In the period from the impact until 30 minutes 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.
ii. *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.

## 2.3 Euro NCAP – Testing of Electric Vehicles Technical Procedure

The technical procedure in the testing of Electrical Vehicles as stipulated in the Euro NCAP protocol comprises acquiring pre-test information, preparing the vehicle, obtaining additional measurements, as well as taking post-test precautionary measures (Euro NCAP, 2010). Each of these shall be explained in the following sub-sections.

### *2.3.1 Pre-test Information*

Additional information is required for the safe preparation of AFVs. This includes 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.

### *2.3.2 Vehicle Preparation*

AFVs will be prepared for the full scale test exactly similar to any other vehicle. However, before the preparation, the service plug needs to be removed to ensure there is no voltage within the high-voltage circuit other than the batteries.

### *2.3.3 Additional Measurements*

A pre-requisite in the Euro NCAP tests is to measure the voltage of the battery during the complete test. UN R94 and R95 protection against electrical shock requirements are also adopted by Euro NCAP, namely (i) the absence of high voltage, (ii) low electrical energy, and (iii) isolation resistance. Regardless, ‘physical protection’ is not adopted by Euro NCAP.

For the first two options, on-board measurements are required during the test which is the option preferred by Euro NCAP. The other options can be performed at any time after the 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 required to provide guidance for mounting the LED lights.

### *2.3.3 Post-test*

After the crash test, extreme care needs to be taken to ensure that there is no high voltage exposed before anybody can touch 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 for instructions on how to discharge the complete high-voltage system to ensure there is no remaining energy. This methodology is also considered by UN regulation.

## 2.4 IDIADA Safety Protocol for Crash Test with AFVs

Besides the aforementioned special requirements that AFVs need to fulfil, an internal procedure is also implemented to alleviate the potential danger inherent to severe crashes with EV/HEVs due the potential electrical and chemical danger.

The Applus IDIADA internal protocol aims to ensure safety of its workers, infrastructure and equipment during crash tests. The protocol is subdivided into before, during, and after crash procedures, as well as in the case of an emergency.

### *2.4.1 Before Test Amendments*

Aiming to safely prepare the vehicle to be crashed, some crucial information must be obtained. Applus IDIADA needs 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 acquired from the OEM.

To prevent workers from misuse, it is necessary to mark AFVs appropriately in order to differentiate them from conventional ICE vehicles. The identification stickers, as shown below in Figure 4, are usually attached 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.


**Figure 4**: IDIADA's identification stickers for hybrid and electric vehicles

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

All the HEVs and EVs 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 they 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, IDIADA installs lighting indicators on board the vehicles in a visible spot 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:

i. **Red light**: There is more than 60 VDC in the vehicle circuit indicating that there is still HV in the vehicle.
ii. **Green light**: The voltage is lower than 60 VDC, indicating no HV on the vehicle and so 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. Figure 5 shows a box to plug the measurement tools located on the left whereas the lighting indicator box is on the right.


**Figure 5**: IDIADA's external instrumentation for HEV/EV

### *2.4.2 During Test Amendments*

During the test, in order to react in the case of emergency whether 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.

The battery temperature must be monitored to detect any anomaly as chemical batteries gradually increase temperature before burning. The temperature is an indicator to an imminent danger and if it happens, the emergency protocol shall commence.

### 2.4.3 After Test Amendments

The after-test measures are listed in a chronological operation sequence which includes:

i. *Air ventilation*: After the crash test, the first measure is to open the laboratory outer doors in order to improve air ventilation.

ii. *Visual inspection*: Next, make sure no one touches the vehicle or traction cable, while the operator in charge of the measurements assesses the situation of the crashed vehicle. The operator shall look for signs 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.

iii. *Ensure the area safety*: Depending on the lighting indicator colour, different procedures shall be performed.

   a. **Red light**: The values of insulation resistance are insufficient, hence, it is crucial that no worker enters the crash area, and nobody can touch the traction cable or the vehicle itself. Next, the person responsible will place the insulation blanket (Figure 6, left) to allow the test engineer to safely check the insulation and record the voltage standing on it.

   b. **Green light**: The values of insulation allow the engineer to check and record the voltage. Furthermore, the signal acquisition devices can be removed from the vehicle to obtain 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 shown in Figure 6 (right).

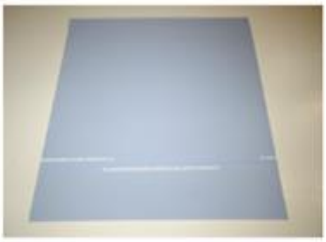



**Figure 6**: Insulation blanket (left), insulated pole to react against electroshock (right)

iv. *Making the vehicle safe*: Once all the measures are taken, the SD-switch is disconnected. If parts of the vehicle need to be removed, it has to be done 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 completed, the vehicle is transported to an outside area and covered, where it will remain until the battery removal is agreed by the client.

v. *In case of emergency*: When an emergency situation occurs, the rescue priority has to be clear. People shall be the first priority, followed by the measurement equipment and facilities. The emergency protocol covers three main risk situations, namely electroshock, fire, and chemical fluids spillage. Some of the emergency situations and procedures to react to are explained below:

a. Having high voltage (>60 VDC) 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 such cases is as follows: the test engineer responsible must remove the SD-switch and the ignition key before opening the doors and taking photographs. After an interval of five minutes, 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: It is important to avoid any chemical contamination of facilities. 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 no one is allowed 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 airbag deployment, or whether there 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, only IDIADA's fire-fighting team will approach the vehicle, as the main goal is to extinguish the fire, even if it means damaging the equipment or losing the test data. If the fire cannot be extinguished in the first attempt, the vehicle must be dragged outside for further action to put out the fire.

## 3.0 CONCLUSION

In conclusion, alternative fuel vehicles are subject to similar crash testing as conventional vehicles. However, they pose more danger during the crash test due to potential electroshock and chemical fire hazard. Accordingly, aside from the extra requirements in official standards as mentioned in this paper, IDIADA has developed its internal safety procedure to reduce any untoward incident and personal damage risk as much as possible. The procedure also underlines the steps to be taken in case of such an incident, by emphasising quick actions to safely reduce its consequences.

According to the European regulations (UN R94, UN R95, Euro NCAP) and US regulations (FMVSS), some voltage measurements and calculations after crashing have to be taken. The IDIADA internal safety protocol takes a stricter safety approach in all cases. In addition, a display is mounted in the vehicle to determine whether the voltage is higher than allowed (60V) without touching the vehicle. An extra switch is also installed in the vehicle while a temperature recording system is fixed to the battery to determine the risk of fire. Finally, specific actions for emergency cases are also clearly indicated in case they are needed.

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