# STANDARDS GUIDANCE FOR ELECTRIC TWO- AND THREE-WHEELERS AND CHARGING INFRASTRUCTURE IN PAKISTAN


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# List of Acronyms

| | |
|---|---|
| AIS | Automotive Industry Standard |
| BIS | Bureau of Indian Standards |
| BMS | battery management system |
| EDLC | electric double-layer capacitor |
| EV | electric vehicle |
| EVCS | electric vehicle charging station |
| E2W | electric two-wheeler |
| E3W | electric three-wheeler |
| GTR | Global Technical Regulation |
| IEC | International Electrotechnical Commission |
| ISO | International Organization for Standardization |
| NTSB | National Transportation Safety Board |
| OCV | open-circuit voltage |
| SAE | Society of Automotive Engineers |
| SDO | Standard Development Organization |
| U.N. | United Nations |
| UNEP | United Nations Environment Programme |
| V2G | vehicle-to-grid |

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# 1 Introduction

One-quarter of the energy-related global greenhouse gas emissions are from the transport sector (UNEP 2023), and carbon emissions are rising faster in transportation than any other economic sector (Bakker et al. 2019). The reason behind the high contribution from transportation vehicles is that they typically rely on petroleum-based internal combustion engines, producing high greenhouse gas emissions and reducing local air quality. Pakistan and many other developing countries rely on two- and three-wheelers as a dominant transportation source (Kokate et al. 2020; IEA 2018). These vehicles disproportionately impact local air quality because they often do not have onboard emissions control systems (Mulhall et al. 2009).

Electric two-wheelers (E2Ws) and electric three-wheelers (E3Ws) have reached upfront cost parity with their conventional counterparts in a number of markets (IEA 2022). Furthermore, E2Ws and E3Ws provide outsized air quality benefits because conventional motorcycles and rickshaws emit more local air pollutants per kilometer than passenger cars (Adak et al. 2016; Hassani and Hosseini 2016). Therefore, Pakistan has embraced E2Ws and E3Ws in their *National Electric Vehicle Policy* (Government of Pakistan 2019b). Specifically, this policy targets 50% of new two- and three-wheeler sales to be electric by 2030. In the short term, this policy targets five times as many E2Ws and E3Ws as cars, vans, and pickups.

In order to meet these goals in a safe, reliable, and efficient manner, Pakistan needs to develop and implement standards related to E2W and E3W vehicles and charging infrastructure, including battery swap stations. Without standards, E2Ws and E3Ws can be dangerous, unreliable, incompatible with charging stations, or diminish the grid's electricity quality (Goel and Singh 2019; Sasidharan 2020). Fortunately, there are several global and local efforts to establish standards that Pakistan can learn from or adopt. This document explains the purpose and process of standards development and introduces the international standards development organizations involved and relevant classification and testing systems. It then introduces and lists many standards related to the vehicles, batteries, and charging equipment so that Pakistan can adopt or reference these standards when developing its own.

# 2 Purpose of Standards

Developing and implementing two- and three-wheeler standards can help a government achieve four key objectives, as outlined by the United Nations Environment Programme (UNEP) and International Climate Initiative 2020 (UNEP 2020):

1. **Safety:** Safety is one of the primary purposes of standards and vehicle-focused transportation policy. This includes safety for the vehicle drivers, operators, and passengers, as well as protection for other road users, passersby, and those that share common facilities that could be harmed through fire, or short circuits.
2. **Quality:** Standards are developed to set a minimum level of quality for the target equipment. Quality requirements ensure that the vehicles can operate satisfactorily for a reasonable period of time, while maintaining nominal temperature. The quality of the electric vehicle charging station (EVCS) is essential to avoid the injection of significant current and voltage harmonics into the power grid through poor charger design. Furthermore, standards-based conformity testing provides consumers with a fair basis for comparing the quality and performance of similar products.
3. **Compatibility:** Standards ensure that vehicle components are compatible with one another and that electric vehicles (EVs) are compatible with EVCSs. The compatibility between equipment and components maximizes efficiency by reducing redundancies in part supplies and charging infrastructure. Standards are required for battery swap schemes to ensure that batteries are compatible with all participating vehicles, swap stations, and chargers.
4. **Policy framework:** Additionally, standards help provide a framework for policies and regulations, including vehicle licensing, registration, taxation, insurance, and usage.

## 2.1 Standards Development and Implementation Process

Standards aim to require a degree of safety and quality, and certification of products is not possible without following standards. Therefore, it is essential to understand how standards are developed and adopted to decide if Pakistan wants to establish its own standards, adopt standards from international standards development organizations, or take input from trustworthy sources from multiple organizations. Standards adoption is common practice in different organizations. When international standards are adopted in North America, the draft of the standard is made publicly available through a public review process. This practice allows stakeholders to share their feedback, which must be considered while adopting or developing the standards.

Global EV standards are largely developed through a set of standards development committees, as shown in Figure 1. The two main committees are in the United States and Canada—the Canadian Mirror Committee and the U.S. Technical Advisory Group (TAG), respectively. The committee members participate in standards development activities for other countries and put forward those standards with international organizations. The important committees and subcommittees in the EV space at the international level are shown in Figure 1, which work on electric road vehicles, plugs, sockets, components of EVs, batteries, and electrolytes.

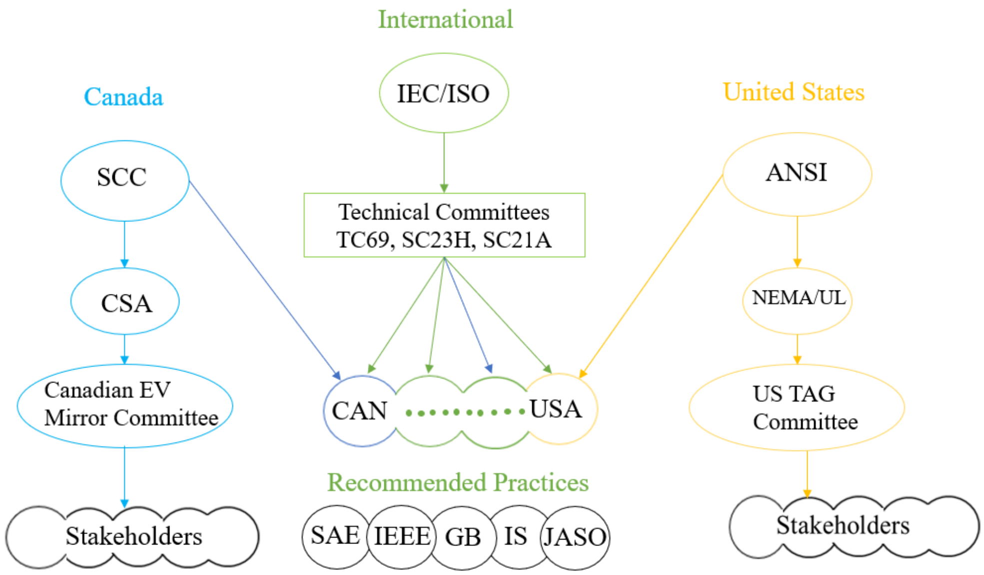


**Figure 1. Graphical view of global EV committee structure.**

Source: Green, Hartman, and Glowacki 2016

Note: Acronyms, going down columns from left to right are a follows: Standards Council of Canada (SCC), Canadian Standards Association (CSA), International Electrotechnical Commission (IEC), International Organization for Standardization (ISO), Technical Committee 69 (TC69), Subcommittee 23H (SC23H), Subcommittee 21A (SC21A), American National Standards Institute (ANSI), National Electrical Manufacturers Association (NEMA), Underwriters Laboratories (UL) United States Technical Advisory Group (US TAG).

## 2.2 Standards Organizations for EVs

Seven organizations are essential in developing, testing, and certifying standards and requirements for major markets worldwide. Many have overlapping duties for different markets. Standards developed by these organizations could be referred to or integrated into Pakistan's market, as further discussed below.

1. International Organization for Standardization (ISO).
2. International Electrotechnical Commission (IEC).
3. SAE International (formerly the Society of Automotive Engineers).
4. Bureau of Indian Standards (BIS).
5. Guobiao (GB).
6. Japanese Automotive Standards Organization (JASO).
7. UL (formerly Underwriters Laboratories).

# 3 Two- and Three-Wheeler Classification

Not all standards are equally applicable to all vehicles. Therefore, standards organizations categorize vehicles through a combination of three primary attributes:

1. **Top speed:** Categorizes vehicles by their maximum speed. Safety and performance are more difficult to achieve at higher speeds, so applying different standards according to the top speed is logical. The top speed of the vehicles must also be limited, considering the average possible speed of that vehicle on the roads.
2. **Vehicle weight and number of wheels:** Categorizes vehicles by maximum vehicle weight and the number of wheels. Larger vehicles generally require more durable and higher power rated components to withstand a given drive cycle. Furthermore, vehicle size can also determine what duty cycle the vehicle is likely to drive.
3. **Engine capacity:** Categorizes vehicles by vehicle power or engine capacity. This is often stated in cubic centimeters (cc) of engine displacement for conventional vehicles or in kilowatts (kW) for EVs. Most organizations use a standard conversion to compare the two types of vehicles (e.g., 1 kW = 20.1 cc) (UNEP 2020). This conversion should be carefully chosen, as it depends on numerous assumptions that differ between technologies and will change over time. The kW rating decision should also involve the maximum instantaneous torque value of the vehicle.

## 3.1 European Commission Classification System

The European Commission has developed a vehicle classification system that is broadly used. These categories are based on a combination of the aforementioned attributes and are essential in developing emissions standards and other vehicle regulations. Category "L" represents motorcycles, tricycles, and other small vehicles. The different vehicle categories are listed in Table 1, and Table 2 covers the different types of Category L vehicles. Automotive Industry Standard (AIS) 156 relates to Category L EVs (Automotive Industry Standards Committee 2020). The document consists of two parts; Part I is about the needs of a vehicle for its electrical safety, and Part II covers the requirements of a rechargeable electrical energy storage system or battery for its protection. Standard L13 is a Malaysian standard related to electrically propelled vehicles, which complies with ISO/TC 22/SC 37 and WP29 (1958 Agreement) UNR30, R54, and R75.

**Table 1. General Vehicle Categories in the European Union (Automotive Industry Standards Committee 2020)**

| Category | Vehicle Type |
|---|---|
| Category L | Mopeds, motorcycles, motor tricycles, and quadricycles |
| Category M | Motor vehicles having a minimum of four wheels and carriage of passengers |
| Category N | Power-driven vehicles with a minimum of four wheels and carriage of goods |
| Category O | Trailers (including semitrailers) |

| Table 2. Divisions of Category L – Mopeds, Motorcycles, Motor Tricycles, and Quadricycles (TransportPolicy.net 2018) | |
|---|---|
| **Category** | **Vehicle Description** |
| **Mopeds** | |
| L1e | Two-wheel vehicles with a maximum design speed of 45 kph and characterized by an engine whose (1) cylinder capacity does not exceed 50 $cm^3$ in the case of the internal combustion engine, or (2) maximum continuous rated power is 4 kW for an electric motor. |
| L2e | Three-wheel vehicles with a maximum design speed of not more than 45 kph and characterized by an engine whose (1) cylinder capacity is 50 $cm^3$ of the spark (positive) ignition type, (2) maximum net power output is 4 kW in the case of other internal combustion engines, or (3) maximum continuous rated power is 4 kW in the case of an electric motor. |
| **Motorcycles** | |
| L3e | Two-wheel vehicles without a sidecar fitted with an engine having a cylinder capacity of more than 50 $cm^3$ if of the internal combustion type and/or having a maximum design speed of 45 kph. |
| L4e | Two-wheel vehicles with a sidecar fitted with an engine having a cylinder capacity of more than 50 $cm^3$ if of the internal combustion type and/or having a maximum design speed of 45 kph. |
| **Motor Tricycles** | |
| L5e | Vehicles with three symmetrically arranged wheels fitted with an engine having a cylinder capacity of more than 50 $cm^3$ if of the internal combustion type and/or a maximum design speed of 45 kph. |
| **Quadricycles: Motor vehicles with four wheels having the following characteristics** | |
| L6e | Quadricycles whose unladen mass is not more than 350 kg, not including the mass of the batteries in the case of EVs whose maximum design speed is not more than 45 kph, and whose:<br>Engine cylinder capacity does not exceed 50 $cm^3$ for spark (positive) ignition engines.<br>Maximum net power output is 4 kW for internal combustion engines.<br>Maximum continuous rated power is 4 kW for electric motors.<br>Unless specified differently, these vehicles shall fulfill the technical requirements applicable to three-wheel mopeds of Category L2e. |
| L7e | Quadricycles other than in Category L6e, whose unladen mass is a maximum of 400 kg (550 kg for vehicles intended for carrying goods), not including the mass of batteries in the case of EVs, and whose maximum net engine power does not exceed 15 kW. Unless specified differently, these vehicles shall be motor tricycles and fulfill the technical requirements applicable to motor tricycles of Category L5e. |

As mentioned above, several categories are suitable for electric drivetrains and are already seeing many EVs globally.

## 3.2 E-Rickshaws

The electric rickshaw (e-rickshaw) is a motor tricycle commonly used in Pakistan as a for-hire taxi. Alternative to the auto rickshaw powered by combustion, e-rickshaws have gained popularity in rural and urban areas of most Asian countries (Nambisan, Bansal, and Khanra 2020). These e-rickshaws are cheaper, more sustainable, and a more ecological mode of transportation than their alternative gasoline counterparts. The emissions benefits of e-rickshaws are desirable because they typically replace gasoline three-wheelers with no onboard emissions controls, drive many hours a day, and circulate in areas with high population density (Nambisan, Bansal, and Khanra 2020). The energy storage system is the main attribute enabling an e-rickshaw's technical, economic, and environmental benefits throughout its lifetime.

A schematic diagram of the e-rickshaw is shown in Figure 2. The main components are grouped into the battery charging system and the drive system.

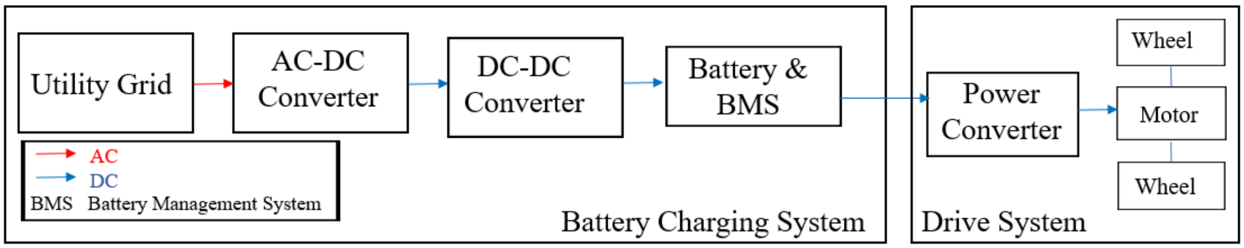


**Figure 2. Schematic diagram of an e-rickshaw.**

Derived from Sahu and Nayak 2021

## 3.3 Electric Mopeds and Motorcycles

Electric mopeds and motorcycles are gaining popularity because they have lower life cycle costs and are now similar in upfront cost to their gasoline counterparts in many markets (IEA 2022). They are easier to maintain and replace engines that do not have onboard emissions control systems. ISO/TR 13062:2015 lists terms and definitions related to electrically propelled mopeds and motorcycles (ISO 2015a). The details in ISO/TR 13062:2015 are associated with ISO/TC 22/SC 38 standards, which are specific to propulsion systems of electrically propelled mopeds and motorcycles. Malaysia provides an excellent example of how they created standards that apply specifically to their growing EV fleet, with specifications that can be borrowed. MS 2413-1:2011 specifies the general attributes of electric bicycles with speeds >50 kph for on-road use (ISO 2012a). MS 2688 details the specifications for electric mopeds with speeds 25–50 kph (Department of Standards Malaysia 2018).

## 3.4 E-Bikes

Electric bicycles (e-bikes) are revolutionizing the transport sector in several African and Asian countries with a strong potential to provide a clean environment with economic opportunities for poor communities (Pittaway 2021). E-bikes use electric motors to assist human propulsion. They are generally lighter and less powerful than electric motorcycles.

Speed, range, and battery capacity determine a vehicle's performance. Relevant standards for e-bike performance are given in Table 3 (Intertek 2023b). This section first provides a list of international standards for e-bikes, and then applicable electrical safety standards for E2Ws and E3Ws. At the end of this section, some vehicle performance measurements and environmental durability tests are highlighted.

**Table 3. International Standards for E-Bikes (Intertek 2023b)**

| No. | International Standard | Particulars and Status |
|---|---|---|
| 1 | EN 60086-4 | Safety of lithium batteries |
| 2 | EN 62133 | Safety requirements for portable sealed secondary cells |
| 3 | EN 61960 | Secondary lithium cells and batteries for portable applications |
| 4 | EN IEC 62485-5 | Secondary lithium cells and batteries for portable applications |
| 5 | ISO 13064-1:2012 | Battery-electric mopeds and motorcycles — Performance — Part 1: Reference energy consumption and range. These apply to e-bikes. |
| 6 | ISO 13064-2:2012 | Battery-electric mopeds and motorcycles — Performance — Part 2: Road operating characteristics |
| 7 | ANSI/ CAN/ UL 2849 (2022) | The standard UL 2849 focuses on pedal-assist and non-pedal-assist e-bike electrical systems and battery chargers to address specific issues related to those products, including mechanical, electrical, and functional safety. |
| 8 | EN 15194:2017 | Cycles – Electrically power-assisted cycles – EPAC Bicycles |
| 9 | MS 2514:2015 | Electric bicycles with speed <25 mph (electric pedal-assisted bicycles) (Department of Standards Malaysia 2015) |
| 10 | UN R136 | Specific requirement for the electric power train for Category L EVs (U.N. 2016) |
| 11 | ISO 13064-1:2012 | Battery-electric mopeds and motorcycles — Performance — Part 1: Reference energy consumption and range (ISO 2012a) |
| 12 | ISO 13064-2:2012 | Battery-electric mopeds and motorcycles — Performance — Part 2: Road operating characteristics (ISO 2012b) |
| 13 | ISO 23280:2022 | Electrically propelled mopeds and motorcycles — Test method for evaluating energy performance using a motor dynamometer (ISO 2022d) |
| 14 | IS 14664: 2010 | Automotive Vehicles-Performance requirements and testing procedure for the braking system of two- and three-wheeled motor vehicles |
| 15 | IS 15886: 2010 | Road vehicles battery-operated vehicles – code of practice |
| 16 | MS 2413-1:2011 | General specification of electric motorcycles for on-the-road use |
| 17 | MS 2688 | Specifications of electric mopeds |
| 18 | ISO 4210-10 | Safety requirements for bicycles-Part 10: Safety requirements for electrically power assisted cycles |
| 19 | UL 2489 | E-bikes and pedal-assisted electric cycles |
| 20 | UL 2850 | Investigation of Electric Scooters and Motorcycles |

While EVs are safer than combustion engines in many regards, their electric powertrains and associated components may pose additional risks that need to be accounted for. Therefore, standards need to be set, and related tests need to be prescribed to ensure that the electrical risks of EVs are minimized or mitigated. Commonalities can be identified between them, suggesting some best pathways to developing or adopting appropriate standards.

## 3.5 Electrical Safety Standards

The organizations mentioned in Section 2 have developed several standards relevant to E2Ws and E3Ws. These standards and related tests are listed below. Some are specified to be used for certain parts of the world by UN R136 (Cho 2016). It should be noted that most tests treat vehicles differently based on their voltage, with 60V DC and 30V AC being the cutoff between high- and low-voltage systems. These standards are shown in Table 4.

**Table 4. International Standards for Electrical Safety in E2Ws and E3Ws**

| No. | International Standard | Details and Status |
|---|---|---|
| 1 | UN R136 Standard Regulation - 1 (U.N. 2016; JASIC 2016) | Uniform provisions concerning the approval of vehicles of Category L about specific requirements for the electric powertrain. Part I: Requirements of a vehicle regarding its electrical safety. |
| 2 | UN R136 Standard Regulation - 2 | Uniform provisions concerning the approval of vehicles of Category L regarding specific requirements for the electric powertrain. Part II: Requirements of a REESS regarding its safety |
| 3 | UN 38.3 (Intertek 2023b) | Transportation Testing for Lithium Batteries and Cells. This standard applies to batteries transported independently or installed in a device (UN codes 3090/3091 for lithium, 3480/3481 for Li-ion). |
| 4 | ISO 13063:2012 (ISO 2012) | Electrically propelled mopeds and motorcycles — Safety specifications |
| 5 | ISO 13063-1:2022 (ISO 2022a) | Electrically propelled mopeds and motorcycles — Safety specifications — Part 1: On-board rechargeable energy storage system (RESS) |
| 6 | ISO 13063-2:2022 (ISO 2022b) | Electrically propelled mopeds and motorcycles — Safety specifications — Part 2: Vehicle operational safety. |
| 7 | ISO 13063-3:2022 (ISO 2022c) | Electrically propelled mopeds and motorcycles — Safety specifications — Part 3: Electrical safety. |
| 8 | JIS C8714 (JSA 2017) | Defines safety standards for portable cells and batteries. It is specific to two different chemistry systems: Li-ion and nickel. |
| 9 | IEC 62281 (IEC 2019) | This standard specifies test methods and requirements for primary and secondary (rechargeable) lithium cells and batteries to ensure their safety during transport other than for recycling or disposal. |
| 10 | IEC 62133-2 (IEC 2017b) and UL 62133-2 (UL 2020) | Secondary cells and batteries containing alkaline or other non-acid electrolytes – Safety requirements for portable sealed secondary cells and batteries made from them for use in portable applications – Part 2: Lithium systems |
| 11 | BATSO 01 (BATSO 2008) | Manual for Evaluating Energy Systems for Light Electric Vehicle (LEV) Secondary Lithium Batteries. Specifies test methods for secondary lithium batteries for safe use in light EVs. Transport safety tests are also specified. |
| 12 | ISO 18246 (ISO 2015b) | Electrically propelled mopeds and motorcycles — Safety requirements for conductive connection to an external electric power supply. |
| 13 | ISO/TS 4210-10 (ISO 2020a) | Cycles — Safety requirements for bicycles — Part 10: Safety requirements for electrically power-assisted cycles (EPACs) |
| 14 | ISO/DIS 5474-1 (ISO 2023d) | Electrically propelled road vehicles — Functional requirements and safety requirements for power transfer — Part 1: General requirements for conductive power transfer. |
| 15 | ISO 19363:2020 (ISO 2020c) | Electrically propelled road vehicles — Magnetic field wireless power transfer — Safety and interoperability requirements. |

### 3.5.1 Global Technical Regulation No. 20

The United Nations (U.N.) World Forum for Harmonization of Vehicle Regulations established Global Technical Regulation (GTR) No. 20 for EV safety (UNECE 2021). This regulation's purpose is to develop safety requirements for high-voltage equipment and components. The safety requirements include (1) rechargeable electrical energy storage system safety (vibration, thermal shock and cycling, water leakages, and fire resistance); (2) battery management system functionality (protection requirements from external short circuit, overcharge, overdischarge, high temperature, low temperature, and overcurrent); (3) management of gases emitted from the battery; (4) single-cell thermal runaway and propagation; and (5) post-crash (electric shock prevention, battery retention, electrolyte spillage, battery integrity, and fire safety requirements). GTR No. 21 is related to the determination of electrified vehicle power, and GTR No. 22 is about in-vehicle battery durability for electrified vehicles (UNECE 2022).

## 3.6 Vehicle Performance Measurements

Vehicle performance must meet a set of minimum requirements to be certified by relevant authorities. UNEP 2020 recommends the tests listed below, which we have supplemented with some applicable testing standards from other sources:

1. **Top speed:** Vehicles cannot meet customer expectations or travel on certain roadways safely unless they can achieve certain speeds, particularly on inclined surfaces, depending on the vehicle category.
2. **Braking distance:** Braking distance is essential to vehicle safety, as shorter braking distances will enable drivers to avoid collisions. Brakes should be tested in both dry and wet conditions. An example standard for braking distance is Malaysian Standard 2688 (Department of Standards Malaysia 2018).
3. **Range:** The initial maximum achievable range needs to be verified. UNEP 2020 recommends that this be done by driving at a constant speed, but it can also be done by testing over a standard drive cycle, as is commonly done for larger EVs. A suitable test procedure to test the energy consumption and range for electric cars and light commercial vehicles, including three-wheelers, is given in ISO/DIS 8714 (ISO 2023a).
4. **Battery life and health:** The number of battery cycles that the battery can endure before its capacity drops below 20% of maximum capacity or minimum rated state of charge (Hamzah et al. 2021). UNEP 2020 recommends that the battery must be able to endure more than 300 charge–discharge cycles. Still, there are numerous reasons (such as consumer satisfaction or waste reduction) why Pakistan might want to require a more significant number of cycles.

## 3.7 Common Vehicle Test Conditions and Environmental Durability Tests

All vehicles within a category must be tested under standard conditions, which must be set to represent a likely scenario for a typical vehicle trip. This typical trip depends on location, so tests from countries with environmental and traffic conditions similar to Pakistan (perhaps India) will be more helpful. Some vehicle test conditions according to policy guidelines set by UNEP 2020 for Southeast Asian countries are as follows:

| | |
|---|---|
| Wind | Less than 3 kph in any direction. |
| Road surface | Smooth and flat with less than 0.5% gradient. |
| Temperature | Between 25°C and 35°C. |
| Rider weight | 75 kg ± 5 kg (use ballast weight if necessary). |
| Rider posture | Upright riding position (i.e., not tucking in). |
| Speed measurement | Device should be calibrated and accurate to within 0.5 kph. |
| Rain/fog | Testing is not permitted on a wet surface or during rain or heavy fog. |
| Tire pressure | Within 5% of stated maximum pressure, or 2 bar (if not stated). |
| Battery state of charge | As close to full charge as possible, nominally 90%–100%. |

In addition to the standard vehicle test conditions, extreme conditions and durability should be accounted for in standards tests. Below are a few of the tests recommended by UNEP 2020:

1. **Tropical rain test:** EVs must withstand a certain amount of rain that could realistically fall in the region. The test needs to specify how much rainwater is dropped over a given duration of time.
2. **Flood fording:** The test needs to specify the depth of water and the distance (or length of time) the vehicle needs to travel at a given depth. It must then pass operational tests after the fording event.
3. **Mechanical shock and vibration:** Shock tests try to simulate the impact of being dropped or hit by another vehicle at a given speed. Vibration tests need to specify the strength and duration of the vibration.

The protection of EV users (passengers, drivers, and technician) is the most important aspect considered while developing the standard. The protection can be through insulation resistance to avoid direct and indirect contact.

**Table 5. Standards Related to Protection**

| No. | Hazards | Standard |
|---|---|---|
| 1 | Electrical shock | ISO 6469-3:2021 details the safety requirements against electrical shock and thermal incidents. |
| 2 | Insulation resistance | The electrical components should have insulation around them with a specific resistance to avoid electric shock. These are outlined in ISO 6469-1:2009 and ISO 17409:2015 |
| 3 | Direct contact | Protection against direct contact is essential to avoid any hazards caused by live parts inside passenger or luggage compartments. The shock can be from live connectors or moving electric parts inside the cabin. There should be proper marking with labels, high insulation, and safety protocols to avoid direct shocks from electrical components. UN R136 included details related to protection against direct contact (U.N. 2016). |
| 4 | Indirect contact | Indirect contact can cause electric shock, which can be evaded by grounding. It is mentioned in UN R136 that the exposed conductive parts should be insulated or grounded to prevent this danger. The requirements for charging batteries, earth ground, and withstand voltage are also given in UN R136. |
| 5 | Overload | Overload protection is required to avoid the flow of high currents toward the motor. The details of the overload protection are given in ISO 17409:2020 (ISO 2020b). |
| 6 | Moving mechanical parts | There should not be any moving parts inside the vehicle's driver, passenger, and luggage compartment. Proper protection regulations should be followed. |
| 7 | Overcharging | The protection against overcharging is vital to avoid fire, explosion, and rupture. This test is done with the battery installed in the EV. The details of this test are given in UN R136. ISO15118 provides the standards for bi-directional digital communications between electric vehicles and the charging station. |
| 8 | Overdischarging | The protection against battery overdischarging is helpful to help prevent damage due to overdischarging. The discharge should be performed at a rate of 1/3 C. UN R136 includes details related to overdischarge protection. This test is done with the battery installed in the EV. |

## 3.8 Electromagnetic Compatibility

E2Ws and E3Ws can, in some instances, interfere with existing electronic communication devices. Likewise, electromagnetic radiation generated from switching devices can sometimes interfere with vehicle operations and performance. To avoid these two scenarios, EVs must adhere to specific standards and pass related tests.

1. **Band limits:** In order to avoid having the E2W or E3W send unintended communications to other devices, limits must be set on the microvolts that can be broadcast within any given frequency range. These voltages are standardized by CISPR 12, SAE J 551-2, and others. CISPR 12 has posted a related test.
2. **Vehicle immunity:** EVs also need to be immune to radio waves so they do not interfere with operations. ISO 11451-2 tests vehicles' response to radio waves with their keys on and motors running. Another set of standards applies to vehicles in charging mode and coupled to the power grid. They must be immune to electric surges and electrostatic discharges. MS IEC 61000-4 and ISO 11451-2 are two such standards with related test specifications.

# 4 Batteries

EVs are propelled by energy stored in rechargeable traction batteries. These batteries are composed of multiple individual cells forming a module. The modules are connected in series to form the battery pack. Batteries must be standardized at both the cell level and the entire battery pack. Battery cell testing occurs in the initial phase of the battery's design and manufacturing process. The chemical functionality and performance of battery cells are tested and verified before they are stacked to form modules and batteries, whereas the battery pack testing focuses on the system's overall engineering (Element 2023).

Furthermore, the performance and durability of the battery packs need to be tested. Standards for both the cell and the whole battery pack have been introduced internationally for electrically propelled road vehicles, as listed in Table 6. As explained in the table, their applicability depends on the energy capacity and the size of vehicles. These standards are supplemented by one from India, AIS-048, that could be particularly applicable to the developing EV market in Pakistan.

**Table 6. International Standards for Electrically Propelled Road Vehicle Batteries**

| No. | International Standard | Details and Status |
|---|---|---|
| 1 | ANSI/CAN/UL/ULC 2271 (UL 2018) | Batteries for Use in Light Electric Vehicle (LEV) Applications |
| 2 | ISO/IEC PAS 16898 (2012) | Electrically propelled road vehicles — Dimensions and designation of secondary lithium-ion cells. Does not apply to cells specifically used for mopeds, motorcycles, and vehicles not primarily defined as road vehicles (i.e., material handling trucks or forklifts). |
| 3 | IEC 62660-1 (2018) | Secondary lithium-ion cells for the propulsion of electric road vehicles – Part 1: Performance testing. It specifies performance and life testing of secondary lithium-ion cells used for propulsion of EVs, including battery-electric vehicles and hybrid electric vehicles. |
| 4 | IEC 62660-2 (2018) | Secondary lithium-ion cells for the propulsion of electric road vehicles – Part 2: Reliability and abuse testing. It specifies reliability and abuse testing of secondary lithium-ion cells used for propulsion of EVs, including battery-electric vehicles and hybrid electric vehicles. |
| 5 | IEC 62660-3 (2022) | Secondary lithium-ion cells for the propulsion of electric road vehicles – Part 3: Safety requirements. It specifies test procedures and acceptance criteria for safety performance of secondary lithium-ion cells used for propulsion of EVs, including battery-electric vehicles and hybrid electric vehicles. |
| 6 | ISO 12405-1(2011) | Electrically propelled road vehicles — Test specification for lithium-ion traction battery packs and systems — Part 1: High-power applications. It specifies standard test procedures for basic characteristics of performance, reliability, and abuse of lithium-ion battery packs and systems. |
| 7 | ISO 12405-2(2012) | Electrically propelled road vehicles — Test specification for lithium-ion traction battery packs and systems — Part 2: High-energy applications. |
| 8 | ISO 12405-4:2018 (ISO 2018) | Electrically propelled road vehicles —Test specification for lithium-ion traction battery packs and systems — Part 4: Performance testing. |
| 9 | ISO 18243 (2017) | Electrically propelled mopeds and motorcycles — Test specifications and safety requirements for lithium-ion battery systems. |
| 10 | EN 50604-1:2016 (iTeh 2021) | Secondary lithium batteries for light EV (electric vehicle) applications – Part 1: General safety requirements and test methods |

| | | |
|---|---|---|
| 11 | ISO/AWI 18006-1 (ISO 2023b) | Electrically propelled road vehicles — Battery information — Part 1: Labelling and QR/bar code for specification, safety, and sustainability. |
| 12 | ISO/AWI 18006-2 (ISO 2023c) | Electrically propelled road vehicles — Battery information — Part 2: End of life |
| 13 | ISO/TR 8713:2019 (ISO 2019) | Electrically propelled road vehicles — Vocabulary |
| 14 | AIS-048 (InterRegs 2009) | Battery-operated vehicles - Safety requirements for traction batteries |
| 15 | IEC 62619 | Safety requirements for secondary lithium cells and batteries |
| 16 | IEC 63933-1 | Electrical energy storage (EES) systems - Part 1: Vocabulary |

In addition to the standards listed in Table 6, the safety requirements of the rechargeable energy storage system used in EVs equipped with batteries are given in UNECE Regulation No. 100 (TÜV SÜD 2019).

## 4.1 Certification of Small Batteries

Batteries need to be tested and certified because it is critical to determine their quality and performance under particular environmental stresses, as well as confirm they meet mandated government safety requirements (Marsh 2021). Batteries that can readily be charged inside an apartment or enclosed space pose a particular fire risk (Barron 2022), including removable batteries for E2Ws and electric microtransit vehicles such as scooters and e-bikes. These batteries should be required to carry a certification label from UL, Intertek, or CSA Group. All three of these laboratories have small-battery certification programs (UL 2023a; Intertek 2023a; CSA Group 2023). IEC 60086-1 is an international standard for primary batteries that specifies the requirements for primary cells and batteries (e.g., dimensions, safety, performance, configurations) (IEC 2021b). According to AIS-156 (2020) and AIS-038 Revision 2, batteries must also be tested and certified.

## 4.2 Testing Requirements for Shipping Batteries

Lithium batteries can cause a potential fire hazard even when not in use. Therefore, they are considered Class 9 dangerous goods when shipped. This creates a potential barrier to entry into the EV market. The U.N. published a manual of tests and criteria for hazardous goods and chemicals presenting physical hazards (UNECE 2023). The manual consists of five parts; one is associated with shipping lithium-ion batteries. In addition to the standards listed in Table 6, it is necessary to test the batteries and cells before transporting them. According to the U.N.'s *Manual of Tests and Criteria* (U.N. 2021), the tests outlined in Table 7 must be performed before shipping. The "pass criteria" must be accomplished to ensure their safety before the batteries/cells are transported.

**Table 7. Tests for Battery Shipping (Inventus Power 2017)**

| Test Name | Description (Purpose and Procedure) | Pass Criteria | Subjected to the Test |
|---|---|---|---|
| T1: Altitude simulation | Air transport is simulated under low-pressure conditions. The test cell/batteries are stored at 11.6 kPa or less pressure for at least 6 hours. The temperature should be ambient (20°C ± 5°C) | No leakage of electrolytes, no venting, no rupture, no fire. Open-circuit voltage (OCV) is not less than 90% before testing. | Cells and batteries |
| T2: Thermal test | Rapid and extreme temperature changes are simulated to assess | No leakage, no venting, no rupture, no fire. OCV | Cells and batteries |

| | | | |
|---|---|---|---|
| | the integrity of the cell and battery's seal and internal electrical connections. Test cells and batteries are stored at least 6 hours at the test temperature (72°C ± 2°C). Next, they are stored for at least 6 hours at −40°C ± 2°C. The time interval is 30 minutes between the two test temperatures, and the whole test is repeated for 10 cycles. Finally, the test cells and batteries are stored at (20°C ± 5°C) for 24 hours. | is not less than 90% before testing. | |
| T3: Vibration test | Vibration is simulated before the transport of batteries and cells. The cells and batteries are placed on the vibration machine to transmit the vibrations. These vibrations are sinusoidal with a logarithmic sweep between 7 and 200 Hz. The whole cycle is repeated 12 times for a total of 3 hours. | No leakage, no venting, no rupture, no fire. OCV is not less than 90% before testing. | Cells and batteries |
| T4: Shock test | The strength of the cells and batteries is determined against accumulative shocks. Each cell is tested against the half-sine shock of peak acceleration of 150 G and pulse duration of 6 ms. However, the larger sized cells face the same shock with peak acceleration of 50 G with pulse duration of 11 ms. | No leakage, no venting, no rupture, no fire. OCV is not less than 90% before testing. | Cells and batteries |
| T5: External short circuit test | The external short circuit is simulated and experienced during transport. The cells/batteries are heated until they reach temperature of (57°C ± 4°C). The time period depends on the size and design of the battery. | External case temperature shall not be above 170°C. No fire, rupture, or disassembly within 6 hours after the test. | Cells and batteries |
| T6: Impact/ crush test | The mechanical abuse from an impact or crush is simulated that may cause an internal short circuit. A mass of 9.1 kg ± 0.1 kg is dropped onto the cell from a height of 61 cm ± 2.5 cm. | External case temperature shall not be above 170°C. No fire and no disassembly within 6 hours after the test. | Only cells (cylindrical cells ≥18-mm diameter) |
| T7: Crush test | The test is performed by subjecting the cell to one crush. Crush the cell at 1.5 cm/s until force reaches 13 kN ± 0.78 kN, voltage drops by 100 mV, or the cell deforms more than 50% of its original thickness. | External case temperature shall not be above 170°C. No fire and no disassembly within 6 hours after the test. | Only cells (prismatic, pouch, coin/button, and cylindrical cells <18-mm diameter) |

| | | | |
|---|---|---|---|
| T8: Overcharge | This test determines the battery/cell's ability to tolerate an overcharge condition. Overcharge the battery pack at two times the maximum charge voltage. The test duration is maximum 24 hours. | No fire, no disassembly within 7 days after the test. | Only batteries |
| T9: Forced discharge | The cell's ability to tolerate the forced discharge condition is tested. The cell is subjected to forced discharge by connecting it to a 12V power supply. The current is limited to the manufacturer's specified maximum discharge current. | No fire, no disassembly within 7 days after the test. | Only cells |
| T10: Penetration test | The cell or module should be penetrated using a mild steel rod, which must be insulated from the test fixture. The penetration rate will be 8 cm/s nominal. The test should be conducted in an indoor facility for safety purposes. | No melting of components, fire, or explosion. | Cells and module |

UN 38.3 specifies transportation testing for lithium batteries and cells. This standard has been adopted globally by regulators and competent authorities and is necessary for batteries to be safely shipped. The three major EV markets (European Union, United States, and China) have adopted this standard. The standard is further classified into four types depending on the kind of battery and their transportation, as shown in Table 8.

**Table 8. UN 38.3 Standards for Battery Shipment**

| No. | Standard | Battery Type | Application |
|---|---|---|---|
| 1 | UN 3090 | Lithium batteries | Applies to lithium metal cells and batteries, non-rechargeable, shipped alone. They include power banks, power packs, and batteries shipped separately from the device. |
| 2 | UN 3091 | Lithium batteries within a device | Applies to lithium metal batteries installed within the devices, packed in the same package as the device, with up to two spare batteries shipped in the same box. |
| 3 | UN 3480 | Lithium-ion batteries | Applies to lithium-ion cells and batteries, rechargeable, shipped alone, power banks, power packs, and batteries shipped separately from the device. |
| 4 | UN 3481 | Lithium-ion batteries within a device | Applies to lithium-ion batteries installed within the devices, packed in the same package as the device, and up to two spare batteries shipped in the same box. |

## 4.3 Battery Second Use or Repurposing

Battery end-of-life issues are a potential hurdle to developing an electric transportation sector. Conversely, battery second-use markets can improve the total cost of ownership for EVs. IEC and UL are developing standards to ensure that used batteries are a benefit instead of a burden. IEC 63338 is general guidance on reusing and repurposing secondary cells and batteries and is under development (IEC 2023b). UL 1974 outlines a method to evaluate batteries for repurposing (UL 2023b). The scope of this standard is to measure the condition, safety, and energy capacity of each individual battery pack before it can be integrated into a stationary energy storage system. IEC 63330, under development, will require the reuse of secondary batteries (IEC 2023a).

# 5 Charging Equipment

In addition to vehicles and their components, it is essential to standardize EV charging equipment and battery swap systems.

This impacts many manufacturers' safety, durability, and interoperability between vehicles and charging equipment. It also ensures that charging equipment does not damage the grid or vehicles.

## 5.1 Electric Vehicle Charging Stations

EVCSs need standards to charge vehicles safely, efficiently, and in a way that does not harm the grid or vehicle. These EVCS standards do not differentiate between E2Ws, E3Ws, and electric four-wheelers; however, they categorize power levels that can be more compatible with E2Ws/E3Ws or larger vehicles with larger batteries. In 2021, the Pakistani government decided to follow the IEC standards for EVCSs (National Electric Power Regulatory Authority 2021). These was chosen over the SAE standards, which are largely used in countries with 60Hz electricity in North America and South Korea. The IEC standards for charging stations, as reported by Kumar (2019), are given in Table 9.

**Table 9. Existing International Standards for EVCSs**

| No | Existing International Standards | Application of Use |
|---|---|---|
| 1.1 | IEC 61851 series (IEC 61851-1, IEC 61851-21-1, IEC 61851-21-2, IEC 61851-23, IEC 61851-24)<br>IEC 62955<br>Bharat Charger AC001 and DC001 | For all types of AC/ DC charging stations |
| 1.2 | IEC 61851-3 series (IEC 61851-3-1, IEC 61851-3-2, IEC 61851-3-3, IEC 61851-3-4, IEC 61851-3-5, IEC 61851-3-6, and IEC 61851-3-7) | Light EVs like an e-bike, e-kick scooters, and mopeds—general requirements include battery swap, communication, voltage converter, and battery system |
| 2.1 | IEC 62196 series (IEC 62196-1, IEC 62196-2, IEC 62196-3, IEC 62196-3-1 IEC 60309-1, -2, and IEC TS 62196-4) | Charging inlets, sockets, and EV plugs (CGs)—dimensional compatibility and interchangeability |
| 2.2 | IEC 62752 | In-cable control and protection device for Mode 2 charging |
| 3 | IEC 62893-1<br>IEC 62893-2<br>IEC 62893-4-1<br>IEC 62893-4-2 | Cables, including liquid-cooled cables |
| 4 | IEC 61439-7<br>IEC 60364-7-717 | Low-voltage switchgear and control gear assemblies of EVCSs |
| 5 | IEC 61540<br>IEC 62752<br>IEC 61008<br>IEC 61508<br>ISO 17409<br>IEC 61140<br>IEC 61009<br>IEEE 519-2014 | Functional safety and protection requirements, personnel protection circuits requirements, and power quality standards |

| | | |
|---|---|---|
| 6 | IEC 61980 series (IEC 61980-1, IEC 61980-2, and IEC 61980-3)<br>ISO PAS 19363 | Wireless charging system (general, communication, and magnetic power transfer) |
| 7 | IEC 62840 series (IEC TS 62840-1 and IEC 62840-2) | Battery swapping process (general and safety requirements) |
| 8 | IEC 61851-21-1<br>IEC 61851-21-2<br>IEC 61000-6 series (IEC 61000-6-1, IEC 61000-6-2, IEC 61000-6-3, and IEC 61000-6-4)<br>IEC 61000-3-12<br>AIS 138-1<br>AIS 138-2 | Electromagnetic compatibility-related evaluations (harmonics, emissions, and immunity tests) |
| 9 | IEC 61851-24, CHAdeMO, DIN 70121, DIN 70122<br>ISO 15118 series (ISO 15118-1, ISO 15118-2, ISO 15118-3, ISO 15118-4, ISO 15118-5, ISO 15118-6, ISO 15118-7, and ISO 15118-8) | Digital communication for AC/DC EVCSs and EVs (includes vehicle-to-grid [V2G]) |
| 10 | Open Charge Point Protocol (OCPP version 2.0.1)<br>IEC 6274610-1 (OpenADR 2.0)<br>IEC 63110-1 ed.1 | Communication between EVCS and utility. Used in peak load management in utilities |
| 11 | IEEE 2030.5 (Smart Energy Profile-SEP) | Communication standard between intelligent grid and customers |
| 12 | IEC 61851-25:2020 | EV conductive charging system-Part 25: DC EV supply equipment where protection relies on electrical separation |

Charging E2Ws and E3Ws is much more convenient than charging larger EVs for two reasons. First, regular AC power outlets can charge light EVs in a reasonable amount of time. Second, many vehicles have batteries that can easily be removed and charged at any charging station or the owner's house. UNEP defines the compatibility requirements for the battery chargers in Pakistan as 56–60 Hz and 220–240 VAC. However, the current should draw less than 10 A (UNEP 2020). Specific water ingress protection should be used for charging the EVs outdoors.

EVCSs in Pakistan must have connectors that comply with IEC 62196 (National Electric Power Regulatory Authority 2021). This standard covers the requirements of plugs, connectors, vehicle inlets, interchangeability requirements, and more. This was chosen over the SAE J1772 standard, which is consistent with other countries with 50Hz electricity. Figure 2 shows the AC connectors required by IEC 62196. These are used on Mode 1, 2, and 3 chargers—the only modes suitable for two- and three-wheelers.

**Figure 3. Vehicle side of a Mennekes Type 2 connector, as required for AC charging stations by IEC 62196.**

Source: Prateek Joshi, NREL

Note: When the cover is removed from underneath the Mennekes port, it becomes compatible with a CCS2 DC connector.

In addition to IEC 62196, it is worth noting the standards that BIS has developed because of the similarities India and Pakistan have regarding vehicle population, vehicle availability, economy, and geography. Furthermore, India has made good progress on researching and adopting or setting standards for EVCSs in a market with many E2Ws and E3Ws. It is valuable to track what standards India has developed or is implementing. BIS standards for EVCSs are given in Table 10 (Kumar 2019; Kumar, Kumar, and V.S 2022).

**Table 10. BIS Standards for EVCSs**

| No. | Standard From BIS | Particulars and Status |
|---|---|---|
| 1 | IS 17017-Part 1:2018<br>Bharat Charger AC-001 | Electric Vehicle Conductive Charging System<br>Part 1—General Requirements for both AC and DC charging stations |
| 2 | IS 17017: Part 21: Sec 1:2019<br>IEC 61851-21-1:2017<br>AIS 138 (Part 1) | Electromagnetic compatibility requirements for an onboard charger or AC EVCS |
| 3 | IS 17017: Part 21: Sec 2:2019<br>IEC 61851-21-2:2018<br>AIS 138 (Part 2) | Electromagnetic compatibility requirements for off-board or DC EVCS |
| 4 | IS 17017-Part 23 [a]<br>Bharat Charger DC-001 | Especially for DC EVSE (will be adapted from IEC 61851-23) [a] |
| 5 | IS 17017-Part 24 [a] | Requirements for Control Communication between DC EVSE and EV (will be adapted from IEC 61851-24) [a] |
| 6 | IS 17017-Part 2: Sec 1 [a] | The standard for the plugs, socket outlets, vehicle couplers, and vehicle inlets. This standard is not yet published and is adapted from IEC 62196-1 [a] |
| 7 | IS 17017-Part 2: Sec 2:2020 | The standard for the plugs, socket outlets, vehicle couplers, and vehicle inlets. This standard is published and is adapted from IEC 62196-2 but is specific to Indian requirements. |
| 8 | IS 17017-Part 2: Sec 3 | The standard for the plugs, socket outlets, vehicle couplers, and vehicle inlets. This standard is adapted from IEC 62196-3 |
| 9 | IS/ISO 15118 Series | Details on-road vehicles—vehicle-to-grid communication interface between EV and EVCS. Eight standards under this series are directly adopted from the ISO 15118 series from Part 1 to 8. Except for Parts 6 and 7, all standards have been published |
| 10 | IS 17017 (Part 3) [a] series | This standard is exclusively for light EVs, consisting of seven sections. The standard will be adopted from IEC 61851-3 series [a] |
| 11 | CEA Regulations, 2019 (Measures relating to Safety and Electric Supply) and (Technical Standards for Connectivity to the Grid) | Voltage change, frequency variations, power factor, harmonics measurements, flicker, DC injection, V2G process, and the safety of EVCSs. IS 17017 (Part 5) will be prepared by BIS soon regarding grid connectivity and EVCSs. |
| 12 | IS 14700-6-2<br>IS 14700–6-3<br>IS 14700-3-12 | Electromagnetic compatibility testing for emissions, immunity, and harmonic measurements |

[a] This standard is pre-publication.

### 5.1.1 Harmonic Pollution

EV battery chargers can reduce the quality of grid electricity through harmonic pollution if proper precautions are not taken (Sasidharan 2020). The EVCS should be equipped with protective equipment to minimize harmonics. While installing an EVCS, the location should be selected away from the transformers because transformers are both the source of harmonics and bear the impact of harmonics caused by EVs (Xu et al. 2014). IEC 61000-3-12/2-4 is an international standard which discusses the impacts that harmonic distortion can have on distribution assets, particularly transformers, power cables, capacitors, metering, relaying and switch gear. Both propose limits for voltage and current distortions and limits for individual frequencies.

Figure 3 shows how harmonic pollution distorts the line voltage, which can cause malfunctions or even damage the electrical equipment. The standards in Table 11 were developed to limit harmonic pollution.

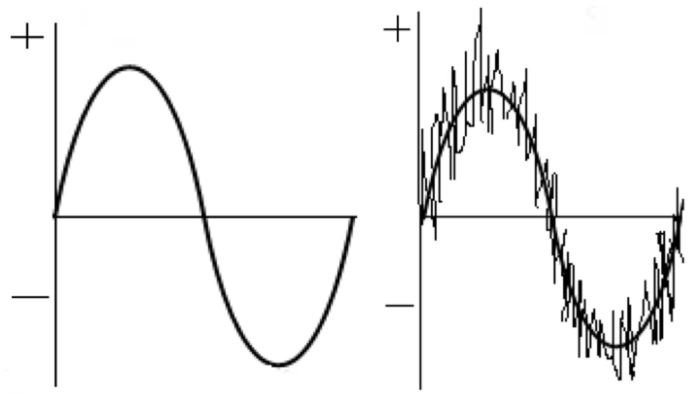

**Figure 4. Alternating current on the grid and AC electricity that harmonics have distorted**

Source: Rabia Khan, Washington State University

**Table 11. International Standards for Harmonic Pollution**

| No. | International Standard | Particulars and Status |
| --- | --- | --- |
| 1 | IEC 61851-1:2017 (IEC 2017a) | Electric vehicle conductive charging system – Part 1: General requirements address harmonic pollution |
| 2 | IEC 61000 Testing<br>EN 61000 Testing (Keystone Compliance 2023) | Include testing for harmonic distortions |
| 3 | IEEE 519-2014 (IEEE 2014) | IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems |
| 4 | IEC 61851-25:2020 (IEC 2020) | Electric vehicle conductive charging system – Part 25: DC EV supply equipment where protection relies on electrical separation |

## 5.2 Battery Swap Systems

Battery swapping technologies allow EV drivers to obtain a fully charged battery in a fraction of the time it would take to plug in and charge their vehicle. In addition, it takes up less space because vehicles do not need space to park while charging, and it allows for greater charge management because the batteries can have longer to charge. However, the main hurdle has been cost because it requires spare batteries and, at least for electric four-wheelers, requires expensive robotics to lift heavy batteries. The technology is growing fastest in the E2W and E3W markets because these smaller vehicles require smaller (less expensive) batteries that can be removed by hand, therefore obviating the need for these expensive robotics.

Figure 4 shows a Gogoro battery swap station for E2Ws and E3Ws. One obstacle to the battery swap system is that vehicle owners cannot keep their specific battery. For example, they could swap a new battery with better state of health for an old battery with poor state of health. Therefore, battery swap schemes must own and lease the batteries to the vehicle owners. An ancillary benefit to this business model is that an EV sold without the battery costs nearly 40% less than an EV sold with the battery (Research and Markets 2022). A second obstacle to battery swap schemes is that the batteries must be compatible with all the chargers and other vehicles in the system. This requires standardization of the batteries, chargers, and vehicles.


**Figure 5. Gogoro battery swap station in Taiwan.**

Source: Prateek Joshi, NREL

The danger of neglecting standardization of battery swap systems is that it can cause incompatible or exclusive systems that can only be used by one corporation. Additionally, the batteries in the system can be vulnerable to theft or forgery. Without precaution, people can steal and exchange batteries with dummy ones. Theft-deterrent devices such as a radio module, intelligent communication system, or remote alarm are imperative to avoid such issues. Future standards should include one or more of these precautions.

India has one of the world's largest and fastest-growing E2W/E3W markets and aggressive electrification goals, so looking at their actions to standardize battery swapping is beneficial. Their national government has announced in their budget of 2022-2023 to introduce battery swapping policy and interoperability standards (NITI Aayog 2022). The policy aims to develop principles behind technical standards that would allow the interoperability of components in a battery swapping ecosystem. The interoperability between EVs, batteries, and their components enhances the battery swapping system's performance, safety, and efficiency.

IEC 62840 addresses EV battery swap systems and has two parts. Part 1 is related to general specifications and guidance, while Part 2 covers safety requirements for battery swap systems operating with removable rechargeable energy storage systems or battery systems (IEC 2021a). In addition to IEC, BIS is a front-runner in developing standards for battery swap systems and chargers. Table 12 lists standards for battery swap systems and chargers, with most coming from BIS. Battery swap systems are still a very active research, development, and collaboration area. Honda, KTM, Piaggio, Yamaha, and others have formed the Swappable Batteries Motorcycle Consortium, developing more international specifications for batteries, swap stations, and E2Ws (Swappable Batteries Motorcycle Consortium 2023).

**Table 12. Standards for Battery Swap Systems**

| No. | Standard From BIS | Particulars and Status |
|---|---|---|
| 1 | IEC 62840-1 | General specifications and guidance |
| 2 | IEC 62840-2 | Safety requirements for battery swap systems operating with removable rechargeable energy storage system or battery systems |
| 3 | IS 17896 (Part 1): 2022 | Electric Vehicle Battery Swap System – Part 1 General and Guidance |
| 4 | IS 17896 (Part 2): 2022 | Electric Vehicle Battery Swap System – Part 2 Safety Requirements |
| 5 | IS 17017: Part 21: Sec 2:2019/ IEC 61851-21-2:2018 and AIS 138 (Part 2) | Electromagnetic compatibility requirements for off-board or DC EVCS |
| 6 | IS 17017-Part 23 [a] and Bharat Charger DC-001 | Especially for DC EVSE (will be adapted from IEC 61851-23) [a] |
| 7 | IS 17017-Part 24 [a] | Requirements for Control Communication between DC EVSE and EV (will be adapted from IEC 61851-24) [a] |
| 8 | IS 17017-Part 2: Sec 1 [a] | Standard for the plugs, socket outlets, vehicle couplers, and vehicle inlets. This standard is adapted from IEC 62196-1 [a] |
| 9 | IS 17017-Part 2: Sec 2: (2020) | Standard for the plugs, socket outlets, vehicle couplers, and vehicle inlets. This standard is published and is adapted from IEC 62196-2 but is specific to Indian requirements. |
| 10 | IS 17017-Part 2: Sec 3 | Standard for the plugs, socket outlets, vehicle couplers, and vehicle inlets. This standard is adapted from IEC 62196-3 |
| 11 | Swappable Batteries Motorcycle Consortium | This set of standards is being developed for battery swap systems, batteries, and E2Ws [a] |

[a] This standard is currently in pre-publication status.

# 6 EV Labeling Requirements

In addition to standards for the manufacture and testing of equipment, there are also labeling requirements. The labels allow vehicle assemblers, drivers, and maintenance professionals to anticipate any possible hazards that could be imposed.

## 6.1 EV Labels

All EVs should have a label marking them as an EV. The labeling helps in case of emergencies so fire responders, medics, and maintenance experts can understand the expected fire profiles. Each vehicle should have a label that is suitable with respect to its type. Most countries with EVs have labeling programs, and Pakistan plans to adopt one (Government of Pakistan 2019a). ASEAN policy guidelines (UNEP 2020) recommend that bicycle-type vehicles have a label of at least 25 mm, whereas larger vehicles should have a label of 100 mm. One example that meets these requirements is the Malaysian EV standard label (UNEP 2020) for light-duty vehicles, as shown in Figure 5.


**Figure 6. Malaysian EV standard label.**

Source: UNEP 2020

## 6.2 High Voltage Warning Label

A warning symbol of high voltage is essential for vehicles with high-voltage batteries. The display symbol should be used on the protective cover before anyone can access the batteries. The label warning for high voltage is issued by ISO 3864, as shown in Figure 6.

**Figure 7. ISO 3864 high voltage label**

Source: ISO 3864

## 6.3 Battery Recycling Label

A battery recycling program and related policies must be developed to avoid e-waste problems. If battery recycling is not adopted from the beginning, the used and damaged batteries will pile up with increased EV adoption (Mandal 2020). Battery second use and battery recycling must be more progressively adopted to avoid such waste and to reduce the raw materials needed to manufacture new batteries. Therefore, the materials inside a battery should be included on the label, along with any applicable disposal requirements (UNEP 2020). Furthermore, clear labels are needed in order to remind battery users to properly discard their batteries rather than throw them in the trash. The symbol used in the European Union, for the Waste from Electrical and Electronic Equipment directive, is a crossed-out trash bin, as shown in Figure 7. This symbol is required in order to import or manufacture batteries to be sold in the European Union (Mo 2021).

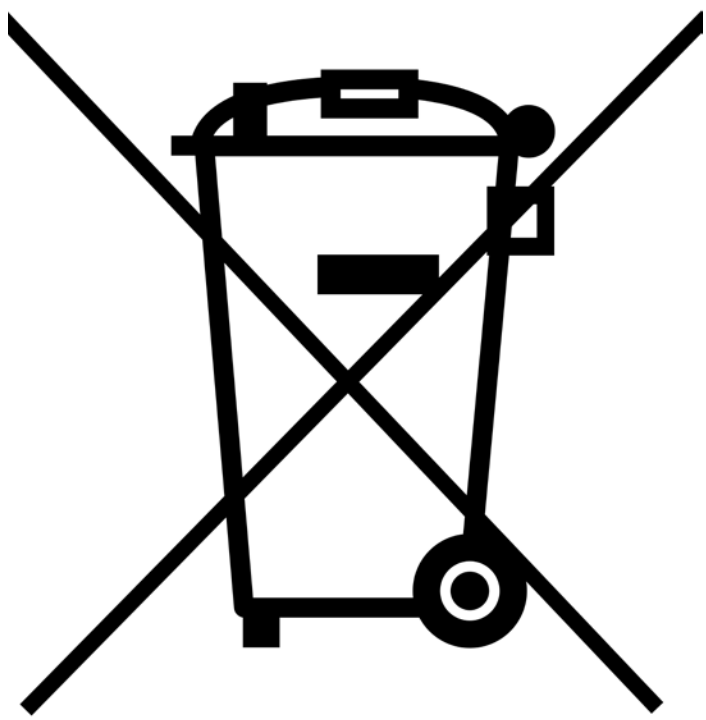

**Figure 8. Separate battery collection symbol used in the European Union**

Source: Getty Images

## 6.4 Vehicle Identification Number

E2Ws and E3Ws with a top speed of 25 kph or greater must have a vehicle identification number (VIN), as required by ISO 3779 (UNEP 2020). This is important for tracking vehicles, registration, and other attributes of the vehicle market.

## 6.5 Lithium-Ion Battery

The National Transportation Safety Board (NTSB) has recommended inclusion of information for fighting high-voltage lithium -ion battery related fires in the emergency response guides (NTSB 2021). In the electric vehicle industry, the term high voltage indicates a voltage of 60 above. The voltage level for the E2Ws and E3Ws is from 24 V to 72V. The label for high-voltage lithium-ion battery in ab electric vehicle is shown in Figure 8.


**Figure 9. Warning- Risk of Fire due to high-voltage Li-Ion Battery**

Source: (Hazard Control Technologies 2023)

# 7 Emerging Technologies

Electric mobility is developing rapidly, and many new technologies are emerging. Therefore, standards must continue to evolve at pace with advancements. Standards must be written to ensure safety and promote interoperability without stifling innovation. Research areas related to EVs include:

- New battery chemistries and architectures.
- EV battery secondary usage.
- Protection and care of stranded energy[1] after a crash, fire, or flood (Zhang 2022).
- Recycling batteries.
- Electric double-layer capacitors (EDLCs).
- Start/stop "micro-hybrid" architecture.
- Battery swap systems.
- Smart controls to prevent theft of swappable batteries.

EDLCs are called supercapacitors or ultracapacitors. Batteries and EDLCs are combined internally within a device or externally in a system to complement one another. Batteries have a high energy density, low self-discharge, and constant voltage output. Supercapacitors have short charging time, excellent temperature performance, high instantaneous current, and are mechanically flexible. Combining both storage devices capitalizes on each one's operational strengths, making it more useful for EVs. There is a lack of testing and certification for the batteries employed in these vehicles, and their rapid international growth presents a hazard.

Furthermore, a significant failure could reverse substantial progress in the industry toward electrification. For these reasons, the topic is actively being pursued by both SAE and Batt International, with the support of both CSA Group and UL, to develop awareness documents, recommended practices, and, ultimately, standards for certification.

Multiple standards development organizations (e.g., SAE, UL, CSA Group, Batt International) are targeting the research and development of batteries, EDLCs, and their hybrid systems. These organizations also work on safety, recommended regulations, and standards for these technologies.

[1] The energy remaining inside any undamaged or damaged battery following an accident.

# 8 Conclusions

The electrification of Pakistan’s transportation system, as well as related environmental and economic benefits, will require a robust market of E2Ws, E3Ws, and related charging infrastructure. This charging infrastructure will likely include battery swap stations to add convenience, save space, and enable business models where the battery and vehicles have different owners. An early step to catalyze such a market should be the development of standards that ensure the safety, quality, and interoperability of the EVs, EVCSs, and battery swap stations. The European Commission has developed a vehicle classification system that facilitates the standardization of E2Ws and E3Ws. UNEP 2020 has developed a set of tests to ensure vehicle safety, customer satisfaction, and environmental durability. Numerous SDOs have developed standards and related tests to ensure the electrical safety of EVs and their batteries. This includes the shipment of batteries, their usage, and recycling. India and Malaysia have developed some standards outside the SDOs that could be particularly relevant for Pakistan to consider, and their standards have been incorporated in the lists of previous sections.

A few SDOs have developed standards for EVCSs that are only compatible within their standardization systems because they have connectors meant to fit vehicles with matching receivers. Pakistan has decided to use the IEC standard compatible with the European market, and they should adopt numerous related IEC standards to ensure compatibility. India, with a much heavier reliance on two- and three-wheelers, has also built upon the IEC standards where they saw the need, and Pakistan might find it beneficial to borrow from this set of standards. Battery swap systems have a few general IEC standards, and India has also built upon these. However, there is a need for greater standardization of these systems, and a consortium of motorcycle manufacturers is working to fill this gap (Hyatt 2021). Labeling requirements have been developed to ensure better and safer interactions with vehicles and charging technologies. Finally, several emerging technologies will need to be addressed and standardized for them to be incorporated into future E2W and E3W markets.

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