SAE INTERNATIONAL

SURFACE VEHICLE STANDARD

J1766 | JAN2014

Issued 1996-02
Revised 2014-01

Superseding J1766 APR2005

(R) Recommended Practice for Electric, Fuel Cell and Hybrid Electric Vehicle Crash Integrity Testing

RATIONALE

This version of SAE J1766 represents a significant update to the April 2005 version that it replaces. The substantive revisions are summarized as follows:

- The definition of high voltage (and corresponding applicability of this Recommended Practice) has been updated to include upper limits of 1,500 VDC and 1,000 VAC, consistent with international convention.
- The references to crash test procedures and test conditions have been updated and clarified.
- Electrolyte spillage provisions have been updated to reflect international regulatory requirements.
- Component retention provisions have been updated to be consistent with the requirements of Federal Motor Vehicle Safety Standard (FMVSS) 305.
- The previous version of SAE J1766 included three alternatives for providing post-crash electrical safety - electrical isolation, low voltage, and low energy. This update provides a fourth option for post-crash electrical safety, specifically an electrical protection barrier option. This fourth option aligns with ECE R94 and R95, the current draft of the fuel cell vehicle (FCV) global technical regulation (GTR), ISO 6469-3, and the consensus of international regulatory and industry experts that electrical protection barriers are foundational to in-use and post-crash electrical safety. In order to expedite acceptance of the electrical protection barriers, requirements for these electrical protection barriers were developed to verify that adequate electric shock protection is still provided after the crash. Test methods and rationale for these requirements are provided in Appendix C.
- The time criterion for initiating verification of post-crash electrical safety was also changed from 5 seconds after the vehicle comes to rest to 10 seconds after initial impact. Basing the criterion on time after initial impact provides more accuracy in establishing the allowable time period and aligns the criterion with other international standards. The increase from 5 to 10 seconds accounts for the post-crash period where the vehicle or parts of the vehicle could still be moving.
- The test procedures now contained in Appendices A and B have been updated and expanded.
- The rationale for the 0.2 Joules low-energy option has been expanded and updated. This updated rationale is provided in Appendix D.

FOREWORD

This SAE Recommended Practice describes methods for evaluating the vehicle high voltage system performance when subjected to specified FMVSS crash test procedures. It addresses electrolyte spillage, retention of electrical propulsion components, and post-crash electrical safety. It is intended to provide vehicle designers with recommended tests and performance criteria relating to Electric, Fuel Cell and Hybrid vehicles. Test personnel should exercise caution when conducting the procedures described in this document. Each testing organization is encouraged, upon experience, to send comments and suggested revisions to these procedures. Please send comments or suggestions to: SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, attention: Fuel Cell Standards Committee.

TABLE OF CONTENTS

1. SCOPE

Electric, Fuel Cell and Hybrid vehicles may contain many types of high voltage systems. Adequate barriers between occupants and the high voltage systems are necessary to provide protection from potentially harmful electric current and materials within the high voltage system that can cause injury to occupants of the vehicle during and after a crash. This SAE Recommended Practice is applicable to Electric, Fuel Cell and Hybrid vehicle designs that are comprised of at least one vehicle propulsion voltage bus with a nominal operating voltage greater than 60 and less than 1,500 VDC, or greater than 30 and less than 1,000 VAC. This Recommended Practice addresses post-crash electrical safety, retention of electrical propulsion components and electrolyte spillage.

1.1 Purpose

The purpose of this document is to define test methods and performance criteria to evaluate the post-crash electrical safety, retention of electrical propulsion components and electrolyte spillage in Electric, Fuel Cell and Hybrid vehicles during and after specified crash tests.

1.2 Field of Application

The vehicles covered in this document are Electric, Fuel Cell and Hybrid vehicles with a gross vehicle weight rating of 4,536 kg (10,000 lb) or less whose speed attainable in 1.6 km on a paved level surface is more than 40 km/h, and that use more than 60 and less than 1,500 volts DC, or more than 30 and less than 1,000 volts AC for propulsion power.

1.3 Product Classification

Not available.

1.4 Form

Not available.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. The latest issue of FMVSS and SAE publications shall apply unless otherwise specified. Applicable FMVSS shall supersede any SAE Recommended Practices referenced in this document.

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 724-776-4970 (outside USA), www.sae.org.

SAE J1715 Hybrid Electric Vehicle (HEV) & Electric Vehicle (EV) Terminology

SAE J2344 Guidelines for Electric Vehicle Safety

SAE J2578 Recommend Practice for General Fuel Cell Vehicle Safety

2.1.2 Federal Motor Vehicle Safety Standards & Regulations

Code of Federal Regulations, Title 49, Part 571, which contains the current Federal Motor Vehicle Safety Standards (FMVSS) and Regulations (FMVSR) issued under Chapter V – National Highway Traffic Safety Administration—Available from Superintendent of Documents, Government Printing Office, Washington, DC 20408, Phone: 202-366-3238. Current versions of FMVSS and FMVSR can also be viewed at the Electronic Code of Federal Regulations website – http://ecfr.gpoaccess.gov.

FMVSS 208 Occupant Crash Protection (as amended through February 8, 2010)

FMVSS 214 Side Impact Protection (as amended through March 15, 2010)

FMVSS 301 Fuel System Integrity (as amended through March 15, 2010)

FMVSS 305 Electric-Powered Vehicles (as amended through July 29, 2011)

FMVSR 572 Anthropomorphic Test Devices (as amended through June 2, 2011)

FMVSR 587 Moving Deformable Barrier (as amended through July 29, 2003)

2.1.3 FMVSS Test Procedures

The NHTSA test procedures for FMVSS are available from Administration/Technical Reference Division, NHTSA, NAD-52, phone: 202-366-4946, or within NHTSA's website – http://www.nhtsa.gov.

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 724-776-4970 (outside USA), www.sae.org.

SAE TSB 001 SAE Technical Standards Board Rules and Regulations

SAE TSB 002 SAE Preparation of SAE Technical Reports

SAE TSB 003 Rules for the SAE Use of SI (Metric) Units

SAE J1115 Guidelines for Developing and Revision SAE Nomenclature and Definitions

SAE J1772 SAE Electric Vehicle Conductive Charge Coupler

SAE J1773 SAE Electric Vehicle Inductively Coupled Charging

SAE J1797 Recommended Practice for Packaging of Electric Vehicle Battery Modules

SAE J1798 Recommended Practice for Performance Rating of Electric Vehicle Battery Modules

SAE J2574 Fuel Cell Vehicle Terminology

SAE J2929 Electric and Hybrid Vehicle Propulsion Battery System Safety Standard - Lithium-Based Rechargeable Cells

SAE Report Format Guidelines for Electronic Capture of SAE Documents

SAE Committee Guidelines Manual

2.2.2 Other Publications

UL 2202 Electric Vehicle (EV) Charging System Equipment

3. DEFINITIONS

Except as noted below, all definitions are in accordance with SAE J1715.

3.1 AUTOMATIC DISCONNECT

Means a device that when triggered, conductively separates a high voltage source from the rest of the circuit.

3.2 CHARGING SYSTEM

Means the device(s) and associated equipment necessary to properly recharge the high voltage energy storage system in an Electric, Fuel Cell or Hybrid vehicle from the electrical grid or other off board power source.

3.3 ELECTRIC ENERGY STORAGE DEVICE

Means a high voltage source that stores energy for vehicle propulsion. This includes, but is not limited to, a high voltage battery or battery pack, rechargeable energy storage device, and capacitor module used for vehicle propulsion.

3.4 ELECTRIC ENERGY STORAGE/CONVERSION DEVICE

Means a high voltage source that stores or converts energy for vehicle propulsion. This includes, but is not limited to, a high voltage battery or battery pack, fuel cell stack, rechargeable energy storage device, and capacitor module used for vehicle propulsion.

3.5 ELECTRIC ENERGY STORAGE/CONVERSION SYSTEM

Means an assembly of electrical components that stores or converts electrical energy for vehicle propulsion. This includes, but is not limited to, high voltage batteries or battery packs, fuel cell stacks, rechargeable energy storage systems, capacitor modules, inverters, interconnects, and venting systems.

3.6 ELECTRIC POWER TRAIN

Means an assembly of electrically connected components which includes, but is not limited to, electric energy storage/conversion systems and propulsion systems.

3.7 ELECTRICALLY-CONDUCTIVE CHASSIS

Means conductive parts of the vehicle whose electrical potential is taken as reference and which are: (1) conductively linked together, and (2) not high voltage sources during normal vehicle operation.

3.8 ELECTRICAL ISOLATION RESISTANCE (*or* Isolation Resistance)

Means the electrical resistance between a high voltage source and any of the vehicle's electrically-conductive chassis divided by the maximum working voltage of the high voltage source.

3.9 ELECTRICAL PROTECTION BARRIER

Means the part(s) providing first-fault or post-crash protection against contact with live parts from any direction of access.

3.10 EXPOSED CONDUCTIVE PART

Means the conductive part that can be touched under the provisions of the IPXXB protection degree and becomes electrically energized under isolation failure conditions. This includes parts under a cover that can be removed without using tools.

3.11 HIGH VOLTAGE

Means voltage levels greater than 30 VAC and less than 1,000 VAC, or greater than 60 VDC and less than 1,500 VDC.

3.12 HIGH VOLTAGE SOURCE

Means any electric component contained in the electric power train or conductively connected to the electric power train that has a maximum working voltage greater than 30 and less than 1,000 VAC, or greater than 60 and less than 1,500 VDC.

3.13 LIVE PARTS

Means conductive part(s) that are intended to be energized during normal vehicle use.

3.14 PROPULSION SYSTEM

Means an assembly of electric or electro-mechanical components or circuits that propel the vehicle using the energy that is supplied by a high voltage source. This includes, but is not limited to, electric motors, inverters/converters, electronic controllers, and associated wire harnesses and connectors, and coupling systems for charging rechargeable energy storage systems.

3.15 PROTECTION DEGREE IPXXB

Means the protection provided by a barrier/enclosure that prevents contact with live parts by a test probe as defined in ISO 20653 and in Appendix C.

3.16 Maximum Working voltage

Means the highest root mean square voltage of the voltage source, which may occur across its terminals or between its terminals and any conductive parts in open circuit conditions or under normal operating conditions.

3.17 X-CAPACITORS

Refer to capacitors within the high voltage system that are connected between buses (or rails) of the circuit. .

3.18 Y-CAPACITORS

Refer to capacitors within the high voltage system that are connected between a bus (or rail) of the circuit and the electrically-conductive chassis of the vehicle.

4. TEST PROCEDURES AND CONDITIONS

NOTES:

1.) During, before, and after functional Electric, Fuel Cell and Hybrid vehicle crash testing, appropriate safety precautions must be taken to prevent injury to test personnel. Safety hazard training should be given to test personnel before testing.

2.) Where a range is specified in the test procedures, the vehicle must be capable of meeting the requirements at all points within the range.

4.1 Crash Test and Post-Crash Static Rollover Procedures

Electric, Fuel Cell and Hybrid vehicles shall meet the performance criteria specified in 5 when tested to the following crash test and post-crash static rollover procedures:

4.1.1 Frontal Barrier Impact

The vehicle is travelling longitudinally forward at any speed, up to and including 48 km/h, and impacts a fixed collision barrier that is perpendicular to the line of travel of the vehicle, or at any angle up to 30 degrees in either direction from the perpendicular to the line of travel of the vehicle.

4.1.2 Side Moving Deformable Barrier Impact

The vehicle is impacted from the side by a barrier that conforms to 49 CFR Part 587 that is moving at any speed up to and including 54 km/h, with the appropriate 49 CFR Part 572 test dummies as specified in 49 CFR Part 571.214.

4.1.3 Rear Moving Barrier Impact

The vehicle is impacted from the rear by a barrier that conforms to paragraph S7.3(b) of 49 CFR Part 571.301 that is moving at any speed up to and including 80 km/h, with the test dummies as specified in paragraph S6.2 of 49 CFR Part 571.301.

4.1.4 Post-Crash Static Rollover

After each of the crash tests described in 4.1.1, 4.1.2 and 4.1.3 above, the vehicle is statically rolled on a fixture according to the procedure specified in paragraph S7.4 of 49 CFR Part 571.301.

4.2 Test Conditions

The following test conditions apply to the crash tests and post-crash static rollover procedures in 4.1.

4.2.1 Propulsion System

Prior to any specified crash test, the energy storage/conversion system is connected to the vehicle's propulsion system, and the vehicle ignition is in the "on" (propulsion system energized) position. The switch or device that provides power from the high voltage system to the propulsion motor(s) is in the activated (ready-to-drive) position. Bypass any devices or systems that do not allow the propulsion system to be energized at the time of impact when the ignition is on and the vehicle is in neutral.

It shall be permissible to perform the test with all or parts of the electrical power train not being energized insofar as there is no negative influence on the test result. See 5.3.

4.2.2 State-of-Charge

An electric-energy storage device shall be at the state-of-charge specified in paragraph (a), (b), or (c), as applicable:

a) At the maximum state-of-charge in accordance with the vehicle manufacturer's recommended charging procedures, as stated in the vehicle's owner's manual or on a label that is permanently affixed to the vehicle; or

b) If the manufacturer has made no recommendation for charging procedures in the owner's manual or on a label that is permanently affixed to the vehicle, then at a state-of-charge of not less than 95 percent of the maximum capacity of the electric energy storage device; or

c) If the electric energy storage device is rechargeable only by an energy source on the vehicle, then at any state-of-charge within the normal operating voltage range defined by the vehicle manufacturer.

4.2.3 Parking Brake

The parking brake is disengaged for the crash tests of 4.1.1, 4.1.2 and 4.1.3. For the static rollover test of 4.1.4, the parking brake is set.

4.2.4 Transmission

The transmission, if any, is in the neutral position.

4.2.5 Tire Inflation

Tires are inflated according to the manufacturer's specifications.

4.2.6 Vehicle Loading

A passenger car is loaded to its unloaded vehicle weight plus its rated cargo and luggage capacity weight, secured in the luggage area, plus the necessary test dummies specified in 4.1, restrained only by means that are installed in the vehicle for protection at its seating position. A multipurpose passenger vehicle, truck, or bus with a gross vehicle weight rating of 4536 kilograms or less is loaded to its unloaded vehicle weight plus the necessary test dummies specified in 4.1, plus 136 kilograms or its rated cargo and luggage capacity weight, whichever is less. Each dummy is restrained only by means that are installed in the vehicle for protection at its seating position.

4.2.7 Environmental Conditions

The environmental conditions are those specified in the applicable FMVSS crash test procedures.

4.2.8 Voltage confirmation

The voltage(s) is/are measured as shown in Figure A1.1 and the high voltage source voltage(s) (Vb) is/are recorded. Before any vehicle impact test, Vb shall be under the voltage condition(s) defined in 4.2.2.

5. REQUIREMENTS

5.1 Electrolyte Spillage

When tested to any one of the crash tests and subsequent rollover procedure specified in 4.1, the vehicle shall be inspected for electrolyte spillage. Battery, fuel cell and other coolant is not considered electrolyte. When necessary, a colorant, chemical analysis, or other means may be used to distinguish between electrolyte and non-electrolyte spillage. Verification of electrolyte may be determined by visual inspection, litmus paper testing, and/or chemical analysis.

In the period from impact until 30 minutes after impact, no electrolyte from the RESS shall spill into the passenger compartment and no more than 5 liters from the RESS shall spill outside the passenger compartment.

5.2 Component Retention

When tested to any one of the crash tests and the subsequent vehicle rollover procedure specified in 4.1, components shall be retained as follows:

a) Electric energy storage/conversion devices shall remain attached to the vehicle by at least one component anchorage, bracket, or any structure that transfers loads from the device to the vehicle structure, and

b) Electric energy storage/conversion devices located outside the occupant compartment shall not enter the occupant compartment.

5.3 Electrical Safety

After each specified crash test, each high voltage source in the vehicle shall meet one or more of the following voltage, isolation, energy, or electrical protection barrier criteria. The chosen criterion for providing post-crash electrical safety shall be satisfied continuously from 10 seconds after initial impact of the crash test, during a 30-minute period after crash, and throughout the post-crash rollover test.

The manufacturer can choose the methodology (e.g., testing, simulation, or engineering analysis) to demonstrate that this requirement is met. The test may be performed, for example, with an alternative to the hydrogen fuel or with these high voltage sources(s) that are not energized for the crash test as long as the manufacturer can demonstrate compliance.

NOTES:

1) The above 10 second requirement is also being considered at fuel cell and electric vehicle GTR and ISO TC/SC21 meetings, and there is a possibility that the requirement will be revised in the future to harmonize with international regulations and standards.

2) Rationale for electrical protection barrier requirements are provided in Appendix C.

3) Rationale for the 0.2J energy requirement used in 5.3.2 and 5.3.3 is provided in Appendix D. The analysis based on DC systems but also applies to AC traction systems that are energized but not producing power such as post-crash vehicles that are not moving.

5.3.1 Voltage

The voltages Vb, V1 and V2 (see figure A1.1) shall be equal to or less than 30 VAC or 60 VDC within time period specified in 5.3. See Appendix A for the voltage measurement procedure.

5.3.2 Electrical Isolation

The electrical isolation requirements between each high voltage bus and the electrically-conductive chassis after each specified crash test are defined in 5.3.2.1 and 5.3.2.2 depending on the type of electrical system that is being evaluated. See Appendix A and B for electrical isolation measurement and calculation procedures.

Electrical isolation is not applicable and Sections 5.3.2.1 through 5.3.2.2 shall not be used if more than a single potential of a part of a conductively connected high voltage circuit is not protected under the conditions of protection IPXXB unless the voltage difference between those unprotected live parts is less than 30VAC or 60VDC or the potential energy between them is less than 0.2J.

5.3.2.1 High Voltage Buses within DC Systems

The electrical isolation resistance between each high voltage bus and the electrically-conductive chassis shall be greater than or equal to 100 ohms/volt.

The total circuit Y-capacitance energy shall be less than 0.2J within the time period specified in 5.3 per 5.3.3.2. Alternatively, the system shall be protected by electrical protection barrier(s) meeting Items 1 and 2 in 5.3.4.

5.3.2.2 High Voltage Buses within AC systems

The high voltage AC buses shall meet one of the following requirements:

1. The electrical isolation resistance between each bus and the electrically-conductive chassis shall be greater than or equal to 500 ohms/volt.

2. The electrical isolation resistance between each bus and the electrically-conductive chassis shall be greater than or equal to 100 ohms/volt and the AC portion of the system shall be protected by electrical protection barrier(s) meeting Items 1 and 2 in 5.3.4.

The total circuit Y-capacitance energy shall be less than 0.2J within the time period specified in 5.3 per 5.3.3.2. Alternatively, the system shall be protected by electrical protection barrier(s) meeting Items 1 and 2 in 5.3.4.

NOTE: Meeting only Items 1 and 2 in 5.3.4 is necessary for the electrical protection barrier as Item 3 is already met (exceeded) by the above isolation resistance requirements.

5.3.3 Energy

The electrical energy stored in the X-capacitors and Y-capacitors shall be less than 0.2 Joules within the time period specified in 5.3. The electric energy stored is calculated as follows:

$TEx+TEy<0.2$ Joules where TEx and TEy are defined in 5.3.3.1 and 5.3.3.2, respectively.

The amount of energy of 0.2 Joules criterion prevents exposure to hazardous body current. See Appendix B for the calculation procedures, and Appendix D for the rationale.

5.3.3.1 Electrical energy in X-capacitors (TEx)

The energy stored in X-capacitors (TEx) is calculated by the voltage Vb and the capacitance of the X-capacitors (Cx) according to formula (a) or (b) in Appendix B.1.

5.3.3.2 Electrical energy in Y-capacitors (TEy)

The energy stored in Y-capacitors (TEy) is calculated by the voltages V1 and V2 and the capacitance of the Y-capacitors (Cy) according to formulas (c) or (d) in Appendix B.2.

5.3.4 Electrical Protection Barrier

Protection against electric shock shall be demonstrated by meeting either Items 1, 2, and 3 or Items 1 and 4 of the following requirements:

1. Access to live parts is prevented by protection degree IPXXB. See Appendix C.1 for the applicable test procedure.

2. The resistance between exposed conductive parts of the electrical protection barrier(s) and the electrically-conductive chassis is less than 0.1 ohms when there is a current flow of at least 0.2 amperes. This requirement is deemed satisfied if the galvanic connection has been made by welding, and the weld is intact after each of the specified crash tests. See Appendix C.2.1 for the applicable test procedure.

3. The resistance between the circuit and exposed conductive parts of the electrical protection barrier shall be ≥ 0.01 ohms/VDC or 0.05 ohms/VAC. This requirement is deemed satisfied if the system meets isolation requirements in 5.3.2. See C.2.2 for the applicable test procedure for other situations.

4. The voltages between the electrical protection barrier and other exposed conductive parts (that are not protected by IPXXB) shall be equal to or less than 30 VAC or 60 VDC within the time period specified in 5.3. See C.2.3 for the applicable test procedure.

NOTES:

1) Other alternative measures (such as activation of fuses or automatic disconnection of high voltage bus, for example) may be used if they limit body current sufficiently to prevent electric shock per 5.3.1 or 5.3.3.

2) See Appendix C for rationale for the above electrical protection barrier requirements. Further changes are also being considered at fuel cell and electric vehicle GTR and ISO TC/SC21 meetings, and there is a possibility that the requirement will be revised in the future to harmonize with international regulations and standards.

6. NOTES

6.1 Marginal Indicia

A change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

PREPARED BY THE SAE FUEL CELL STANDARDS SAFETY WORKING GROUP
OF THE SAE FUEL CELL STANDARDS COMMITTEE

APPENDIX A - MEASUREMENT OF VOLTAGE AND ELECTRICAL ISOLATION RESISTANCE

Appendix A describes test procedures that may be used to determine voltage and electrical isolation resistance of an Electric, Fuel Cell, and Hybrid vehicle high voltage source.

Measurement of voltage, electrical isolation resistance, or energy shall be conducted for each high voltage source. According to the circuit structure analysis, measurement of some of the high voltage sources may be skipped.

For a high voltage source that has an automatic disconnect that is physically contained within the high voltage source enclosure complying with 5.3.4, measurements after the crash test are made from the side of the automatic disconnect connected to the electric power train or to the rest of the electric power train if the high voltage source is a component contained in the power train.

For a high voltage source that has an automatic disconnect that is not physically contained within the high voltage source enclosure, measurements after the crash test are made from both the high voltage source side of the automatic disconnect and from the side of the automatic disconnect connected to the electric power train or to the rest of the electric power train if the high voltage source is a component contained in the power train.

The voltmeter used in this test shall measure DC values and have an internal resistance of at least 10 million ohms.

A.1 VOLTAGE

For the purpose of determining the voltage level of the high voltage source as specified in 5.3.1, voltages Vb, V1 and V2 are measured as shown in Figure A1.1. The voltage measurements shall be made not later than 10 seconds after the initial impact.

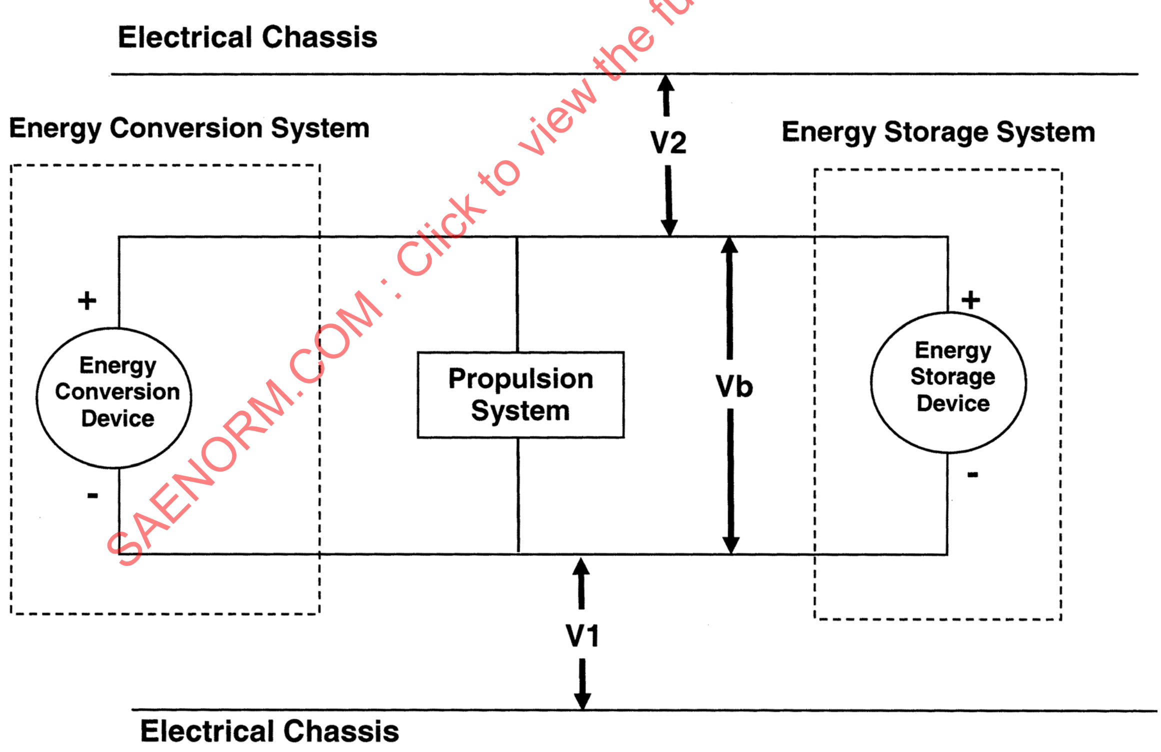


FIGURE A1.1

A.2 ELECTRICAL ISOLATION RESISTANCE – USING VOLTAGE MEASUREMENTS

The high voltage bus shall be energized by the vehicle's own RESS or energy conversion system or other voltage sources and this voltage level shall be in the range of the working voltage during normal operation as specified by the vehicle manufacturer.

If the RESS or energy conversion system or other voltage sources are automatically disconnected from the high voltage circuit during crash test, an external voltage source(s) may be connected to the circuit for the isolation resistance measurement. The external voltage source shall provide at least the same voltage level as the RESS or energy conversion system or other voltage sources.

The following procedure may be used to determine electrical isolation as specified in 5.3.2.

Measure voltages Vb, V1 and V2 as shown in Figure A1.1.

If V1 is greater than or equal to V2, insert a known resistance (Ro) between the negative side of the high voltage source and the electrically-conductive chassis. With the Ro installed, measure the voltage V1' as shown in Figure A2.1 between the negative side of the high voltage source and the electrically-conductive chassis. Calculate the electrical isolation resistance (Ri) according to the formula shown. Either divide Ri (in ohms) by the maximum working voltage of the high voltage source (in volts) to obtain the electrical isolation (in ohms/volt) or use the following formula to remove the influence of the resistance of voltmeter:

$$Ri = R0 * Vb * (1/V1'-1/V1).$$

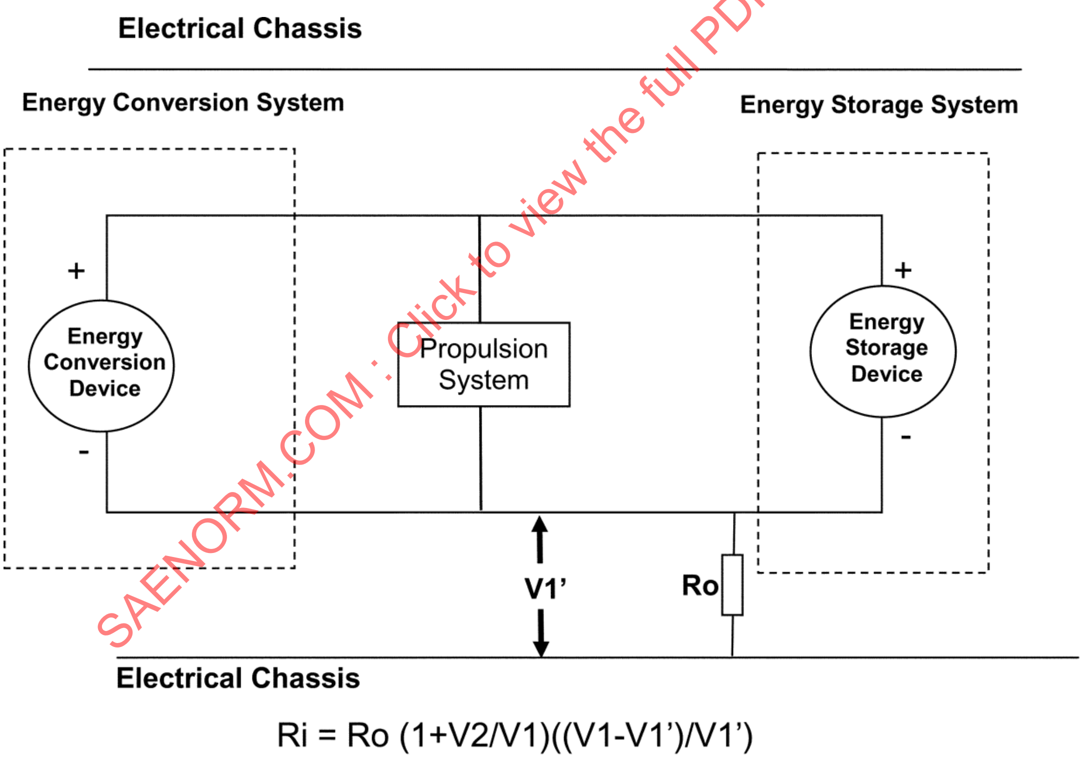
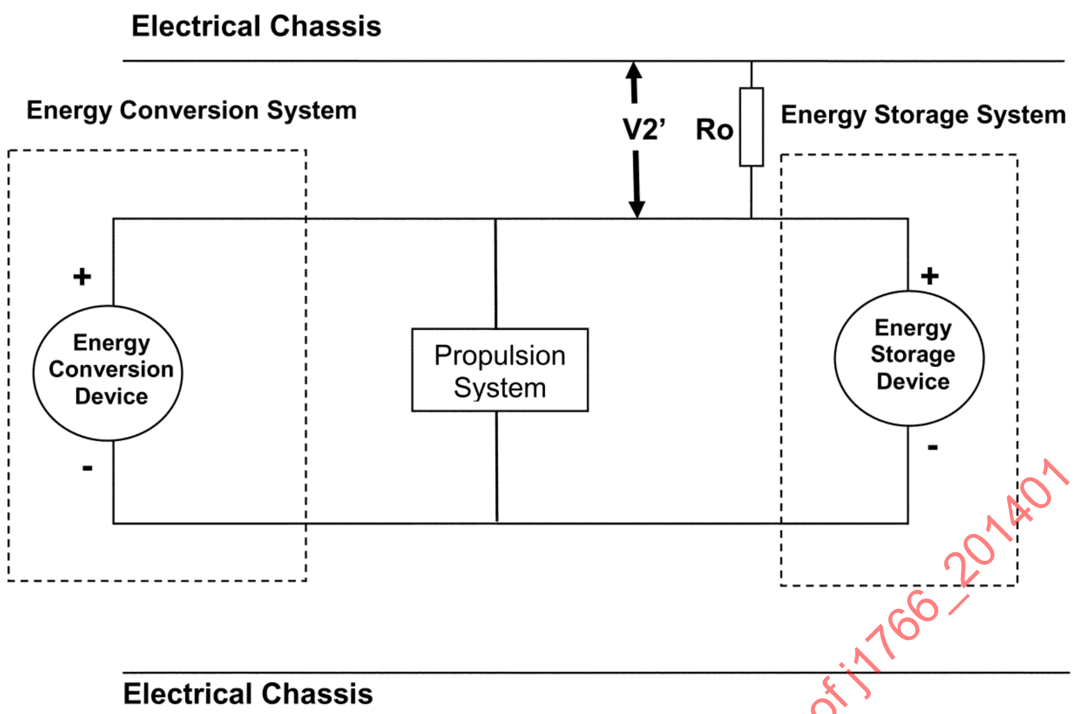


FIGURE A2.1

If V2 is greater than V1, insert a known resistance (Ro) between the positive side of the high voltage source and the electrically-conductive chassis. With the Ro installed, measure the voltage (V2') as shown in Figure A2.2 between the positive side of the high voltage source and the electrically-conductive chassis. Calculate the electrical isolation resistance (Ri) according to the formula shown. Divide Ri (in ohms) by the maximum working voltage of the high voltage source (in volts) to obtain the electrical isolation (in ohms/volt) or use the following formula to remove the influence of the resistance of voltmeter:

$$Ri = R0 * Vb * (1/V1'-1/V1).$$



$$Ri = Ro\ (1+V1/V2)((V2-V2')/V2')$$

FIGURE A2.2

NOTE 1: The standard known resistance Ro (in ohms) should be approximately the value of the minimum required isolation resistance (Ω /V) multiplied by the maximum working voltage of the vehicle plus/minus 20 per cent. Ro is not required to be precisely this value since the equations are valid for any Ro; however, an Ro value in this range should provide good resolution for the voltage measurements.

A.3 ELECTRICAL ISOLATION RESISTANCE – USING A MEGOHMMETER

The electrical isolation measurement procedure described in the preceding section (A.2) requires the presence of voltage on the high voltage bus in order for the equations used to determine electrical isolation to be valid. (In the absence of voltage, the equations call for division by zero, which is not valid.) In addition, the voltage-measurement procedure may not be appropriate for AC high-voltage sources.

An alternative to the voltage-measurement procedure is to use a megohmmeter to determine electrical isolation. The megohmmeter provides a test voltage, rather than relying on voltage already present on the bus, to determine electrical isolation. Specifically, one lead from the megohmmeter is attached to the electrically-conductive chassis, while the other lead is attached to one of the rails of the high-voltage source being evaluated. The voltage applied by the megohmmeter should be equal to or greater than the maximum working voltage of the high-voltage bus being evaluated.

With the voltage applied, the megohmmeter will generally display isolation resistance, but may instead display current flow. If current flow is displayed, the total electrical isolation resistance (in ohms) between the electrically-conductive chassis and the rail is equal to the applied test voltage (in volts) divided by the indicated current flow (in amperes). The rail's isolation resistance is then divided by the maximum working voltage of the high voltage source to obtain the electrical isolation (in ohms/volt) for that rail. This process is repeated for the other rail(s) on the bus to determine the electrical isolation for each rail. The lowest isolation resistance level of all the bus rails shall be used for the evaluation.

NOTES:

1) The safety against electric shock is evaluated by the resistance value using voltage measurement method. The resistance measured by meg-ohmmeter is equal to or lower than that using voltage measurement method. Therefore, the resistance measured by meg-ohmmeter also can be used for the evaluation as it produces a conservative result.

2) The current limit of meg-ohmmeter should be considered. The applied test voltage may be adjusted and decreased automatically due to the current limit. In this situation, the meg-ohmmeter may not deliver the required voltage.

3) Isolation measurement using a constant-voltage supply and an ammeter is also available. The isolation resistance is calculated with the applied voltage divided by the measured current flow.

APPENDIX B- CALCULATION OF ELECTRICAL ENERGY

This Appendix describes how to determine electrical energy in X and Y-capacitors. The energy values acquired with these methods in Appendix B are used for the electrical safety evaluation in 5.3.3.

B.1 ENERGY CALCULATION FOR X-CAPACITORS

Measure the voltage Vb on the high voltage bus after any of the specified crash tests as shown in Figure A1.1. Record the Vb voltage no later than 10 seconds after the vehicle comes to rest following the crash test. The energy stored in X-capacitors (TEx) on the high voltage bus is calculated according to the formula (a) with substituting the measured Vb and the capacitance of X-capacitors (Cx).

$$TEx = 0.5 \times Cx \times Vb^2 \quad (a)$$

Alternatively, the calculation of *TEx* may be conducted according to the formula (b) with using Vbe, the maximum working voltage of Vb.

$$TEx = 0.5 \times Cx \times Vbe^2 \quad (b)$$

B.2 ENERGY CALCULATION FOR Y-CAPACITORS

Measure the voltages V1 and V2 on the high voltage bus after any of the specified crash tests as shown in Figure A.1.1. Record these V1 and V2 voltage levels not later than 10 seconds after the vehicle comes to rest following the crash test. The energy stored in Y-capacitors (TEy) on the high voltage bus is calculated according to the formula (c) with substituting the measured V1, V2, and the capacitances of Y-capacitors (Cy).

$$TEy = 0.5 \times Cy \times (V1^2 + V2^2) \quad (c)$$

Alternatively, the calculation of TEy may be conducted according to the formula (d) with using Vbe, the maximum working voltage of Vb.

$$TEy = 0.5 \times Cy \times Vbe^2 \quad (d)$$

NOTE: This TEy represents the maximum possible energy value that can be stored in Y-capacitors.

APPENDIX C - EVALUATION OF ELECTRICAL PROTECTION BARRIER

C.1 PROTECTION AGAINST DIRECT CONTACT

This Appendix describes a method to evaluate if electrical protection barriers provide post-crash protection from direct contact from high voltage.

Following any of the specified crash tests, the hood, trunk and occupant-entry doors of the vehicle shall be opened using tools, if necessary. In addition, any electrical protection barriers surrounding high voltage components shall be, without the use of tools, opened, disassembled or removed. All remaining surrounding parts that cannot be opened, disassembled or removed without the use of tools are considered to be part of the physical protection.

The jointed test finger described in ISO 20653 is inserted into any gaps or openings in the electrical protection barrier(s) with a test force of 10 Newtons ± 10%. If partial or full penetration of the test finger into the electrical protection barrier occurs, the test finger is maneuvered inside the barrier as follows: Starting from the straight position, both joints of the test finger shall be rotated progressively through an angle of up to 90 degrees with respect to the axis of the adjoining section of the finger and shall be placed in every possible position.

The protection against direct contact specified in 5.3.4 is met if the jointed test finger is unable to contact high voltage live parts during the above procedure. A mirror or fiberscope may be used in order to inspect whether or not the test finger contacts live parts. Alternatively, a low-voltage supply (of not less than 40 V and not more than 50 V) in series with a suitable lamp may be connected between the jointed test finger and the live parts inside the electrical protection barrier. In this case, the acceptance criterion is that the lamp not illuminate when the test finger is maneuvered inside the electrical protection barrier as described in the preceding paragraph.

C.2 PROTECTION AGAINST INDIRECT CONTACT

The purpose of these requirements are to ensure that a person who touches two electrical protection barriers or an electrical protection barrier and the electrically-conductive chassis does not experience electric shock due to contact of the high voltage bus(es) with the barrier.

The first step in providing such protection (assuming the circuit remains live) is to ensure that the electrical protection barriers are adequately bonded to the electrically-conductive chassis. The bonding requirement of less than or equal to 0.1 ohms between the barrier and electrically-conductive chassis is based on common industrial practice. The test procedures to confirm the adequacy of these bonds is provided in C.2.1.

The second step is to ensure that the resistance due to contact, if any, of the bus(es) with electrical protection barriers is sufficiently large compared to the bonding resistance such that maximum possible body current is 10ma DC or 2ma AC. The minimum allowable resistance of buses can be calculated based on the maximum allowable voltage levels of buses (1500 VDC and 1000VAC) using the circuit diagram shown in Figure C1 and assuming that the body current for someone touching two different protective enclosures is 10 maDC or 2 maAC.

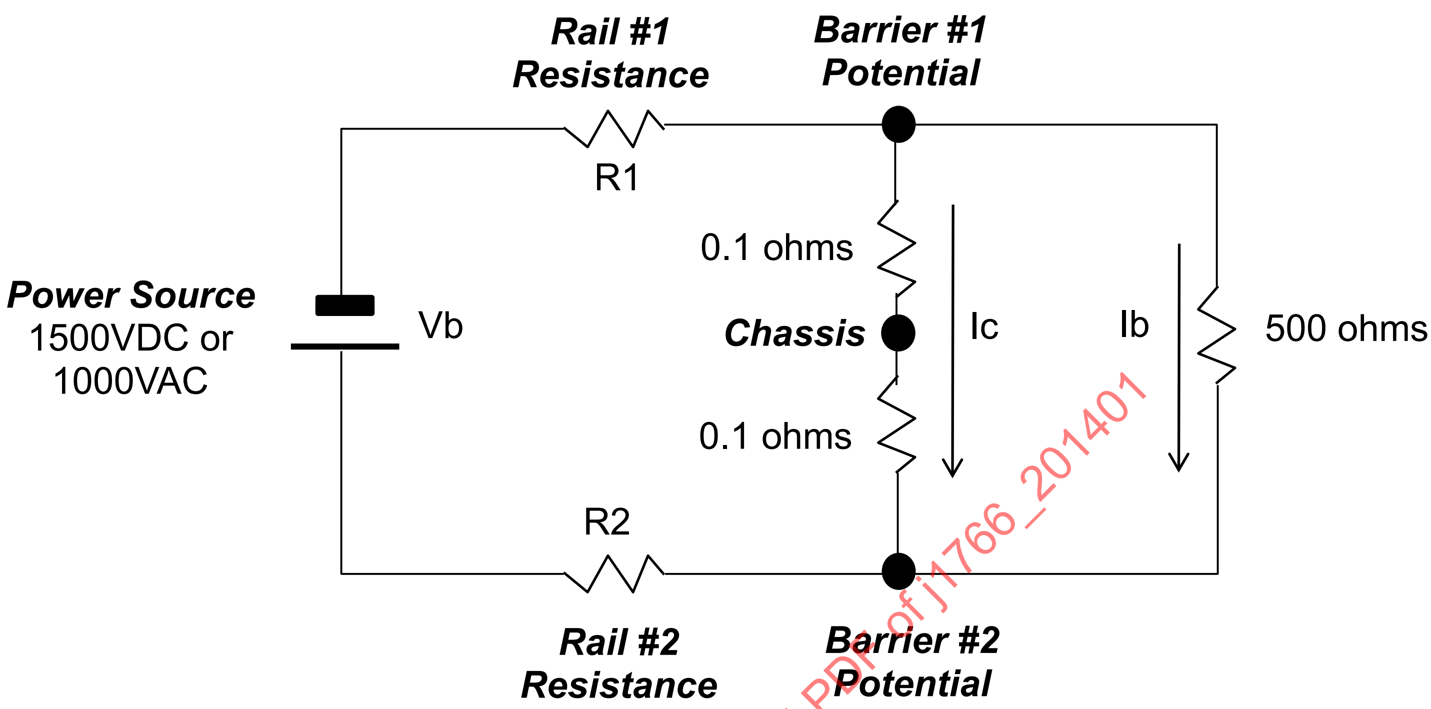


FIGURE C1 - ELECTRICAL DIAGRAM FOR CALCULATING MINIMUM ALLOWABLE RESISTANCE

The resultant minimum allowable resistance for the circuit (that is, the combined resistance of all buses in the circuit) is 0.01 ohms/VDC or 0.05 ohms/VAC for DC and AC circuits, respectively. The resistance for the circuit can be determined by the test procedure in C.2.2.

As an alternative to measuring, it is possible to simply measure the voltage difference between the electrical protection barrier and the electric conductive chassis. The resultant voltage of the above analysis is approximately 1 volt. Since this voltage difference is well less than levels necessary to create a shock hazard, the voltage levels used in 5.3.1 are imposed as the criteria for consistency with the criteria used for live parts.

C.2.1 Verification of Electrical Protection Barrier Bonding to the Electrically-conductive Chassis

The bonding between exposed conductive parts of the electric protection barrier(s) and the electrically-conductive chassis shall be tested with a test current of a minimum 0.2A, which shall be passed through the potential current path between exposed conductive parts and the vehicle electrically-conductive chassis for at least 5 seconds (unless sufficient accuracy can be obtained in less time). These exposed conductive parts shall include high voltage component housings.

C.2.2 Verification of High Voltage Bus Resistance to the Electrically-conductive Chassis

The resistance of the circuit is determined by measuring the resistance of the circuit (including all conductively-connected bus(es) in the circuit) to the electrically-conductive chassis. The measurement may be performed by any means that provides sufficient accuracy for the post-crash situation that exists.

NOTE: A resistance meter may be an appropriate instrument if it covers the resistance value of the system after crash. If the resistance value is sufficiently high, meg-ohmmeter measurement in A.3 may be usable.

If the resultant resistance is ≥ 0.01 ohms/VDC or 0.05 ohms/VAC, the requirement has been met.