A Comparative Study on Electric Vehicle Testing Standards

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Government of India envisages e-mobility on Indian roads by 2030. The number of electric vehicles in India is expected to rise significantly in near future. With the surge in acceptance for electric vehicles (EVs), the standardization of the testing procedures for EVs constructional and functional safety has become an important issue to be addressed.

Safety standards for electric vehicles address environmental conditions for electrical and electronic equipment which specifies the requirements for construction and functional safety recommended for the components of battery operated electric vehicles. The objective of this article is to compare three testing standards for electric vehicles (EVs); viz. Indian Standards (AIS-038 and 048), Federal Motor Vehicle Safety Standards (FMVSS 305 and 141)and European Economic Commission Standards (R100); and present a comparative study in order to identify possible scope for improvement in electric vehicle testing standards adopted in India. This study is believed to help the policymakers, while formulating the newer edition of Indian testing standards for EVs to select the best criteria out of these three standards under consideration.

***Keywords*:** *Electric Vehicles (EVs), FMVSS, ECE standards, AIS*

**1. INTRODUCTION**

An electric vehicle (EV) runs entirely using one or more [electric motors](https://en.wikipedia.org/wiki/Electric_motor) for propulsion, powered by electricity either from off-board sources, or self-contained with a [battery](https://en.wikipedia.org/wiki/Electric_vehicle_battery), [solar panels](https://en.wikipedia.org/wiki/Solar_panel) or an [electric generator](https://en.wikipedia.org/wiki/Electric_generator) to convert fuel to electricity. The traditional internal combustion engine is absent in EVs, which results in the lack of tailpipe emissions [1].

Electric Vehicle standards are published by multiple organizations. Given the wide range of components that must all work together to provide the desired experience and reliability that automotive manufacturers and consumers alike want in their cars, standardization plays a key role in electric vehicles. With the recent surge in popularity for electric road vehicles like hybrid electric vehicles and plug-in electric vehicles, the standardization of testing procedures for safety of the vehicle as well as pedestrians become vital. The vehicle is supposed to meet the requirements of these standards in order to be eligible for roadworthiness [2, 3 and 4].

This article presents methodologies used for requirements for construction and functional safety of battery operated electric vehicles. Overview of different types of tests along with the required instrumentations has been provided so as to show the strictness involved in testing functional safety of EVs. However, the main contribution of this article is a comparative study among three testing standards for EVs, namely Indian Standards (AIS-038 and AIS-048), Federal Motor Vehicle Safety Standards (FMVSS 305 and 141) and European Economy Commission Standards (R100). This study shall be useful while formulating new editions or revising the existing testing standards for EVs in AIS standards. The scope of functional safety testing considered here is limited to the battery operated electric vehicles.

**2. INSTRUMENTATIONS**

The general details of the instrumentations required for during the tests which are specified in the testing standards for EVs are given in this section.

**2.1 Access Probe**

Access probes required as a protection for avoiding the access of persons to hazardous parts of an electric vehicle and its test conditions are described in standards AIS-038 and ECE R100.

**2.2. Hose Nozzle**

The hose nozzle as specified in standard AIS-038 is used for the test of protection against water effect.

**2.3. Device for measurement of voltage**

The voltmeter with the internal impedance of at least 10MΩ and capable of measuring AC and DC values is used for the tests given in the testing standards. A fusible link is included in the test interface port for protecting the data measurement and recording devices from damage and the test technicians from electric shock [3].

**2.4. Machine for Static Rollover Test**

The static rollover machine used must be capable of holding and rotating the test vehicle up to 5443 kg about the horizontal axis, with a rotational increment of 90o, 180o and 270o at a uniform rate of 90o in a time interval of 1 to 3 minutes [3].

**2.5. Containers for collecting Electrolyte and Stoddard solvent**

Two separate containers for collecting Stoddard solvent and electrolyte from propulsion battery are required along with a stopwatch for measuring the time intervals of fluid collection [3]. Measurement of spillage volume after the impact test of an electric vehicle involves placing the container beneath the source of leakage and measuring the collected electrolyte samples (tea cup method) [3].

**3. TESTING METHODOLOGIES FOR ELECTRIC VEHICLES**

Following are the methodologies used for testing of electric vehicles to decide their roadworthiness.

**3.1. Vehicle construction requirements**

This clause specifies the requirements for the construction and mounting of the battery for battery operated vehicles (BOVs) for the purpose of establishing compliance to statutory requirements.

***3.1.1. Installation of the traction battery***

Proper ventilation shall be provided for avoiding any potential accumulation of hazardous gases produced by the battery modules. Properly rated fuse or circuit breakers should be provided to protect the traction battery and the power train [2].

***3.1.2. Mounting of batteries***

The mounting of batteries in the battery operated vehicle shall be such that batteries / battery packs are not displaced from their place and there is no spillage of electrolyte when vehicle is driven on gradient or any other type of road [2].

***3.1.3. Creepage Distance Measurement for Traction Batteries***

This clause deals with leakage current hazards between the connections terminals of a traction battery module and any conductive fittings/parts attached to them, due to the risk of electrolyte spillage in normal operating conditions [2]. The minimum creepage distance shall be as follows:

a) In the case of a creepage distance between two battery connection terminals [2]:

**d > 0.25 U + 5 (1)**

Where, d is the creepage distance measured on the tested traction battery in mm. U is the nominal voltage between the two battery connection terminals in volts.

b) In the case of creepage distance between live parts and the electrical chassis [2]:

**d > 0.125 U + 5 (2)**

Where, d is the creepage distance measured between the electric chassis and the live part in mm. U is the nominal voltage between the two battery connection terminals in volts.

This clause does not apply to traction batteries, for which electrolyte leakage will not occur under normal operating conditions e.g. sealed traction batteries [2].

**3.2 Test procedures**

This clause deals with different tests carried out for ensuring functional safety of battery operated vehicles (BOVs), which are as follows:

***3.2.1 Functional safety requirements***

Functional safety requirements are important for ensuring the proper function of electric vehicle and the various electric and electronic equipments incorporated in the vehicle.

***a. Power ON Procedure***

The driver shall not be able to remove power ON key when the drive train is in an active condition and shall get the optical or audible indication when [2],

a) Driving mode of the vehicle is active

OR

b) Placing the vehicle in active driving mode requires at least one further action.

The driver shall get the same indications as mentioned above while leaving the vehicle [2].

***b. Vehicle reversing***

A specific action shall be required while reversing the vehicle which is either:

a) The combination of two different actuations for example gear and clutch.

OR

b) An electric switch, allowing vehicles reverse to be engaged only when its forward speed doesn’t exceed 5 km/h.

The vehicle shall have only one stable position for achieving the reverse with a maximum speed not exceeding 20 km/h [2].

***c. Device for emergency power reduction***

The vehicle is to be equipped with an emergency device to limit the performance during the emergency condition (e.g. component overheating) and also the driver shall get an indication of the same [2].

***d. On-board charger***

The charger socket of the on-board charger shall have the time rating in addition to the ampere rating. The time rating shall be 5 h or the recommended time for charging fully discharged battery, whichever is higher. On-board charger shall have soft start facility, limiting the initial in-rush current and also be capable of withstanding the in-rush current in case. The charger shall have at least indication of “charging in process” and “charging is over” [2].

***e. On-board Indicators***

All the indicators meant for the driver referred above shall be suitably located so as to be visible to the driver easily (e.g. on the dashboard). There should be an indication to warn the driver when the battery reaches a level of re-charging or a level at which driving the vehicle further may cause damage to the battery. Additional indications of temperatures like motor temperature, battery temperature shall be provided [2].

***f. On-board isolation resistance monitoring system***

Following method is used to confirm the function of this system:

The warning signal shall be activated when isolation resistance between electric chassis and terminals being monitored drop below the value of required minimum isolation resistance [5].

***3.2.2 Electric shock protection***

***a. Direct contact with live parts of the power train***

Insulation or covers, perforated metal sheets, etc. shall be provided to avoid direct contact with the live parts of the electric power train of a vehicle having a maximum voltage of at least 60 V DC or 25 V AC [2 and 5].

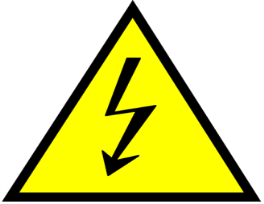


Figure 1: Symbol for the indication of a voltage

The symbol shown in Figure 1 shall be marked on the protection covers. Enclosures having a protection degree of at least IPXXD shall be used for live parts in passenger and load compartment and IPXXB for enclosures of other areas of the vehicle. These protection degrees which related to the jointed test finger and a test wire are specified in AIS 038 and ECE R100 standards [2 and 5].

***b. Indirect contacts with exposed conductive parts of the power train***

This test is required only if the working voltage is above 60 V DC or 25 V AC. Protection against indirect contacts shall be ensured by providing proper insulation and the potential equalization of the exposed conductive parts of on-board equipment is obtained by a protective conductor (e.g. wire, ground truss or the metallic chassis of the vehicle etc.) [2].

***c. Insulation Resistance of Traction Batteries and Electrolyte spillage***

Baseline and after test measurements are done as specified in standard ECE R100 (Pre-impact electrical insulation measurements & calculations).

* **Impact Test of a vehicle**

After a barrier impact test of a vehicle, the visual inspection of the passenger compartment is done to check for the evidence of electrolyte leakage, an intrusion of battery system components, and battery modules retention and photographs of the same should be taken.

The electrolyte from propulsion battery, following the impact test, shall have electric isolation above 500 ohms/volt else a test failure has occurred [3].

* **Static Rollover Test of a vehicle**

This test must be conducted within 45 minutes after the vehicle impact and voltage measurement is to be done for each rotational increment of 90o, 180o, 270o and 360o of static rollover machine.

The electrolyte leakage is measured at each rotational increment using tea cup method and the volume of electrolyte shall not exceed 5 litres and electric isolation should be above 500 ohms/volt [3].

***d. Thermal Shock***

This test is required to check the behavior of the energy storage system for sudden temperature changes experienced during its life.

The system/device to be tested is stored for six hours at a temperature of 60 ± 2 oC, followed by storing the system for at least six hours at a temperature of -40 ± 2 oC. The time interval of 30 minutes shall be kept between the test temperature extremes. This procedure shall be repeated for a minimum of 5 complete cycles and then the system/device is stored for 24 hours at ambient temperature. After 24 hours of storage, a test procedure as given in Table 1 shall be conducted [5].

Table 1: Procedure for conducting a standard cycle [5]

|  |  |
| --- | --- |
| **Process** | **Criteria** |
| Discharge rate | Manufacturer specified.  If not specified, then it shall be a discharge with 1 C current. |
| Discharge limit (end voltage) | Manufacturer specified. |
| Rest period after discharge | Minimum of 30 min. |
| Standard charge | Manufacturer specified.  If not specified, then it shall be a charge with C/3 current. |

The test procedure ends with an observation period of one hour at an ambient temperature of the test environment [5].

***e. Vibration test***

This test is carried out to ensure the safety performance of the vehicle and its systems under a vibration environment which energy storage system experiences during the normal operation of the vehicle. The device/system to be tested shall be subjected to vibration with a sinusoidal waveform having a standard defined sweep rate.

The Table 2 given below gives the correlation between the frequency and acceleration of the vibration generated in the vehicle.

Table 2: Frequency and acceleration correlation [5]

|  |  |
| --- | --- |
| **Frequency (Hz)** | **Acceleration (m/s2)** |
| 7 - 18 | 10 |
| 18 - 30 | gradually reduced from 10 to 2 |
| 30 - 50 | 2 |

After the storage for 24 hours, a test procedure similar to as described in Table 1 shall be conducted. The test procedure ends with an observation period of one hour at an ambient temperature of the test environment [5].

***f. Vehicles connection to the mains network***

The vehicle should not be capable of moving on its own when it is connected electrically to a supply network or to an off-board charger [2].

***3.2.3 Protection against water effect***

The tests as per given below in a, b & c shall be performed. After each exposure (vehicles still in a wet condition), the vehicle shall comply with the test as mentioned in Insulation Resistance of Traction Batteries specified in article 3.2.2, with the requirements of at least 100 Ω/V [2].

***a. Washing***

This test is carried out to simulate the conditions of a normal washing of critical areas (like a seal of two parts as flaps, glass seals, outline of opening parts, outline of front grille, seals of lamps, etc.) of battery operated vehicles. The test uses a hose nozzle which uses water having a flow rate of 12.5 litres/min. specified in the instrumentation section of this article. Keeping a distance of 3 m from nozzle aperture all the borderlines/critical areas shall be exposed to water stream at a speed rate of 0.1 m/s in all the directions [2].

***b. Flooding***

This test is carried out to simulate the driving conditions of a vehicle on flooded streets or in water puddles. The test includes driving the vehicle at a speed of 20 km/h in a shallow wading pool (10 cm in depth), for a 500 m distance within a time period of approximately 1.5 min. The vehicle is driven for several laps in a wading pool having a length less than 500 m, with the total time period including the periods outside the wading pool less than 10 min. [2].

***c. Heavy Rainstorm***

This test is carried out to simulate a sudden heavy rainstorm condition (e.g. a thunderstorm), to ensure the safety of passenger, load and motor compartments especially which are open except those requiring one or more tools. The test uses a hose nozzle having a flow rate of 10 litres/min. specified in the instrumentation section of this article. All the opening parts shall be exposed, possibly with a regular movement of a nozzle for 5 min. [2].

**3.3 Minimum sound requirements for electric vehicles**

This rule establishes a new FMVSS standard (FMVSS141) to reduce the risk of pedestrian crashes, especially for the blind and visually impaired, by setting minimum sound requirements for electric vehicles (EVs). Due to these minimum sound levels, the blind, visually impaired and other pedestrians shall be able to detect and recognize the nearby passing electric vehicles. This standard requires electric passenger cars to produce minimum sound levels for detection of an electric vehicle, some of which are as shown in Table 3 [4].

Table 3: Minimum sound levels for detection mentioned in FMVSS 141 [4]

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Significant Component frequency (Hz)** | **Minimum sound level (dB)** | | | | |
| **Stationary** | **Reverse** | **10 km/h** | **20 km/h** | **30 km/h** |
| 315 | 39 | 42 | 45 | 52 | 56 |
| 400 | 39 | 41 | 44 | 51 | 55 |
| 500 | 40 | 43 | 46 | 52 | 57 |
| 630 | 40 | 43 | 46 | 53 | 57 |
| 800 | 41 | 44 | 47 | 53 | 58 |

**4. COMPARATIVE STUDY AMONG TESTING STANDARDS**

This section presents the comparative study among the three international EV testing standards being considered in this article in order to identify possible scope for improvement in electric vehicle testing standards adopted in India.

**4.1. Functional safety requirements**

Table 4 presents the availability status with regard to functional safety requirements for the three international EV testing standards being considered in this article.

Table 4: Comparison of functional safety requirements

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Sr. No.** | **Functional safety requirements** | **Indian Standard (AIS-038)** | **FMVSS**  **(FMVSS 305)** | **ECE**  **(R100)** |
| **1** | Power ON Procedure | Available | Not Available | Available |
| **2** | Reversing | Available | Not Available | Available |
| **3** | Emergency Power Reduction | Available | Not Available | Available |
| **4** | On-board charger | Available | Not Available | Available |
| **5** | On-board Indicators | Available | Not Available | Available |
| **6** | On-board insulation | Not Available | Available | Not Available |

**4.2. Electric shock protection and electrolyte spillage**

***a. Direct contact with live parts of the power train***

AIS-038 and ECE R100 mentions the equipment’s and procedure for protection from electric shock against direct contact with live parts of the power train.

***b. Indirect contacts with exposed conductive parts of the power train***

This procedure for safety testing is mentioned in AIS-038, whereas not mentioned in ECE R100. FMVSS also doesn’t include this procedure for safety testing.

***c. Insulation Resistance of Traction Batteries and Electrolyte spillage***

AIS-038 requires this test to be carried out after the vehicle is maintained at the following conditions for conditioning time of 8 hours.

|  |  |
| --- | --- |
| Temperature | 20 to 35 0C |
| Humidity | 90% (+10% or -5%) |

FMVSS 305 and ECE R100 in addition to above conditions also mentions about this test to be carried out after impact test and static rollover test for insulation resistance and electrolyte spillage which are not mentioned in AIS-038. Table 5 mentions the minimum electric isolation of traction battery for vehicle to pass the test for approval.

Table 5: Minimum electric isolation of traction battery

|  |  |  |  |
| --- | --- | --- | --- |
| **Standard** | AIS-038 | FMVSS 305 | ECE R100 |
| **Polarity (Ω/V)** | 500 | 500 | 100 |

***d. Thermal Shock***

FMVSS 305 doesn’t mention this test to be performed. AIS-048 and ECE R100 requires this test to be performed for ensuring the performance and safety of electric vehicle to sudden changes in temperature which it experiences during its life.

***e. Vibration test***

FMVSS 305 doesn’t mention this test to be performed. AIS-048 and ECE R100 requires this test to be performed. In AIS-048 the battery module is subjected to sinusoidal vibration of 3g in both axis and a frequency of 30 – 150 Hz at a sweep rate of 1 octave per minute. Testing is to be carried out for 2 hours in each axis [2]. ECE R100 defines sweep to be between 7 Hz and 50 Hz and back to 7 Hz traversed in 15 minutes. Within a total of 3 hours, this cycle is repeated 12 times in the direction vertical to the mounting orientation of the energy storage system [5].

***f. Vehicles connection to the mains network***

AIS-038 mentions this test whereas this test procedure is not included in FMVSS 305 and ECE R100.

**4.3. Protection against water effects**

AIS-038 mentions this test for ensuring protection of electric vehicles against water effects. FMVSS 305 and ECE R100 do not include this test.

**4.4. Minimum sound requirements for electric vehicles**

FMVSS 141 mentions this requirement to ensure the safety of pedestrians against crashes, especially for blind and visually impaired. AIS and ECE don’t mention this requirement.

**5. CONCLUSION**

This article makes an effort to present an overview of the testing methodology followed in general for electric vehicles. The comparative study is presented to help gain insights into the three electric vehicles testing standards, viz. AIS, ECE and FMVSS.

Though the AIS standard includes some of the clauses which are not mentioned in other two standards (i.e. protection against water effects), still one of the issues, i.e. on-board insulation resistance is worth adding during the next revision of Indian standard. Also, the insulation resistance of traction battery and electrolyte spillage after impact test and static rollover test mentioned in FMVSS and ECE must be given strict consideration during next revision. The minimum sound requirement for electric vehicles mentioned in FMVSS 141 to reduce the risk of pedestrian crashes, especially for the blind and visually impaired can be considered as an important consideration for Indian road traffic conditions as well.

Incorporation of these tests will make Indian standards for electric vehicles more stringent which will contribute to the road safety. This comparative study shall be helpful for the policy makers, industry experts while drafting revised testing standards for electric vehicles.

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4. Federal Motor Vehicle Safety Standards (FMVSS) – FMVSS No. 141.
5. European Economy Commission (ECE) Standards - R100