ULSE Safety Guidelines for Safe Electric Vehicles in India

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Foreword

To create a safer, more sustainable world, data and scientific discoveries must be amplified and translated into action.

UL Standards & Engagement pursues this mission through the development of consensus-based standards for everyday products and systems ranging from life jackets to batteries to autonomous cars. Through data analysis, expert testimony, and deliberation, we work to bring members of technical committees into alignment on a common set of safety requirements to help guide these technologies.

With electric vehicles playing an important role in global initiatives to address climate change, various electrochemical energy storage systems have evolved, and lithium-ion batteries have emerged as one of the preferred methods of powering these vehicles. Standards for these batteries, along with the other components in the EV system, play an important role in helping to ensure safety. Addressing safety in the entire EV value chain – from manufacturing to consumer use and safe disposal – is essential.

Through our commitment to helping guide the safe development of evolving technologies, including safer deployment of electric vehicles in India, we are proud to facilitate the development of the *ULSE Safety Guidelines for Safe Electric Vehicles in India*. We invite stakeholders to review and comment on this document, and we look forward to what we will accomplish together as we dedicate our efforts toward the development of a safer EV ecosystem in India.

Sonya Bird
Vice President, International Standards
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Acknowledgement

We want to express our deepest appreciation to all the subject matter experts and stakeholders who contributed to bringing out this ‘Safety guideline for Safe Electric Vehicles in India’. This document authored by Principal Engineer - Energy Systems and e-Mobility, UL Solutions Sh. Rebecca Le, Principal Engineer - Energy Storage and Stationary Battery Systems, UL Solutions, Sh. LaTanya Schwalb, and Sh. Laurie Florence, Principal Engineer for stationary/motive batteries and ESS, (retired) released on August 23, 2023, for review comments by stakeholders, during the Conference on Standards for Safe - Secure - Sustainable Indian EV Ecosystem in New Delhi. ULSE’s CSDS (Collaborative Standards Development System) online collaboration tool was leveraged to collect inputs and comments from stakeholders. The comments from key stakeholders have been included in the guidelines after thorough consultation with the subject matter experts.

Furthermore, we would also like to introduce and acknowledge with much appreciation the crucial role of authors in preparing this safety guideline.

1. Sh. Rebecca Le, Principal Engineer - Energy Systems and e-Mobility, UL Solutions: Rebecca Le has 16+ years with UL Solutions in product safety certification focused on portable, motive, and stationary batteries for consumer, commercial, and industrial applications. Her current role at UL Solutions is Principal Engineer for motive batteries, ultracapacitors and portable power stations. She represents UL Solutions on several technical committees including UL1974 and UL2271/UL2580 as well as other industry standards and battery committees across ANSI, SAE, IEC and SAC. She is a Distinguished Member of the Technical Staff of UL.

2. Sh. LaTanya Schwalb, Principal Engineer - Energy Storage, UL Solutions: LaTanya Schwalb has 20+ years of experience in product safety certification with the past 9 years focused on portable, motive, and stationary batteries for consumer, commercial, and industrial/e-mobility applications. Her current role at UL Solutions is Principal Engineer for energy storage systems, stationary battery systems, fuel cells, and hydrogen generators. She represents UL Solutions on a variety of UL standards technical committees including UL 1973, UL 1989, UL 9540/9540A as well as other industry standards and battery committees across ANSI, SAE, IEC, CSA, and NFPA.

3. Sh. Laurie Florence: Laurie Florence was a UL Corporate Fellow and UL Solutions Principal Engineer for stationary/motive batteries and ESS. She represented UL on a variety of UL standards technical panels including 1973/1989, 1974, 2580/2271, 810/810A/810B, 2267 and 9540/9540A – as well as other industry standards and battery committees across ANSI, SAE, ISO, IEC, IECEE, CSA, and NFPA. Laurie was also the chair of IEC SC21A, convener for IEC SC21A WG 5, and a member of IEC TC 120. After more than 30 years in her illustrious career, Laurie retired November 2022.

ULSE SAFETY GUIDELINES FOR SAFE ELECTRIC VEHICLES – MANUFACTURERS

1. Current practice in India for EV batteries with a focus on e-2W:

In recent years, India has seen a growing trend of electric vehicle use, with two-wheeled vehicles (referred to as e-2W) making up approximately 85% of EV sales. This market grew by 133% in 2021, with 8.15 Lakh EVs on the road in 2022-23, and is anticipated to increase by an additional 65% by 2025.[1]

In addition to the growth of electric vehicles, there has been a shift in EV battery technology from lead acid to lithium-ion construction. In 2021, lithium-ion made up approximately 85% of battery sales, while lead acid made up only 15% of battery sales. The most common battery chemistry utilized for lithium-ion batteries is nickel-manganese-cobalt (NMC), with other chemistries such as nickel-cobalt-aluminum (NCA) and lithium-iron-phosphate (LFP) being used to a lesser degree. The batteries used for the e-2W lithium-ion batteries range in size from about 26 Ah to 83 Ah.

The growth in electric vehicles has been driven in part by government policies supporting research and manufacturing. These policies have led to increased EV use in all sectors, from e-2Ws to electric buses, with EV charging infrastructure throughout the country to support this growing market. The growth in e-2Ws is attributable largely to the release of the remodeled FAME II, which has seen a multifold increase in production, growing from 3,000 vehicles per month when it was released in July 2021, to more than 90,000 in 2022. In addition to federal incentives, more than 26 states and union territories have already declared EV policies with incentives for demand and manufacturing, to support the electrification of transportation. As part of the policies to address EV batteries in India, standards have been developed by organizations including the Bureau of Indian Standards and the Automotive Research Association of India for various types of EVs. For e-2Ws, the applied standards are as follows:

- AIS-004 – Part 3 – Automotive Vehicles – Requirements for Electromagnetic Compatibility
- AIS-040 – Revision 1 – Electric Power Train Vehicles – Method of Measuring the Range
- AIS 041 – Revision 1 – Electric Power Train Vehicles Measurement of Net Power and The Maximum 30 Minute Power
- AIS 039 – Revision 1 – Electric Power Train Vehicles – Measurement of Electrical Energy Consumption
- AIS 048 – Battery Operated Vehicles – Safety Requirements of Traction Batteries
- AIS-156 – Specific Requirements for L Category Electric Power Train Vehicles

In addition to these standards, the Government of India has also established goals for second-use applications of EV batteries, including energy storage. Further goals address recycling lithium-ion batteries in the end-of-life stage to recover rare materials.

With this proliferation of EVs including e-2W vehicles in India powered by lithium-ion batteries, there has also been an increase in incidents involving the lithium-ion batteries used for these vehicles. There have been approximately 30 fires involving e-2W batteries over the past three years. Although a majority of the fires are attributable to overcharge and over-discharge, a few of them include defects with the batteries, including defects with the cells and with the battery pack design.[2] Reports on research into the cause of the fires point to the low quality of some battery cells and insufficient testing of battery packs under anticipated use conditions. The history of commercialization of lithium-ion batteries demonstrates that the safety of the batteries starts with good quality cells and battery designs with sufficient protection to ensure the safety of the cells. It is also clear that they must be maintained within their specified operating ranges and with consideration of the anticipated environmental conditions to which the battery will be exposed. The cells and batteries should be evaluated for suitable cell and battery safety requirements.

2. **Approach to be considered for increased safety.**

There are standards that have been developed and can be utilized to build a safer EV battery. AIS 156 and AIS 038 are both used by the automotive industry and supported by the Ministry of Road Transport and Highways in India.

AIS 038, Rev. 2, Specific Requirements for Electric Power Train of Vehicles, Parts I and II, issued in September 2020 is a mandatory requirement for M and N categories of electric vehicles as of October 1, 2022, and its latest amendment, issued in September 2022, came into full effect on March 31, 2023.

This standard covers the specific tests and requirements for safety of M and N Category Electric Power Train Vehicles, which includes four-wheel vehicles for carrying goods or passengers. The standard was written in line with *UN ECE R100 Rev 3, Uniform provisions concerning the approval of vehicles with regard to specific requirements for the electric power train* and *UN GTR 20, Global Technical Regulation No. 20 (Electric Vehicle Safety (EVS)*.

AIS 156, Specific Requirements for L Category Electric Power Train Vehicles, issued in September 2020. This standard covers the specific required tests and other requirements for safety of Category L Electric Power Train Vehicles, which includes two and three-wheels vehicles. The latest amendment for this standard was issued in September 2022 – the requirements in this amendment will take effect March 31, 2023. Unlike AIS 038, which is mandatory, the requirements in AIS 156 for L Category Electric Vehicles are recommended. This standard was also developed in line with *UN ECE R136,* Uniform provisions concerning the approval of vehicles of category L with regard to specific requirements for the electric power train.

The requirements outlined in AIS 038 and AIS 156 address the safety features of battery management systems (BMS) that serve to keep the cells in the battery pack within their safe operating limits. The BMS should protect the battery pack against overvoltage, overcurrent, over discharge, overtemperature, overcharge, and short-circuit conditions as stated in these standards. In addition, the BMS shall comply with EMC requirements as specified in these standards.

As well as the safety of the BMS, these standards also address electrical, mechanical, and environmental conditions that a battery pack could be exposed to, such as vibration, short-circuit, drop, or thermal shock and cycling, to name a few.

The safety of the battery pack has at its foundation the safety of the cells that compose it. AIS 038 and AIS 156 require cells to comply with IS 16893, Part 2, which is the India Standard for Secondary Lithium-Ion Cells for the Propulsion of Electric Road Vehicles Part 2 Reliability and Abuse Testing and IS 16893, Part 3, which is the India Standard for Secondary Lithium-ion Cells for the Propulsion of Electric Road Vehicles Part 3 Safety Requirements. These cell standards align with the requirements in IEC 62660-2 and IEC 62660-3, respectively.

IEC 62660-2, Secondary lithium-ion cells for the propulsion of electric road vehicles – Part 2: Reliability and abuse testing identifies tests related to the reliability and abuse behavior of cells used in electric vehicle applications. *IEC 62660-3*, *Secondary lithium-ion cells for the propulsion of electric road vehicles – Part 3: Safety requirements* is a standard developed based on IEC 62660-2 with safety criteria added for each test and small revisions on some tests and addition of the internal short circuit test, which can be used to evaluate the design of the cells to establish a minimum level of safety.

UL 2580, *Batteries for Use in Electric Vehicles* includes safety requirements for cells used in EV batteries as well as safety requirements for the battery pack. Like the aforementioned standards, UL 2580 includes as criteria some general concepts that are important for good cell safety design, including sufficient separator overlap of active materials. UL 2580 cell criteria also require that the cells be provided with instructions for the safe installation and operation in the end use application. This would include a cell specification sheet outlining the safe operating region of the cells for voltage, current, and temperature during charging and discharging. This information is critical for the safe design of the battery system that provides sufficient protection for the cells. *UL 2271, Batteries for Use in Light Electric Vehicle (LEV) Applications*, is similar to UL 2580, but the scope of this standard covers the batteries used in LEV such as electric scooters, electric wheelchairs, and electric bicycles, etc.

Other standards for battery system and battery pack safety or abuse testing include *ISO 6469-1, Electrically propelled road vehicles – Safety specifications – Part 1: Rechargeable energy storage system (RESS) that can be used to evaluate the safety of the EV battery; SAE J2929,* *Safety Standard for Electric and Hybrid Vehicle Propulsion Battery Systems Utilizing Lithium-based Rechargeable Cells; and SAE J2464, Electric and Hybrid Electric Vehicle Rechargeable Energy Storage System (RESS) Safety and Abuse Testing.* These standards include tests and requirements with regards to mechanical, electrical, environmental, and abuse conditions that batteries can be subjected to.

Testing the cells to a suitable set of requirements for EV cells is not sufficient to ensure safety. It is important to also have ongoing quality control of the manufacturing of these cells and third-party oversight, or inspection, of the manufacturing production. UL Solutions provides a safety certification program that includes ongoing production inspection. The UL standards also require that the manufacturer have a manufacturing quality control program. This quality control is essential to the safe manufacturing of lithium-ion cells and batteries.

Even with a good cell design that meets appropriate safety criteria, it is not enough to ensure that the battery design is safe. The battery needs to provide sufficient electrical, thermal, and mechanical protection of the battery cells and other critical components that make up the EV battery to provide sufficient safety. Starting with the enclosure, the material and construction need to be robust enough to handle the mechanical and temperature stresses that the battery pack will be exposed to. The safety controls including the BMS will need to maintain the cells within their operating region for charging and discharging. The safety controls including the BMS will also need to be evaluated for reliability based upon the safety analysis and in accordance with an appropriate functional safety standard. The key components, such as gasket, switches, contactors, fuses, connector shall have suitable rating for the application and shall have been evaluated for their reliability after aging. UL 2580, *Batteries for Use in Electric Vehicles,* includes detail requirements for the BMS and other components that make up the battery pack including the enclosure. UL 2580 also includes tests to evaluate the battery and has test and quality control requirements for the ongoing production of the batteries. UL 2580 is a standard that can be utilized as a guidance for production design, and for third party certification of the battery packs; it includes requirements for testing and inspection for ongoing production.

When batteries are to be repurposed in a second application such as light electric vehicles, the repurposed battery manufacturer should have the necessary process control to disassembly, screening, sorting, and reassembling and testing to ensure the basic performance and safety of the repurposed batteries meets the second application requirement. UL 1974, *Evaluation for Repurposing Batteries*, can be used as a conformance requirement for the repurposing facility.

3. **Methods for checking battery health through its use.**

Once the battery is sold to the user, there needs to be some method for ongoing checks of the battery health. It is important that if the battery health is at all in question, the BMS or vehicle controller should notify or warn the user that it should be repaired or replaced. If there is any safety risk from the battery or vehicle, the BMS or vehicle controller should notify or warn the user through visual or audible signals immediately and inform the user of the appropriate emergency handling measures or where to find corresponding emergency measures in the user manual.

The battery health can be checked when the vehicle is taken in for routine maintenance to check the BMS and date of the battery. If the battery is part of a swapping scheme for charging, then this can be done as an ongoing check of the discharged batteries that are dropped off. It would start first with a check of battery age. There can also be a quick check of the BMS data to determine if there had been an out-specification condition that needs to be reviewed, such as battery temperature, voltage and current. In addition, the battery internal resistance, isolation resistance and imbalance conditions can be checked if applicable. If there are any issues with the battery health, the battery should be replaced and removed from service.

For batteries that are charged within the vehicle or that are charged by the user, there should be instructions indicating potential signs of trouble with the battery that require the replacement of the battery. The instructions shall also recommend that batteries be replaced after their age meets a certain milestone after the date of manufacture that is marked on the battery.

AIS 156 and AIS 038 amendment 3 require that the key parameter data of the battery pack should be logged by the BMS, and the latest data should be stored in the BMS or cloud for at least one month, this amendment can help to obtain more battery status and error information during maintenance or in a swapping station and help to better analyze and identify potential battery problems.

4. <u>Tracking of EV Batteries from cell to vehicle</u>

Tracking of a battery pack, starting at the cell, and moving through its life as part of a battery pack and into an end-product such as an E-2W may be done by the cell manufacturer, the battery pack manufacturer, and the end-product manufacturer.

The cell manufacturer may be able to trace a cell based on its date of manufacture or its lot number to the manufacturer that purchased the cell to use as part of a battery pack. Typically, that is the extent of traceability for the cell manufacturer to the pack manufacturer.

A battery pack, or REESS pack, manufacturer may be able to trace the cells used back to their cell suppliers. They can trace back their battery packs based on the battery pack’s model number or lot number or date of manufacture and can determine the end-product manufacturer to whom their battery packs were sold. REESS manufactures are required to maintain a record of the cell manufacturing dates for the cells used in the battery packs. Additionally, cells used for REESS are required to be certified according to IS 16893-Part 2 and Part 3. These requirements are noted in AIS 156, Annexure 8K and AIS 038, Annexure IX-K.

End-product manufacturers of electric vehicles may be able to trace the battery packs used in those vehicles to their pack suppliers based on the battery pack’s model or lot number or date of manufacture. Again, as required by AIS 156 and AIS 038, pack manufacturers must include the manufacturing date of the pack on the battery pack itself. Battery packs should also include a traceability document that includes cell details, information on the BMS, charge/discharge values, and charger used along with its serial, or batch, number.

Note:

- *The traceability document details shall be mutually agreed upon by the battery manufacturer and EV manufacturer.*
- *EU battery regulation - https://eur-lex.europa.eu/eli/reg/2023/1542/oj which includes digital passport, i.e., information on cell, BMS, etc. can be referenced for further details to be recorded.*
- *Also, the minimum data requirement as mentioned in UL 1974 for repurposing can be referenced.*

As part of the manufacturing process, it is critical for the battery pack that it is designed within the cell's specifications for voltage, current, and temperature; that the cells used in a pack are the same (no mixing of different cell models or cells from different manufacturers); and that the cells used are not damaged. Also, if the pack is provided with a BMS, the BMS parameters should ensure that the cells within the pack are operated and maintained within their normal operating range with regards to voltage, current, and temperature.

The end-product EV manufacturer usually has multiple battery pack suppliers or might purchase more than one model battery pack from a single pack manufacturer based on their product lines. When the end-product EV manufacturer utilizes battery packs that comply with a safety standard such as AIS 038 or AIS 156, it is imperative to maintain the documents for the battery packs that can provide traceability down to the cell level.

It is up to the end-product manufacturer to ensure they are able to track the battery pack model(s) used in the different products manufactured and sold. Should there be an issue with the product related to the battery pack, the end-product manufacturer should be able to trace that battery pack all the way back to the pack manufacturer and the pack manufacturer should be able to trace that pack all the way back to the cell manufacturer.

Current requirements in AIS 156 and AIS 038 state that battery packs must have an RFID (radio-frequency identification) tag. The tag shall include battery parameters related to the history, transactions, and state of health of the battery pack. Also, the BMS for the battery pack should be capable of RF reading and writing. These tools are useful for tracking the health and status of a battery pack.

Therefore, it is critical for the cell, pack, and end-product manufacturers to adhere to robust manufacturing processes that are well-documented and to retain records for products manufactured and distributed.

The BMS for a battery retains data on cell temperature, voltage, current, and other parameters, such as capacity, state of charge, power consumption, remaining operating time, charging cycles, and error logs, based on its design.

Note:

This is recommendatory for battery repurposing and recycling. Also, this data will be useful for investigation in case of failure. Key information to be recorded/stored, whereas recent information can be used for monitoring and assessment.

A BMS may communicate this information directly into an electric vehicle's diagnostic chip or the information may be downloaded directly from the BMS using some form of communication such as CAN BUS or serial communication. This would be done at a vehicle manufacturer's service/repair facility.

However, for an E-2W, there may not be a diagnostic chip within the E-2W because they are not subjected to routine service or maintenance like a 4-wheel vehicle. Tracking information from the battery BMS in these products may not always be done unless a battery is sent in or returned for service or warranty. At the manufacturer's service facility, the data from the BMS may be downloaded and reviewed.

Because a battery BMS is a proprietary design, tracking battery information via the BMS would be done only at the battery manufacturer or authorized service/repair facility. Additionally, the data provided from the BMS would only be available to the battery manufacturer and would not be provided to the general public.

5. Tests for EV batteries to prevent fire and address abusive usage

All cells and batteries must go through testing in accordance with UN 38.3, Classification Procedures, Test Methods and Criteria Relating to Substances and Articles of Transport Class 9. This testing addresses hazards that can arise as a result of transporting or shipping.

6. Tests for EV cells

Both AIS 156 and AIS 038 require that cells used to make REESS, shall be certified as per IS 16893 Part 2 and Part 3. IS 16893 Part 2 and Part 3 are consistent with (a) IEC 62660-2 *Secondary lithium-ion cells used in electrically propelled road vehicles propulsion – Part 2: test of reliability and abuse* and (b) IEC 62660-3 *Secondary lithium-ion cells used in electrically propelled road vehicles propulsion – Part 3: safety requirements separately*.

IEC 62660-3 is a revised version of IEC 62660-2 with minor changes to some test methods and a newly added internal short circuit test. In addition, compliance criteria are added to each test of IEC 62660-3 to constitute a safety standard.

UL 2580 Annex B also includes the safety requirements for lithium-ion batteries for electric vehicle application and light electric vehicle application. The majority of the test program in UL 2580 Annex B refers to IEC 62660-2 and IEC62660-3. In addition, a drop test and projectile test are added. The projectile test is intended to evaluate whether a cell will explode when it is exposed to a fire.

Table 1 below lists the tests from three major EV cell safety standards.

Table 1 – Tests for EV cells and LEV cells

		UL 2580 - Annex B	IEC 62660-2	IEC 62660-3
Electrical tests	External short circuit	X	X	X
	Overcharge	X	X	X
	Forced discharge	X	X	X
	Internal short circuit			X
Mechanical tests	Vibration	X	X	X
	Shock	X	X	X
	Drop	X		
	Crush	X	X	X
Thermal tests	Heating / High Temperature Endurance	X	X	X
	Temperature cycling	X	X	X
	Projectile	X		

Tests for EV battery packs and battery systems

Batteries submitted for certification to a safety standard, such as AIS 038, AIS 156, UL 2271, or UL 2580 undergo a number of tests that address various conditions related to mechanical, electrical, or storage that could result in fire or other damage to the battery. Table 2 below lists the tests from several EV battery safety standards that have been used.

Table 2 – Tests for EV batteries and LEV Batteries

Tests	UL 2580	AIS 038	UL2271	AIS 156
External Short Circuit	●	●	●	●
Overcharge	●	●	●	●
Over discharge	●	●	●	●
Temperature	●		●	
Imbalanced Charging	●		●	
Isolation Resistance	●	● [a]	●	● [a]
Dielectric Voltage	●		●	
Grounding Continuity	●	● [a]		● [a]
Over Current Protection	● [b]	● [c]	● [c]	●
Mold Stress Relief	● [d]		● [d]	
Strain Relief Test			● [e]	
Handle loading			● [f]	
Vibration	●	●	●	●
Mechanical Shock	●	●	●	●
Drop	●		●	●
Rotation	●		●	
Thermal Cycling	●	●	●	●
Crush /Mechanical Integrity	●	●	●	
Water Immersion/Exposure	●	● [c]	●	● [c]
Fire Exposure	●	●	●	●
Salt Spray	●			
Thermal Propagation	●	●		●
AIS 038 is the Safety Standard for M, N category electric power train of a vehicle, which refers to ECE R100. AIS 156 is the Safety Standard for L category electric power train of a vehicle, which refers to ECE R136. [a] Required in vehicle level test. [b] Covered by Functional Safety test. [c] in Amendment 3 of AIS 038 or AIS 156 [d] for plastic enclosure [e] for non-detachable cable [f] for handle				

All of the tests listed above serve to validate the design of the battery and BMS.

The tests listed for mechanical and environmental hazards test the design of the battery by subjecting it to different environments encountered during storage, during transport or while handling the battery, if necessary.

The Tolerance to Internal Cell Failure / Internal Short Circuit test is a cell-level test that determines what happens to the cell if it is subjected to an internal fault or damage that results in thermal runaway. This is important because it allows a manufacturer to assess whether there can be cell-to-cell propagation within the battery pack and how well the pack is able to contain the propagation.

The External Fire Exposure Test, which is done on a battery pack, and the High Temperature Endurance Test, which is done on a cell, are both useful tests to assess what happens to a pack or a cell when they are exposed to flame.

The tests listed under Mechanical and Environmental hazards are tests that simulate conditions during transportation, storage, or installation of the battery pack as well as use conditions of the end-use product with the pack installed.

The tests listed under electrical hazards all test the robustness of the BMS to maintain cells within their operating limits. For battery packs that have no BMS, the tests evaluate the robustness of the battery design. The Temperature Test evaluates the battery pack during normal use to ensure that all the materials used in the manufacture of the battery pack are used appropriately and within their specified temperature and/or electrical ratings.

7. <u>Label and instruction requirements for EV batteries</u>

Safety standards, such as AIS 038, AIS 156, SAE J2929, UL 2271, provide guidance on the information that should be marked on a battery. This information includes basic product information, such as the manufacturer's name, model number, and ratings, but also important information related to charging and handling the battery. The instructions could be in vernacular languages. A QR code redirecting to a website where instructions can be read in various languages can be considered.

First and most important in terms of battery labels and markings is that the markings should be permanent and easy to read. Ink used on labels or for screen-printing should be indelible and not easily rubbed off or washed away. Labels, when used, should be permanent and not able to be peeled off.

Information that should be included on the battery label are as follows.

- Battery manufacturer's name or trademark/tradename
- Battery manufacturer's location or address in the case that there is multiple sites
- Battery model number
- Battery or cell's chemistry
- Battery's date of manufacture
- Battery's electrical ratings
    - Nominal voltage (V_{dc})
    - Working voltage (V_{dc})
    - Capacity (Ah or Wh)
    - Maximum current (A)

    - Configuration of cells within the battery pack
- Identification of a specific charger, including the part number and manufacturer, that should be used with the battery; this marking should be visible after the battery is installed in the e-2W vehicle as well.
    - Alternatively, the battery label should include the charging parameters (voltage, current, and temperature) for the battery.
- Battery's temperature for charging and discharging
- Battery's charging and discharging current and voltage.
- The battery label should include any warnings or cautions that a user should be aware of when using the battery–such as warnings against crushing.
- A warning statement on the label to indicate the user must read the user manual to prevent injury.
- In case of repurposed batteries used, the battery should be marked 'Repurposed' or 'Second Life' and conformance to the battery repurposing standard – such as UL 1974

The battery manufacturer date and Manufacturer location information is important so that in the case of a field incident, the battery can be traced back to the manufacturing site and manufacturing lot. If the issue was the result of a battery defect, then this defect may be present in other batteries from that location and production lot.

The information in the instruction manual should include all the information in the label as noted above. In addition, the manual should include instructions for the safe installation, operation, and maintenance of the battery system. These instructions are critical to ensure the battery is properly installed and operated in the end use vehicles.

- The installation instruction should provide the method by which the battery is to be properly installed in the end use vehicle, including any additional protection that the vehicle needs to provide.
- The operating instructions should provide the safe charging and discharge parameters and temperature range for safely charging and discharging the battery.
- The charging instructions should also include the appropriate method and charger to be used for charging the battery and step-by-step instructions for charging. If the e-2W battery is intended to be removed for charging by the user, the instructions shall recommend that the charging be conducted outside the residence, and the instructions shall be provided to safely remove and reinstall the battery pack. Similar instructions should be provided if the battery pack is intended to be swapped with a pre-charged battery as part of an EV battery swapping system. In all cases for charging, the user shall be provided with instructions on the appropriate methods and markings on the battery where they can be viewed to provide guidance on steps the user should take to safely charge the battery.
- Instructions shall also indicate the anticipated life of the battery for replacement and provide a list of conditions that would indicate that the battery's health may be compromised such that there is a need to replace or repair the battery.

- Instructions should indicate that the batteries have no user-replaceable parts and that the batteries should only be repaired by the manufacturer's authorized service persons. When replacing the battery, the instructions should indicate that the replacement battery must be one authorized by the manufacturer, and that use of unauthorized batteries can lead to potential hazards such as fire and explosion of the battery.
- The battery should be marked with the date of manufacture so that the age of the battery can be easily determined, and it also should indicate the location of manufacture if there are multiple sites. This information is important so that in the case of a field incident, the battery can be traced back to the manufacturing site and manufacturing lot. If the issue was the result of a battery defect, then this defect may be present in other production for that location and production lot.

The battery manufacturer should provide an instruction or installation manual that accompanies the battery pack for the battery pack itself. In addition, the end-product EV manufacturer should incorporate the necessary battery pack manual information within the manual for EV or provide a separate manual for the battery pack that is intended to be used with the EV.

End user should strictly follow the marking on the battery pack and end-product vehicles and associated instructions to use and charging the battery pack.

8. Current conditions for battery management systems in India and safety considerations

A BMS monitors and regulates internal operational parameters, i.e., temperature, voltage and current during charging and discharging of the battery. It also estimates the SoC (State of Charge) and SoH (State of Health) of the battery to improve safety and performance. The BMS will limit the charging / discharging current or shutdown the system to avoid over-charging and over-discharging of the battery pack, and to prevent battery performance decay or safety issues.

Lead-acid batteries were primarily used in e-2W and e-3W EVs in India which rarely use BMS. This is mainly due to lower instances of sudden failures due to undercharging or overcharging. Overcharging a lead-acid battery leads to release of the hydrogen and oxygen gases, which could corrode the battery and reduce the battery capacity. A controller is used to avoid deep discharge and overcharge of a Lead-acid battery in current time.

A Lithium-ion BMS is used in modern e-2W, e-3W, e-4W and e-Buses. For e-2W and e-3W, a single BMS is used to monitor each battery pack. For e-4W and e-bus, slave BMSs (module-level BMS) and master BMS (system-level BMS) work together to ensure the safety of the battery pack. Each battery module is equipped with a slave BMS, which monitors the voltage and temperature information of cells in the module and convey the data to the master BMS. The master BMS communicates with the vehicle controller and charger controller to output power or receive power.

BMS companies in India typically only conduct assembly and design in India, with most components or the entire BMS imported.

Though there are lower fire incidents in the market, the released hydrogen and oxygen gases from lead-acid battery may catch fire or explode due to arcs or hot surfaces, which may result from loosening connections or damaged insulation. It is recommended that a lead-acid battery have a voltage controller in addition to an overcurrent protection or thermal protection. Moreover, the instruction for lead-acid batteries should indicate that the battery must be charged in a well-ventilation location.

For lithium-ion batteries, a BMS is mandatory for its safety. The BMS shall be designed to maintain lithium-ion cells within their normal operating region for voltage, current and temperature during charge and discharge. If the limits are near, the protective circuit shall limit the charging or discharging current to prevent excursions beyond normal operating limit. If the limits are reached, the protective circuit shall shut down the charging or discharging to prevent excursions beyond safety limits.

As required in AIS 038 and AIS156, BMS of REESS shall be verified for following safety features during REESS testing:

a) Over-charge protection
b) Over-discharge protection
c) Over-temperature protection
d) Overcurrent protection
e) Short circuit protection

In addition to above BMS tests, Government of India Ministry of Heavy Industries (MHI) guidelines require following tests for BMS, which are key supplementary test for BMS to ensure battery performance and safety:

1. MOS temperature check
2. Fuse current check
3. Cell balance function check

Though BMS basic functions have been addressed, the reliability of the BMS functions or the BMS functional safety are not addressed in above AIS standards and MHI guidelines.

The BMS must work reliably during the life of the EV battery. An analysis of potential hazards (including an FMEA) should be conducted on the EV battery and its BMS to ensure that events that could lead to a hazardous condition have been identified and addressed through battery and BMS design. The analysis shall consider single fault conditions in the protection circuit/scheme as part of the anticipated faults and abuse use conditions such as overcharging and over-discharging. In addition, the BMS should be tested for functionality in accordance with appropriate functional safety requirements and tests.

UL 2580, *Batteries for Use in Electric Vehicles* includes safety requirements for the BMS. It gives out the detail safety analysis requirement and factors to be considered, it also gives out the functional safety standards list that can be used to evaluate the functionality of the BMS, such as UL 991, UL 1998, UL 60730-1 Annex H, IEC 61508, ISO 26262 and so on. IS 17387 is the safety standard for battery management systems used in energy storage system, with considerable requirements obtained from UL 2271 and UL 2580 that can be referred to for BMS used in EV applications as well. BMS Functional safety evaluation includes an assessment of BMS hardware and software. The former verifies that the BMS functions properly before and after aging, environmental and EMC testing, while the latter verifies that the BMS software works properly though BMS software development process review and software testing. The whole functional safety evaluation ensures that the risks caused by random failures and system failures are addressed.

Most lithium-ion batteries have a maximum operating temperature of 45°C for charge and 60°C for discharge. This is very challenging for EVs in India, as a daily temperature higher than 40°C are common in many cities in India. To prevent potential safety risks from overheating of the cells, EV batteries should be designed with a cooling system to dissipate efficiently the heat generated by the battery. The BMS should be designed with enough temperature sensing and accurate charging and discharging control strategy to prevent the temperature exceeding the maximum operating limit.

As the EV battery ages, the capacity of the battery will decay, the normal/safe operating region of cells will shrink. BMS design should consider these aging effects and set or adjust its protective parameters accordingly.

9. **Testing facilities required to certify EV batteries**

The overall aim of certifying products is to give confidence to all interested parties that a product fulfils specified requirements in a standard. The value of product certification is the degree of confidence and trust that is established by an impartial and competent third party.

A certification body shall be responsible for the impartiality of its certification activities and shall not allow commercial, financial, or other pressures to compromise impartiality. It shall comply with ISO 17065 *Conformity assessment — Requirements for bodies certifying products, processes, and services*.

In addition, a certification body shall have the competence to conduct the required construction review and performance tests, followed by surveillance that takes into account the testing or inspection of samples from production and the open market. The testing lab should comply with ISO 17025 *General requirements for the competence of testing and calibration laboratories*.

EV batteries shall be tested for their safety to withstand various abuse conditions, including electrical abuse, mechanical abuse, environmental abuse, and thermal propagation due to the failure of a single cell. Table 1 and Table 2 in this article shows safety tests for EV cells and batteries in AIS 038 and UL 2580, and LEV Batteries in AIS 156 and UL 2271. There are other safety standards, such as ISO 6469-1, ECE R100, ECE R156, and GB 38031 *Electric Vehicle Traction Battery Safety Requirement* that include similar test programs with differences in test items or test parameter between each standard.

The performance of cells and materials inside an EV battery will decrease after a long period of operation and the degradation will be even faster when the EV battery is exposed to harsh environmental conditions, such as high temperature, high humidity, strong UV etc. The compliance of those material and components with applicable component standards, as well as the compliance of the construction with applicable requirement in EV battery standards are extremely important, such as clearance and creepage for hazardous voltage circuit.

Testing facilities certifying EV batteries should have the capability to perform the battery abuse tests above, as well as the construction review capability, followed by follow up inspection and tests for the production line.

There are few test facilities in India having capabilities to test or certify EV batteries. International Center for Automotive Technology (ICAT) and Automotive Research Association of India (ARAI) are two government / quasi-government test facilities that test vehicles and certify to AIS standards. The scope and testing capabilities of these testing facilities can be obtained by connecting with the respective laboratories. Global testing labs such as UL Solutions may be needed to support the certification service in India.

10. Instructions for safe charging

To address the issue of environmental pollution and fuel depletion, in February 2019, the Indian government approved the Electric Vehicle (Hybrid) Rapid Adoption and Manufacturing Program (FAME-II), which is expected to invest $1.39 billion USD in electric vehicles and their charging infrastructure between 2020 and 2022. From then, many incentive policies were published by Indian government and domestic states for EV and charging stations to promote their development [3]. In July 2021, FAME II was remodeled with a clear focus on incentivizing high-speed electric vehicles, charging stations, and commercial electric vehicles among others. The tweaked FAME II scheme has introduced a demand incentive of Rs.15,000 per kWh for electric two-wheelers with an upper ceiling at 40 percent of the vehicle cost, and the state-owned Energy Efficiency Services (EESL) will launch an aggregate demand for 300,000 vehicles across a variety of user segments.

However, fires incidents accompany the development of EVs. Statistics show that EV fires occur most frequently during charging and post-charging, and the probability increases in the summer.

In order to reduce the fire incidents of EVs and improve the safety of EV charging, every EV shall be provided with detailed instructions for proper charging of EV batteries. The charging instruction shall be strictly followed by user when charging vehicle batteries.

The EV manufacturer shall provide instructions for safe battery charging according to battery intended application and charging scenarios. The following items and information should generally be included in the instruction.

1. The allowable charging conditions of EV batteries, including the maximum charging voltage and current, the maximum charging ambient temperature.
2. If EV battery charging requires the use of a specific charger, the charger information should be provided in the instructions as well as a charging marking near the external surface of the vehicle near the exposed charging connection. Warnings should be provided in the instruction that the original charger shall be used, and the use of other chargers shall be prohibited. The potential safety risks from using other chargers shall also be clarified.
3. If a public charging station is allowed to charge the vehicle battery, proper communications should be set up between vehicle and charger to prevent charging by non-approved chargers and to prevent overcharging.
4. Always check the appearance of the charging device including charger cables and outlets and vehicle inlet before charging. Make sure the charging interfaces are intact and compatible. Do not charge if there is any damage or carbonation or burn trace in outlets or inlets.
5. Lead-acid batteries should be charged in a place with good ventilation, which may release combustible hydrogen gas when overcharged.
6. EV batteries including E2W batteries shall not be charged in a dwelling unit.
7. Relocatable power taps to extend the charger to charge to vehicle battery shall be forbidden. Chargers shall be installed in a well-ventilated place by service man or strictly according to instructions. Any modification to the charging device shall be forbidden unless made by the service man and approved by the manufacturer.
8. Vehicle batteries shall be charged in a location with no combustible material or explosive gas nearby. It is forbidden to put the charger on a combustible substance to charge the battery, such as placing the charger on the seat of the E2W during charging.
9. Confirm charging has stopped before un-plugging from the charger. Press the stop charging button to disconnect the charging process if necessary. Do not directly pull the charging inlet from the charging coupler during charging.
10. Battery chargers shall be stored properly when not charging in accordance with instructions.
11. Batteries intended for removal and charging outside of the vehicle shall be provided with instructions for safe handling including removal and insertion of battery into the vehicle and during charging, as well as instructions for storage of fully charged assemblies.
12. Stop charging immediately if there are any abnormal noises or conditions and contact the manufacturer if necessary.

References:

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[2] https://www.drdo.gov.in/sites/default/files/drdo-news-documents/NPC24May2022.pdf

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