Proceedings of the International Conference on Applied Mechanical Engineering Research (IC-AMER2019)
NIT Warangal, India – May 02-05, 2019
Paper No. XXX (The number assigned when the papaer is accepted)

A Comparative Study on Electric Vehicle Testing Standards

Sachin B. Lokhande[a*], Satyajit R. Patil[a]
[a] *Dept. of Automobile Engineering, Rajarambapu Institute of Technology, Sakharale*
Shivaji University, Kolhapur, Maharashtra, INDIA 415414

*Corresponding author Email: lokhandesachin17@gmail.com

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, the standardization of testing procedures for construction and functional safety has become a vital 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, it is believed, shall help the policy makers to choose the best criteria out of these three while formulating newer edition of Indian testing standards for EVs.

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

1. INTRODUCTION

An electric vehicle (EV) runs entirely using one or more electric motors for propulsion powered by electricity either from off-vehicle sources, or self-contained with a battery, solar panels or an 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 various 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

This section provides some general details about the requirements to be fulfilled before the tests and the instrumentation required for the same.

2.1. Access Probe

Access probes to verify the protection of persons against access to hazardous parts 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. Voltage Measurement Device and Interface

The voltmeter used in this test shall measure AC and DC values and have an internal impedance of at least 10MΩ. The test interface port shall incorporate a fusible link and any other necessary safety device or usage procedure to protect the data measurement and recording equipment from damage, and the test technicians from electrical shock [3].

2.4. Static Rollover Machine

The rollover machine must be capable of rotating, and holding in place, the barrier impacted test vehicle up to 5443 kg about its longitudinal axis with the axis kept horizontal, to each successive increment of 900, 1800, and 2700 at a uniform rate, with 900 of rotation taking place in any time interval from 1 to 3 minutes [3].

2.5. Stoddard and Electrolyte Collection Containers

Containers for the collection of Stoddard solvent and propulsion battery electrolyte and a stopwatch for timing the fluid collection intervals are required [3]. The "tea cup method" is used which involves simply placing a collection vessel beneath the leakage source and spillage volume is calculated by measuring the collected propulsion battery electrolyte samples [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

Battery compartments containing battery modules, which may produce hazardous gases, shall be safely ventilated for avoiding any potential dangerous accumulation of gases. 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]:

$$d > 0.25\,U + 5 \quad (1)$$

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]:

$$d > 0.125\,U + 5 \quad (2)$$

Where, d is creepage distance measured between the live part and the electrical chassis 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

It shall not be possible to remove power ON key in any position that energizes the drive train or that makes active driving possible [2] and optical or audible indication shall be given to the driver when,

a) The vehicle is in “active driving possible mode”

OR

b) At least one further action is required to place the vehicle in “active driving possible mode”.

When leaving the vehicle, the driver shall be informed by an optical or audible signal if the drive train is still in the active driving possible mode [2].

b. Reversing

Reversing shall be possible only after a specific action and shall require either:

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

OR

b) An electric switch, which allows reverse to be engaged only when the vehicle is moving at a forward speed not exceeding 5 km/h.

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

c. Emergency Power Reduction

If the vehicle is equipped with a device to limit the performance in an emergency (e.g. overheating of a component) the user shall be informed by an obvious signal indicating state of limited performance [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 state of charge of 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

The function of the on-board isolation resistance monitoring system shall be confirmed by the following method:

Insert a resistor that does not cause the isolation resistance between the terminals being monitored and the electrical chassis to drop below the minimum required isolation resistance value, otherwise the warning shall be activated [5].

3.2.2 Protection against electric shock

a. Protection against direct contact with live parts of the power train

Direct contact with live parts of the electrical power train whose maximum voltage is at least 60 V DC or 25 V AC shall be prevented either by insulation or by the use of covers, protection grills, perforated metal sheets, etc. [2 and 5].

Figure 1: Symbol for the indication of a voltage

Live parts in passenger and load compartments, shall be protected by enclosures having a protection degree of at least IPXXD. Enclosures in other areas of the vehicle shall have a protection degree of at least IPXXB. Protection degrees IPXXB and IPXXD are related respectively to the contact of a jointed test finger & a test wire with hazardous parts specified in AIS 038 and ECE R100 standards. Protection covers of live parts shall be marked by a symbol shown in Figure 1 [2 and 5].

b. Protection against indirect contacts with exposed conductive parts of the power train

No requirements of this test if the working voltage is lower than 60 V DC or 25 V AC. Insulation used shall ensure protection against indirect contacts and additionally, the exposed conductive parts of the on-board equipment shall be electrically connected together. This potential equalization is obtained by connecting the exposed conductive parts together either by a protective conductor e.g. wire, ground truss, or directly by the vehicle metallic chassis. If there is some discontinuity, this point shall be by-passed by potential equalization [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) [3].

- **Impact Test**

The passenger compartment must be visually checked directly after a barrier impact for evidence of electrolyte leakage, battery system component intrusion, and retention of interior mounted battery modules and photographs of the same should be taken.

Following an impact crash, propulsion battery electrolyte shall not have electrical isolation less than 500 ohms/volt throughout the complete barrier impact test else a test failure has occurred [3].

- **Static Rollover Test**

This test must be conducted within 45 minutes after the vehicle impact and voltage measurement at each increment of 90º, 180º, 270º, and 360º of the static rollover test.

When the test vehicle is rotated in a fixture on its longitudinal axis to each successive increment of 900, following an impact crash, propulsion battery electrolyte shall not exceed 5 liters, and electrical isolation shall not be less than 500 ohms/volt [3].

d. Thermal Shock

The purpose of this test is to verify the resistance of the energy storage system to sudden changes in temperature experienced during its life.

The tested device shall be stored for at least six hours at a test temperature equal to 60 ± 2 °C, followed by storage for at least six hours at a test temperature equal to -40 ± 2 °C. The maximum time interval between test temperature extremes shall be 30 minutes. This procedure shall be repeated until a minimum of 5 total cycles are completed, after which the tested-device shall be stored for 24 hours at an ambient temperature of 20 ± 10 °C. After the storage for 24 hours, a standard cycle as described in Table 1 shall be conducted [5].

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

Process	**Criteria**
Discharge rate	Defined by the manufacturer. If not specified, then it shall be a discharge with 1C current.
Discharge limit (end voltage)	Specified by the manufacturer
Rest period after discharge	Minimum 30 min
Standard charge	Defined by the manufacturer. If not specified, then it shall be a charge with C/3 current.

The test shall end with an observation period of 1h at the ambient temperature conditions of the test environment [5].

e. Vibration test

The purpose of this test is to verify the safety performance under a vibration environment which the energy storage system will likely experience during the normal operation of the vehicle. The tested-devices shall be subjected to a vibration having a sinusoidal waveform with a sweep rate defined by the standard.

The correlation between frequency and acceleration is as shown in Table 2:

Table 2: Frequency and acceleration [5]

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

After the storage for 24 hours, a standard cycle similar to described in Table 1 shall be conducted. The test shall end with an observation period of 1h at the ambient temperature conditions of the test environment [5].

f. Connection of the vehicle to the mains network

In no case the vehicle shall be capable to move by its own when it is electrically connected to an energy 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 wet), the vehicle shall then comply with the insulation resistance test as 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 intended to simulate a normal washing of battery operated vehicles for the critical areas like a seal of two parts as flaps, glass seals, outline of opening parts, outline of front grille, seals of lamps, etc. The test uses a hose nozzle specified in instrumentation section of this article which uses fresh water with a flow rate of 12.5 l/min. All borderlines shall be exposed in all directions with the water stream at a speed rate of 0.1 m/s, keeping a distance of 3 m between the nozzle aperture and the borderline [2].

b. Flooding

This test is intended to simulate the driving of a battery-operated vehicle on flooded streets or in water puddles. The vehicle shall be driven in a wade pool, 10 cm in depth, over a distance of 500 m at a speed of 20 km/h resulting in a time of approximately 1.5 min. If the wade pool used is less than 500 m in length, so that it has to be driven through several times, the total time including the periods outside the wade pool shall be less than 10 min [2].

c. Heavy Rainstorm

This test is intended to simulate a sudden heavy rainstorm e.g. a thunderstorm, when opening parts especially to access to the passenger, load and motor compartments are open except those requiring one or more tools. This test uses a hose nozzle as specified in instrumentation section which uses fresh water with a flow rate of 10 l/min. All surfaces with normally open opening parts shall be exposed for 5 min, possibly through a regular movement of the nozzle [2].

3.3 Minimum sound requirements for electric vehicles

To reduce the risk of pedestrian crashes, especially for the blind and visually-impaired, this rule establishes a new Federal motor vehicle safety standard (FMVSS) setting minimum sound requirements for electric vehicles. This standard will help to ensure that blind, visually impaired, and other pedestrians are able to detect and recognize nearby electric vehicles. This standard requires electric passenger cars to produce minimum sound levels for detection of 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. Protection against electric shock and electrolyte spillage

a. Protection against direct contact with live parts of the power train

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

b. Protection against indirect contacts with exposed conductive parts of the power train

AIS-038 mentions this procedure, whereas ECE R100 does not include this procedure for safety testing. FMVSS also doesn't mention this procedure for safety testing.

c. Insulation Resistance of Traction Batteries and Electrolyte spillage

AIS-038 requires this test to be performed after maintaining vehicle for conditioning time of 8 hours with following conditions:

Temperature	20 to 35 ^{0}C
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. This cycle is repeated 12 times for a total of 3 hours in the vertical direction of the mounting orientation of the energy storage system [5].

f. Connection of the vehicle 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 reduce the risk of pedestrian crashes, especially for the blind and visually-impaired. AIS and ECE doesn’t mention this requirement.

5. CONCLUSION

This article makes an effort to provide 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 include some of the clauses which are not mentioned in other two standards (i.e. protection against water effects), still one of the issue, i.e. on-board insulation resistance is worth adding during 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. 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 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 useful for the policy makers, industry experts while drafting revised testing standards for electric vehicles.

REFERENCES

1. Larminie J, Lowry J., Electric vehicle technology explained. John Wiley & Sons; 2012 Sep 17.
2. Indian Standards (IS) - AIS-038 and AIS-048.
3. Federal Motor Vehicle Safety Standards (FMVSS) – FMVSS No. 305.
4. Federal Motor Vehicle Safety Standards (FMVSS) – FMVSS No. 141.
5. European Economy Commission (ECE) Standards - R100