



SURFACE VEHICLE INFORMATION REPORT

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Technical Information Report for Integration of Battery Pack Systems in Bus Electrification

RATIONALE

The global electrified bus market is growing rapidly to meet the demands of abating environmental impact of fossil fuel-based propulsion systems. This rapid electrification is happening at an accelerated rate with many manufacturers taking design technology to limits, or not understanding the full scope of proper engineering protocols in designing these sophisticated electrified systems. Both of these scenarios may create safety, performance, life, and cost concerns to the manufacturer and to large civic exposure (the passengers of these machines). It is the intent of this SAE Information Report to create a comprehensive information report which provides guidance in areas which are known to create safer performing machines with life expectancies and cost value which provides maximum benefit to the general public. This document will draw information from worldwide standards to provide guidance in design of electrified bus products. It is not the intent of this document to comprehend the entire bus design, but to provide guidance to those design aspects impacted by rechargeable energy storage system (RESS) integration.

This SAE Information Report will provide a compilation of design philosophies in current practices for the bus electrification industry. This will provide industry professionals guidance in key aspects of bus electrification that are important and where to seek further information.

This SAE Information Report is a precursor to an SAE Recommended Practice, which will follow within 18 months of this document's publication date. It is intended to become a historic document for the preservation of design philosophy with current state of the art in electrified bus design. This document creates the consensus knowledge base of participating members who represent the bus industry, battery industry, and ancillary components used in the electrification of buses.

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1. SCOPE

- 1.1 This SAE Information Report is specific to integration of rechargeable energy storage systems (RESS) into electrification of buses of all types which comprehends safety, performance, life, etc., utilizing worldwide standards and regulations as references in order to maximize existing work. This document applies to both purpose-built electric buses and retrofit electrified buses at an original equipment manufacturer (OEM). This document does not comprehend retrofitting of buses outside the OEM manufacturing environment.
- 1.2 Harmonization of worldwide existing standards and regulations help to achieve specific objectives that provide guidance in effective and safe designs of electrified buses which utilize battery pack systems as the rechargeable energy storage device.
- 1.3 This document also provides the guidance on the environmental consideration of RESS integration into electrified buses.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J1211	Handbook for Robustness Validation of Automotive Electrical/Electronic Modules
SAE J1555	Recommended Practice for Optimizing Automobile Damageability and Repairability
SAE J1654	Unshielded High Voltage Primary Cable
SAE J1673	High Voltage Automotive Wiring Assembly Design
SAE J1715	Hybrid Electric Vehicle (HEV) and Electric Vehicle (EV) Terminology
SAE J1715/2	Battery Terminology
SAE J1766	Recommended Practice for Electric, Fuel Cell, and Hybrid Electric Vehicle Crash Integrity Testing
SAE J1939	Serial Control and Communications Heavy Duty Vehicle Network - Top Level Document
SAE J2184	Vehicle Lift Points for Service Garage Lifting
SAE J2223-2	Connections for On-Board Road Vehicle Electrical Wiring Harnesses - Part 2: Tests and General Performance Requirements
SAE J2289	Electric-Drive Battery Pack System: Functional Guidelines
SAE J2464	Electric and Hybrid Electric Vehicle Rechargeable Energy Storage System (RESS) Safety and Abuse Testing
SAE J2910	Recommended Practice for the Design and Test of Hybrid Electric and Electric Trucks and Buses for Electrical Safety
SAE J2929	Safety Standard for Electric and Hybrid Vehicle Propulsion Battery Systems Utilizing Lithium-Based Rechargeable Cells

SAE J2936	SAE Electrical Energy Storage Device Labeling Recommended Practice
SAE J2990	Hybrid and EV First and Second Responder Recommended Practice
SAE J2990/2	Hybrid and Electric Vehicle Safety Systems Information Report
SAE J2974	Technical Information Report on Automotive Battery Recycling

2.1.2 IEC Publications

Available from IEC Central Office, 3, rue de Varembe, P.O. Box 131, CH-1211 Geneva 20, Switzerland, Tel: +41 22 919 02 11, www.iec.ch.

IEC 60730	Software Safety Requirements for Automatic Embedded Control Systems
IEC 61000-4-4	Electromagnetic Compatibility (EMC) - Part 4-4: Testing and Measurement Techniques - Electrical Fast Transient/Burst Immunity Test
IEC 61000-4-5	Electromagnetic Compatibility (EMC) - Part 4-5: Testing and Measurement Techniques - Surge Immunity Test
IEC 61851-1	Electric Vehicle Conductive Charging System - Part 1: General Requirements
IEC 61508 (all parts)	Functional Safety of Electrical/Electronic/Programmable Electronic Safety-Related Systems
IEC 62660-3	Secondary Lithium-Ion Cells for the Propulsion of Electric Road Vehicles - Part 3: Safety Requirements
IEC CISPR 25	Vehicles, Boats and Internal Combustion Engines - Radio Disturbance Characteristics - Limits and Methods of Measurement for the Protection of On-Board Receivers

2.1.3 ISO Publications

Copies of these documents are available online at <https://webstore.ansi.org/>.

ISO 6469-1	Electric Road Vehicles - Safety Specifications - Part 1: On-Board Electrical Energy Storage System
ISO 6469-3	Electric Road Vehicles - Safety Specifications - Part 3: Protection of Persons Against Electric Hazards
ISO 7637	Road Vehicles - Electrical Disturbances from Conduction and Coupling - Part 2: Electrical Transient Conduction Along Supply Lines Only
ISO 11452-2	Road Vehicles - Component Test Methods for Electrical Disturbances from Narrowband Radiated Electromagnetic Energy - Part 2: Absorber-Lined Shielded Enclosure
ISO 11452-4	Road Vehicles - Component Test Methods for Electrical Disturbances from Narrowband Radiated Electromagnetic Energy - Part 4: Harness Excitation Methods
ISO 17409	Electrically Propelled Road Vehicles - Conductive Power Transfer - Safety Requirements
ISO 17840-4	Road Vehicles - Information for First and Second Responders - Part 4: Propulsion Energy Identification
ISO 20653	Road Vehicles - Degrees of Protection (IP Code) - Protection of Electrical Equipment Against Foreign Objects, Water and Access

ISO 12405-4 Electrically Propelled Road Vehicles - Test Specification for Lithium-Ion Battery Packs and Systems - Part 4: Performance Testing

ISO 15118 (all parts) Road Vehicles - Vehicle to Grid Communication Interface

ISO 26262 (all parts) Road Vehicles - Functional Safety

2.1.4 UN and EU Publications

Available from the European Commission, https://ec.europa.eu/info/index_en.

Directive 2007/46/EC Establishing a Framework for the Approval of Motor Vehicles and Their Trailers, and of Systems, Components and Separate Technical Units Intended for Such Vehicles (Framework Directive)

EU Regulation 2018/858 On the Approval and Market Surveillance of Motor Vehicles and Their Trailers, and of Systems, Components and Separate Technical Units Intended for Such Vehicles, Amending Regulations (EC) No. 715/2007 and (EC) No. 595/2009 and Repealing Directive 2007/46/EC

UN 38.3 Recommendations on the Transport of Dangerous Goods, Manual of Tests and Criteria

UN Regulation No. 20* Electric Vehicle Safety (EVS)

UN Regulation No. 118 Burning Behavior of Interior Materials

* Referred to as GTR.20 in this document.

2.1.5 Code of Federal Regulations (CFR) Publications

Available from the United States Government Printing Office, 732 North Capitol Street, NW, Washington, DC 20401, Tel: 202-512-1800, www.gpo.gov.

49 CFR 571, Part 220 School Bus Rollover Protection

2.1.6 UL Publications

Available from UL, 333 Pfingsten Road, Northbrook, IL 60062-2096, Tel: 847-272-8800, www.ul.com.

UL 2580 Batteries for Use in Electric Vehicles

UL 1998 Safety Software in Programmable Components

UL 991 Safety Tests for Safety-Related Controls Employing Solid-State Devices

UL 1974 Safety Evaluation for Repurposing Batteries

UL 9540A Safety Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems

2.1.7 China Publications

GB 38031-2020 Electric Vehicles Traction Battery Safety Requirements

GB 38032-2020 Electric Buses Safety Requirements

GB 38117-2019 Electric Vehicles Product Description Emergency Rescue

GB 7258-2017 Technical Specifications for Safety of Power-Driven Vehicles Operating on Roads

GB/T 18385-2005 Electric Vehicles - Power Performance - Test Method

GB/T 18386-2017	Electric Vehicles - Energy Consumption and Range - Test Procedures
GB/T 31467.1-2015	Lithium-Ion Traction Battery Pack and System for Electric Vehicles - Part 1: Test Specification for High Power Applications
GB/T 31467.2-2015	Lithium-Ion Traction Battery Pack and System for Electric Vehicles - Part 2: Test Specification for High Energy Applications
GB/T 34014-2017	Coding Regulations for Automotive Traction Battery.
GB/T 34015-2017	Recycling of Traction Battery Used in Electric Vehicle - Test of Residual Capacity
GB/T 39086-2020	Functional Safety Requirements and Testing Methods for Battery Management System of Electric Vehicles

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

2.2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J1495	Test Procedure for Battery Flame Retardant Venting Systems
SAE J1634	Battery Electric Vehicle Energy Consumption and Range Test Procedure
SAE J1739	Potential Failure Mode and Effects Analysis (FMEA) Including Design FMEA, Supplemental FMEA-MSR, and Process FMEA
SAE J1742	Connections for High Voltage On-Board Vehicle Electrical Wiring Harnesses - Test Methods and General Performance Requirements
SAE J1772	SAE Electric Vehicle and Plug-in Hybrid Electric Vehicle Conductive Charge Coupler
SAE J1797	Recommended Practice for Packaging of Electric Vehicle Battery Modules
SAE J1798	Recommended Practice for Performance Rating of Lead Acid and Nickel Metal Hydride Electric Vehicle Battery Modules
SAE J1908	Electrical Grounding Practice
SAE J2232	Vehicle System Voltage - Initial Recommendations
SAE J2288	Life Cycle Testing of Electric Vehicle Battery Modules
SAE J2344	Guidelines for Electric Vehicle Safety
SAE J3061	Cybersecurity Guidebook for Cyber-Physical Vehicle Systems
SAE J3073	Battery Thermal Management

2.2.2 IEC Publications

Available from IEC Central Office, 3, rue de Varembe, P.O. Box 131, CH-1211 Geneva 20, Switzerland, Tel: +41 22 919 02 11, www.iec.ch.

IEC 60529-2013	Degree of Protection Provided by Enclosure (IP Code)
IEC 61980-1	Electric Vehicle Wireless Power Transfer (WPT) Systems - Part 1: General Requirements
IEC 62660-1	Secondary Lithium-Ion Cells for the Propulsion of Electric Road Vehicles - Part 1: Performance Testing
IEC 62660-2	Secondary Lithium-Ion Cells for the Propulsion of Electric Road Vehicles - Part 2: Reliability and Abuse Testing
IEC 62576	Electric Double-Layer Capacitors for Use in Hybrid Electric Vehicles - Test Methods for Electrical Characteristics
IEC 62840-2	Electric Vehicle Battery Swap System - Part 2: Safety Requirements
IEC TS 62840-1	Electric Vehicle Battery Swap System - Part 1: General and Guidance

2.2.3 ISO Publications

Copies of these documents are available online at <https://webstore.ansi.org/>.

ISO 6469-2	Electric Road Vehicles - Safety Specifications - Part 2: Functional Safety Means and Protection Against Failures
ISO 6469-4	Electrically Propelled Road Vehicles - Safety Specifications - Part 4: Post-Crash Electrical Safety
ISO 14572	Road Vehicles - Round, Sheathed, 60 V and 600 V Screened and Unscreened Single- or Multi-Core Cables - Test Methods and Requirements for Basic- and High-Performance Cables
ISO 16750	Environmental Conditions and Testing for Electrical and Electronic Equipment
ISO 10605	Road Vehicles - Test Methods for Electrical Disturbances from Electrostatic Discharge
ISO 17840-2	Road Vehicles - Information for First and Second Responders - Part 2: Rescue Sheet for Buses, Coaches and Heavy Commercial Vehicles
ISO 17840-3	Road Vehicles - Information for First and Second Responders - Part 3: Emergency Response Guide Template

2.2.4 UL Publications

Available from UL, 333 Pfingsten Road, Northbrook, IL 60062-2096, Tel: 847-272-8800, www.ul.com.

UL 2202	Electric Vehicle (EV) Charging System Equipment
UL 2231-1	Personnel Protection Systems for Electric Vehicle (EV) Supply Circuits - Part 1: General Requirements
UL 2231-2	Personnel Protection Systems for Electric Vehicle (EV) Supply Circuits - Part 2: Particular Requirements for Protection Devices for Use in Charging Systems

2.2.5 UN Publications

Available from the European Commission, https://ec.europa.eu/info/index_en.

UN 3840	Lithium-Ion Batteries Including Lithium-Ion Polymer Batteries
UN 3841	Lithium-Ion Batteries Packed with Equipment Including Lithium-Ion Polymer Batteries
UN Regulation No. 10	Uniform Provisions Concerning the Approval of Vehicles with Regard to Electromagnetic Compatibility
UN Regulation No. 100	Uniform Provisions Concerning the Approval of Vehicles with Regard to Specific Requirements for the Electric Power Train
UN Regulation No. 107	Uniform Provisions Concerning the Approval of Category M2 or M3 Vehicles with Regard to Their General Construction

2.2.6 Code of Federal Regulations (CFR) Publications

Available from the United States Government Printing Office, 732 North Capitol Street, NW, Washington, DC 20401, Tel: 202-512-1800, www.gpo.gov.

FMVSS 305	Electric Powered Vehicles Electrolyte Spillage and Electrical Shock Protection
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2.2.7 China Publications

GB 18384-2020	Electric Vehicles Safety Requirements
GB/T 31484-2015	Cycle Life Requirements and Test Methods for Traction Battery of Electric Vehicle
GB/T 31485-2015	Safety Requirements and Test Methods for Traction Battery of Electric Vehicle
GB/T 31498-2015	The Safety Requirement of Electric Vehicle Post-Crash

3. DEFINITIONS

3.1 BATTERY

Electrochemical cells electrically connected in a series and/or parallel arrangement. (Definition from SAE J1715.)

3.2 BODY CLEARANCE

The space between the battery pack and vehicle frame to preclude contact of the battery pack or components to the vehicle.

3.3 DUT (DEVICE UNDER TEST)

Device under test.

3.4 ECHELON USE

Using a battery in a different application after the battery was retired from one application in the field and subjected to some level of analysis and reconfiguration, also known as second use or repurposed use.

3.5 EOL (END OF LIFE)

When an energy storage system fails to meet specified capacity, power, or function under specified use conditions. (Definition from SAE J1715-2.)

3.6 EXPLOSION

Very fast release of energy sufficient to cause pressure waves and/or projectiles that may cause considerable structural and/or bodily damage. (Definition from SAE J2929.)

3.7 FIRE

The emission of flames from a battery or device (approximately more than 1 second). Sparks are not flames. (Definition from SAE J2929.)

3.8 GVWR (GROSS VEHICLE WEIGHT RATING)

The maximum operating weight/mass of a vehicle as specified by the manufacturer. For bus, it is the sum of the weight of bus, driver, passengers, and cargoes.

3.9 HIGH VOLTAGE

A voltage greater than 60 VDC or 30 AC RMS.

NOTE: Per SAE J1673, the high voltage is defined as a circuit voltage greater than 50 VDC or AC RMS and less than or equal to 600 VDC or AC RMS. Per SAE J1654, low voltage is considered to be less than or equal to 60 VDC (25 VAC). While in other international standard, such as UL 2580 or ISO 6469-1, high voltage is considered to be above 60 VDC and 30 VAC RMS. In ISO 6469-1, Class B voltage is defined as a voltage greater than 60 VDC or 30 VAC RMS and less than or equal to 1500 VDC or 1000 VAC RMS.

Table 1 - Voltage class between ISO 6469-1 and SAE J1673

Voltage Class	Maximum Working Voltage (ISO 6469-1)		Maximum Working Voltage (SAE J1673)	
	DC in V	AC in V (RMS Value)	DC in V	AC in V (RMS Value)
A	$0 < U \leq 60$	$0 < U \leq 30$	$0 < U \leq 50$	$0 < U \leq 50$
B	$60 < U \leq 1500$	$30 < U \leq 1000$	$50 < U \leq 600$	$50 < U \leq 600$

3.10 IP RATING/IP LEVEL

A coding system to indicate the degrees of protection provided by an enclosure against access to hazardous parts, ingress of solid foreign objects, ingress of water, and to give additional information in connection with such protection. (Definition from IEC 60529.)

3.11 LOW VOLTAGE

A voltage less than or equal to 60 VDC or 30 VAC RMS.

3.12 RECYCLING (BATTERY PRODUCTS)

Recycle or recovery of materials contained in the battery. (Definition from SAE J2974.)

3.13 RECYCLING (NON-BATTERY PRODUCTS)

Recycle or recovery of materials within the RESS but other than the battery for reuse.

3.14 RESS (RECHARGEABLE ENERGY STORAGE SYSTEM)

Any energy storage system that has the capability to be charged and discharged (e.g., batteries, capacitors). (Definition from SAE J1715.)

NOTE: For the purpose of this document, the RESS definition has expanded to include all battery packs or multiple energy storage devices within the bus to be part of the RESS.

RESS, which is defined in the Global Technical Regulation No. 20 as “rechargeable electrical energy storage system (REESS),” has the same meaning as the SAE definition.

3.15 RESS COMPONENTS

Components are those parts of the RESS system which have specific function to complete the operation of the RESS.

Typical components include, but are not limited to, the following:

3.15.1 BATTERY CELL

An assembly of at least one positive electrode, one negative electrode and other necessary electrochemical and structural components. A cell is a self-contained energy conversion device whose function is to deliver electrical energy to an external circuit via an internal chemical process. (Definition from SAE J1715.)

3.15.2 BATTERY MODULE

A grouping of interconnected cells in a single mechanical and electrical unit. (Definition from SAE J1715.)

3.15.3 BATTERY PACK

Interconnected battery modules that have been configured for a specific energy storage application. (Definition from SAE J1715.)

3.15.4 SWITCH BOX

A function subassembly or battery modules used to close or open the RESS power circuit by activities of switches or relays. May consist of, but is not limited to, high-voltage relays, current sensor, voltage sensors, fuses, HVIL, communications, controller board, and low voltage circuit.

3.15.5 HIGH-VOLTAGE CABLES

Cable carrying voltages greater than 60 VDC or 30 VAC RMS.

3.15.6 COMMUNICATIONS WIRING

Wire used for control and signal information transmission, carrying low voltage **as defined in 3.2.2.5** and low current.

3.15.7 THERMAL MANAGEMENT SYSTEM

System to monitor and manage the thermal condition of battery. May consist of thermal sensor, thermal control unit, heating and cooling device, etc.

3.15.8 VENTING SYSTEM

Device or system used to release the pressure and safely dispose or disperse the released product from inside the battery when its internal pressure exceeded a specified value designed by the manufacturer.

3.15.9 BATTERY MANAGEMENT SYSTEM

Electronic device that controls or manages or detects or calculates electric and thermal functions of the battery system and that could provide communication between the battery system and other vehicle controllers. BMS protects the battery from operating outside its normal operating range.

3.15.10 MASTER BATTERY MANAGEMENT SYSTEM

Electronic device that controls, manages, or detects, as a supervisor, all of the battery management systems in a multi-battery pack's architecture, and provides communication between the battery system and other vehicle controllers.

3.16 STRANDED ENERGY

The energy remaining in an energy storage system after a collision which needs to be removed for first responder interaction and safe storage. (Definition from SAE J1715/2, 3.127.)

3.17 THERMAL RUNAWAY

A condition where an increase in temperature of the cell results in exothermic reactions, which further increases the cell temperature due to increased reactions within the cell. A thermal runaway often leads to a destructive result, such as a fire or explosion, when the heat cannot be safely dissipated. (Definition from UL 2580.)

3.18 THERMAL PROPAGATION

The sequential occurrence of thermal runaway within a battery system triggered by thermal runaway of a cell in that battery system. (Definition from GTR.20.)

4. TECHNICAL CONSIDERATIONS

4.1 Classifications of Buses

For convenience, it is assumed for this document that all technical considerations for electric bus will be applicable for all possible buses using a power source from a battery or battery pack located in the vehicle and to be propelled by electric motors. The general definitions are not limited by different usage of electric bus, as well as by their length, and can be devised by following groups.

4.1.1 Definitions in North America

The definitions of buses in the North American market are as noted in Table 2.

Table 2 - Bus classifications in North America

I - Classification According to Size and Duty		II - Classification According to Usage	III - Classification According to Type
Large-size, heavy-duty transit buses	Approx 35-40 feet (10.6-12.1 m) in length, as well as articulated buses <i>Large bus in China (9-12 m)</i>	a. Urban transit bus	a. Standard size bus: Approx 35-41 feet (10.6-12.5 m) in length <i>Extra-large bus in China (12-13.7 m)</i> b. Articulated bus: Approx 55 feet (16.7 m) or more in length with two connected passenger compartments that bend at the connecting point when the bus turns a corner
Medium-size, heavy-duty transit buses	Approx 30 feet (9.1 m) in length	b. School bus	
Medium-size, medium-duty transit buses	Approx 30 feet (9.1 m) in length	c. Motor coach or commuter bus	
Medium-size, light-duty transit buses	Approx 24-30 feet (7.3-9.1 m) in length <i>Medium bus in China (6-9 m)</i>	d. Perimeter-seating buses	
		e. Over-the-road buses	

4.1.2 Definitions in China

The definitions of bus types in China are as outlined in Table 3.

Table 3 - Bus classifications in China

Classification	L = Length of Bus (m)
Extra-large bus	$13.7 \geq L > 12$
Large bus	$12 \geq L > 9$
Medium bus	$9 \geq L > 6$
Mini bus	$6 \geq L > 3.5$

4.1.3 Definitions in Europe

The definition of a bus according to the Directive 2007/46/EC, EU Regulation 2018/858, and UN ECE R107:

Table 4 - EU WVT Directive 2007/46/EC and Regulation (UE) 2018/858

Category		Usage	Seating Positions and Mass
M	M1	Passenger transport	Seating positions ≤ 8 + driver
	M2		Mass ≤ 5 tons Seating positions > 8 + driver
	M3		Max mass > 5 tons Seating positions > 8 + driver
N	N1	Goods transport	Max mass ≤ 3.5 tons
	N2		$3.5 \text{ tons} < \text{max mass} \leq 12 \text{ tons}$
	N3		Max mass > 12 tons
O	O1	Trailers and semi-trailers	Max mass ≤ 0.75 tons
	O2		$0.75 \text{ ton} < \text{max mass} \leq 3.5 \text{ tons}$
	O3		$3.5 \text{ tons} < \text{max mass} \leq 10 \text{ tons}$
	O4		Max mass > 10 tons
G		Off-road	Category M or N vehicle having specific technical features which permit is use off the normal roads
SP		Special purpose	Category M,N or O vehicle having specific technical features to perform a function which requires special arrangements and/or equipment

Table 5 - Buses and coaches UN ECE R 107 (M2/M3)

Category	Accommodation	Passenger-Related Provision
Class I (city bus)	> 22 passengers	With areas to allow frequent passenger movement
Class II (interurban bus or coach)		With standing passengers in the gangway and/or in an area which does not exceed the space provided for two double seats
Class III (touring coach)		With no provisions for standing passengers
Class A	≤ 22 passengers	With provision for standing passengers
Class B		With no provision for standing passengers

Following vehicle considerations guideline presents various bus design issues that need to be considered to ensure safe operations when using electric propulsion. The unique considerations for electric bus design will present to understand what makes the difference to a conventional bus design.

4.2 The Impact of RESS on Vehicle Design

4.2.1 Safety

Safety is the highest level priority for all road vehicle designs. Increased passenger loads on buses compared to passenger cars makes this even more important.

4.2.1.1 Crash

RESS retention during crash is essential to passenger safety. Loss of retention allows for free movement of RESS components which can become projectiles during the crash event. The potential for crush damage of any RESS component must be comprehended. In addition to crush, puncture is a potential issue. Cells and battery modules within a pack should be isolated in the event of a crash. An electric bus-level crash test procedure has been proposed in China for evaluate the structural protection for RESS. RESS retention, electrical protection, and electrolyte leakage should be confirmed. (GB 38032-2020.)

4.2.1.2 Rollover

RESS retention during rollover is essential to passenger safety. Loss of retention allows for free movement of RESS components which can become projectiles during the rollover event. For top-mounted RESS, the impact of a rollover must be comprehended. Regulation requirements need to also be taken into consideration. Federal Motor Vehicle Safety Standard (FMVSS) 49 CFR Section 571, Part 220 provides information for school bus rollover protection. Lower battery installation is a better solution in terms of the impact of the center of gravity and for minimizing potential effects of a rollover.

4.2.1.3 Road Debris

Mounting of the RESS must consider the possibility of road debris, obstacles, and/or other objects which could penetrate the RESS from the bottom, side or top.

4.2.1.4 Moisture Exposure

Exposure of the RESS components to excessive water (fresh or brine), splash, and moisture may cause the components to become damp. (Not including the condition that components within the RESS become submerged, which is described in 4.2.1.5.) This could include, but is not limited to, external vehicle washing, internal vehicle washing, and heavy rain. Electrical isolation resistance should be kept within safe limit.

4.2.1.5 Submersion

Submersion is exposure of RESS components to excessive water (fresh or brine), which covers one or more components of the RESS for some period of time. After submersion, the isolation value of the vehicle level should be guaranteed. The IP level that should be applied depends on the installation in the bus. A vehicle-level submersion test is an effective means to evaluate the safety performance.

4.2.1.6 Vehicle Towing, Transportation, Storage

The vehicle manufacture should provide information for the towing-services through specific information and prescriptions to avoid any damage to the vehicle or risks for the operators (i.e., how to tow this vehicle and to handle vehicle post-fire/crash especially in case of a damaged RESS).

4.2.1.7 Fire and Explosion

Sustainable flames will lead to propagation to other components or systems within the bus architecture. It is necessary to manage fires within the bus. Fire-resistant materials between the battery pack and passenger cabin should be applied (UN Regulation No. 118). NFPA emergency guidelines could also be a useful reference. In case of fire, it is fundamental to guarantee an adequate cool down through a "fireman access" on the RESS to facilitate the cooldown. Effective extinguishment should be conducted through a massive water flow directly injected on the battery housing or if possible directly to the internal battery modules/cells through a melting port (sometimes referred to as a "fireman access") on the battery enclosure.

Battery fires can result in off gassing of flammable gases that may result in combustible concentrations with the potential for explosions, should these concentrations reach hot surfaces. The propensity for an explosion hazard from the battery as a result of an internal or external fire should be determined through propagation and external fire exposure tests. (Refer to UN ECE R100, SAE 2929, UL 2580, GB 38031-2020, or ISO 6469-1 for propagation and external fire exposure tests methods.)

4.2.1.8 Fumes and Smoke

Perceptible odors or visible particulates which lead to respiratory distress or can lead to asphyxiation. RESS should be isolated from passenger cabin; direct contact to RESS from passengers should be avoided. If the RESS is cooled or heated by air from passenger cabin, there should be a fumes and smoke control device in the ducting. Toxic gases must not enter the passenger cabin from RESS under abnormal situations.

4.2.1.9 Electrocuting/Shock

A condition where components of the vehicle or RESS are energized beyond the threshold limits which can lead to shock or electrocution hazard.

The high-voltage system of an electric bus can have an operating range from 200 VDC to 800 VDC. Portions of the high-voltage circuits may be active even when the bus is not operating. The design of the high-voltage system and RESS should minimize the presence of exposed hazardous voltage which could lead to electric shock. Suitable personal protective equipment (PPE) should be worn when servicing high-voltage systems.

4.2.1.9.1 Arc Flash

Inadvertent shorting of a high-voltage and high-energy battery system during maintenance can result in a potential arc flash hazard, which is a hazardous flash over that can result in burns and severe injuries. Suitable personal protective equipment (PPE) should be worn and the potential arc flash hazard of the system should be well understood by technicians servicing the vehicle.

4.2.1.10 Electrolyte Leakage

Under serious conditions like vehicle collision and rollover, electrolyte with strong acid or alkalinity from certain batteries will splash on the passengers and fall into the vehicle body parts.

4.2.1.11 Stranded Energy

RESS will most probably remain at a high voltage level, even in end of life. Engineers should consider how much energy remains in the RESS after an accident or at the end of life and whether there is any shock or electrocution hazard present.

4.2.1.12 Information for First and Second Responders

For first and second responders initiating a rescuing action at a traffic accident site, it is crucial and often requires that a quick decision be made in order to save the lives of the road victims. To overcome this situation, it is necessary to have immediate access to the right information about the vehicles involved—especially in the case of electric vehicles. This concerns not only information about the location of the involved components, but the hazards to be dealt with (e.g., fire in the vehicle, fire in the RESS, dangerous products in the vehicle and vehicle submersion, etc.). For this reason, the vehicle manufacturer should develop an Emergency Response Guide (ERG) following the template outlined in ISO 17840 Part 3, and the data needed for rescue teams (called “Rescue Sheet”) as mentioned in ISO 17840 Part 2. The Rescue Sheet may be created as one sheet covering all vehicle variants and body shapes and drives.

GB/T 38117-2019 specifies the contents and preparation requirements of emergency rescue in the instructions for the use of electric vehicle products.

SAE J2990 reviewed current regulations and standards, leading to an understanding that there is an opportunity to provide a means to better coordinate and communicate those elements from many of the regulations, so that the first and second responders may apply a more standardized execution, and be more confident in their outcome. This recommended practice provides first and second responders with the ability to identify an xEV, avoid the hazards associated with the high-voltage system, communicate hazard identification to other incident responders, and manage the risks in a manner consistent with best practices utilized by first responders, second responders, and by the vehicle manufacturers and other responsible organizations.

SAE J2990/2 describes some of the general safety systems and practices employed by OEMs to help assure the general public of the safety of these vehicles, and to explain why these safety systems and practices help protect against high-voltage contact.

4.2.2 RESS Location

The RESS installation location in electric bus applications should take several key factors into consideration, including the gravity center of the vehicle, crush or impact zones of the vehicle, structure and chassis of the vehicle, and the environmental influences. The temperature distribution of the RESS location, which will have influence on the design of thermal management, should be considered. Additionally, consideration should be made for the routing of the high-voltage cables and RESS accessibility for service and maintenance.

4.2.2.1 Possible Locations of RESS Used in Today's Bus Designs

4.2.2.1.1 Passenger Compartment



Figure 1A - Battery packs located on the front wheel houses
Source: Ortiz, on Wikipedia



Figure 1B - Battery packs located on the front wheel houses
Source: Riley, on Flickr

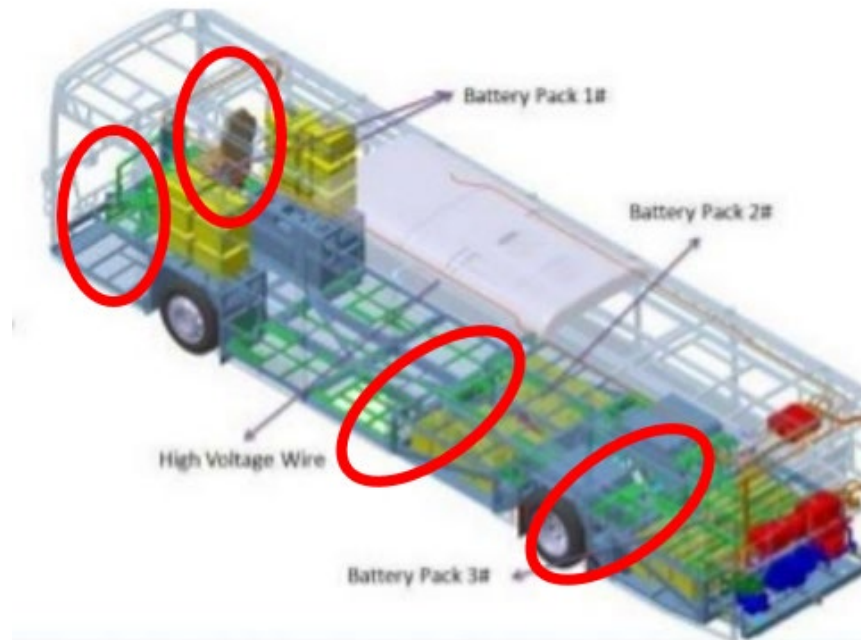


Figure 2 - Battery packs located on the front wheel houses and under passenger seats

Source: Goel, on Slideshare

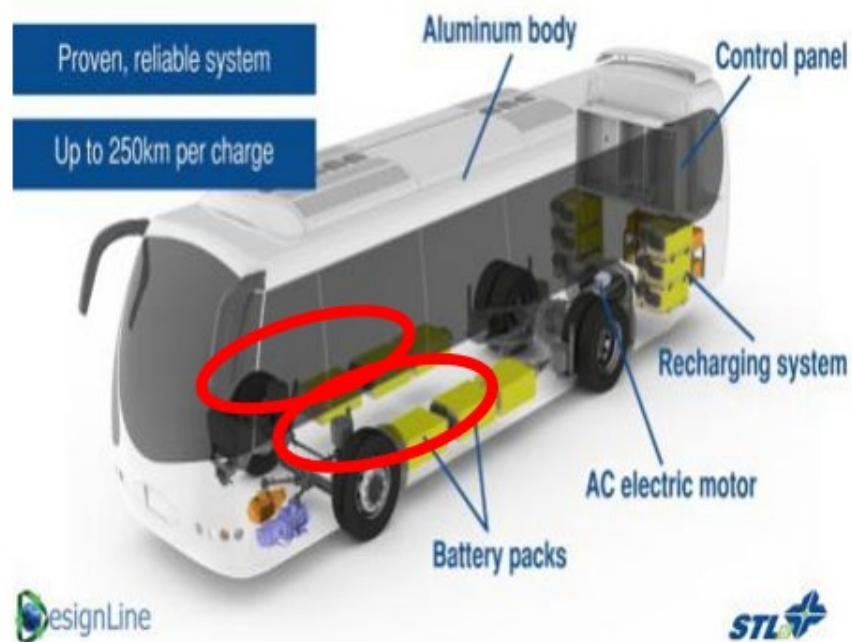


Figure 3 - Battery packs located under passenger seats

Source: News Coverage

4.2.2.1.2 Cargo Bay



Figure 4 - Battery packs located in the cargo bay
Source: Alibaba

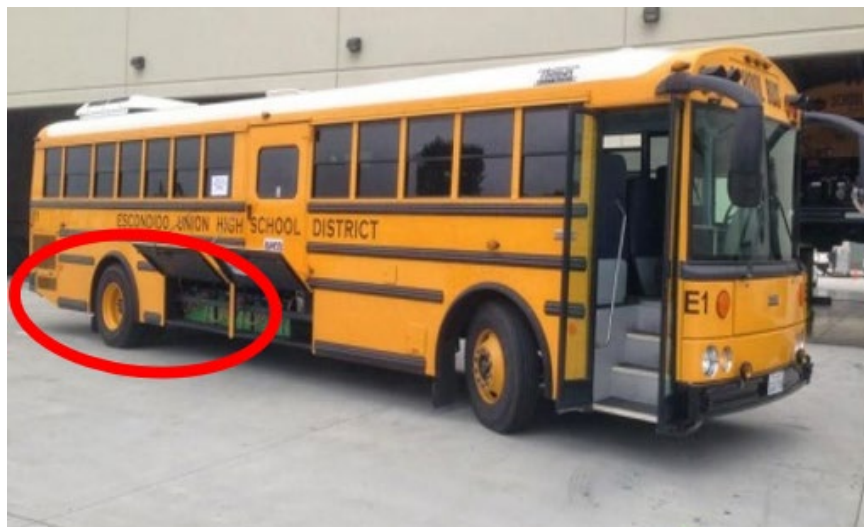


Figure 5 - Battery packs located in the cargo bay
Source: TransPower USA