Safety of Electric Vehicle Supply Equipment (EVSE)

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Plug-In Vehicles are Here, More are Coming

- 2010 - 10 major auto manufacturers with 10 production models
- 2012 - over 20 production models available
- Industry Consensus - 3 Million Plug-in Cars in use by 2015 worldwide
What is an EV (Electric Vehicle)?

- According to NFPA70 (2008 NEC): “An automotive-type vehicle for on-road use, such as passenger automobiles, buses, trucks, vans, neighborhood electric vehicles, and the like, primarily powered by an electric motor that draws current from a rechargeable storage battery, fuel cell, photovoltaic array, or other source of electric current.”

According to UL 2594: (EV) – “An over-the-road automotive type vehicle for highway use, such as a passenger automobile, bus, truck, van, or similar vehicle, which receives primary or supplementary power from an electric motor that draws current from a rechargeable storage battery. This term is used to cover electric vehicles, hybrid electric vehicles, and plug-in hybrid electric vehicles.”

Tesla
What isn’t an EV:

- According to the 2008 NEC:
- For the purpose of this article, electric motorcycles and similar type vehicles and off-road, self-propelled electric vehicles, such as industrial trucks, hoists, lifts, transports, golf carts, airline ground support equipment, tractors, boats, and the like, are not included.

- Note that the UL definition did not exclude motorcycles and specifically did include PHEV (plug in hybrid electric vehicles) and hybrids.
What is EVSE?

- UL 2594 does not define EVSE but refers to the NEC (Article 625.2):
- Electric Vehicle Supply Equipment: The conductors, including the ungrounded, grounded, and equipment grounding conductors and the electric vehicle connectors, attachment plugs, and all other fittings, devices, power outlets, or apparatus installed specifically for the purpose of delivering energy from the premises wiring to the electric vehicle.

- Personnel Protection System: A system of personnel protection devices and constructional features that when used together provide protection against electric shock of personnel.
- EVSE can include standard socket 120 V 5-15 or 5-20 R
What Is Not EVSE:

- Automotive Battery chargers
- Forklift chargers
- Golf Cart Chargers
Examples of EV connectors

- Mennekes
- SCAME
- NEMA 5-20 or 5-15R
- J1772 (USA)
- Schuko
IEC Standards Uncertainty as to which countries will follow these standards

- IEC 61851-1 • Electric Vehicle Conductive Charging Systems
- IEC 61008 • Residual Current Operated Circuit Breakers without Overcurrent Protection
- IEC 61009 • Residual Current Operated Circuit Breakers with Overcurrent Protection (RCD similar to GFCI or CCID)
- IEC 60309-1 • Industrial Connectors
- IEC 62196-1 • Plugs, socket-outlets, vehicle couplers and vehicle inlets – Conductive charging of electric vehicles

Other standards in other countries?
Applicable US Safety Standards

- UL 2202 - Electric Vehicle Battery Chargers
- UL Subject 2594 - Electric Vehicle Supply Equipment
- UL 2251 - Electric Vehicle Connectors
- UL 2231-1, -2 - Standard for Personnel Protection Systems in EV Charging
- UL 62 - Flexible Cords and Cable (Including EV Cable)
- UL 50E - Electrical Enclosures, Environmental Considerations
- UL 991 - Safety Controls Employing Solid State Devices (if used)
- UL 1998 - Software in Programmable Components (if used)
- NFPA 70 - National Electrical Code Article 625, EV Charging Systems
UL EV Charging and EVSE Standards

- UL 2202 Electric Vehicle (EV) Charging System Equipment
  - Scope:
  - Input rating: up to 600 V
  - Inductive or conductive
  - On board or off board charging equipment
  - Off board equipment for indoor or outdoor
  - Ventilation may be required
  - Covers equipment providing current directly to battery packs.

- UL 2594 Outline of Investigation of Electric Vehicle Supply Equipment
  - Scope:
  - Input rating: max 250 V
  - Conductive
  - On board chargers only
  - Indoor or Outdoor
  - Only for use where ventilation not required
  - Does not cover equipment providing current directly to battery packs.
  - Includes indoor and outdoor, portable or permanent EV cordsets
  - Includes charging stations, movable and portable, indoor or outdoor
The remainder of this presentation will focus on US Requirements Found in UL 2594 and related US standards
But what about standards based charging?

- What is SAE J1772?
- What is in J1772?
- Why is J1772 Important?

- Society of Automotive Engineers, J1772: Recommended Practice Electric Vehicle and Plug In Hybrid Electric Vehicle Conductive Charge Coupler
- J1772 defines the following (and more):
  - Levels of charging
  - EV Plug and Connector configuration
  - Control Pilot (The basics of control and data)
- Virtually all new electric vehicles sold in the US will have the same receptacle and be able to connect to any EVSE equipment regardless of vendor
Levels of Charging

- Level 1 AC (max 1.9 kW)

- Level 2 AC (max 19.2 kW)

- Level 3 DC (Hundreds of kW)

- Power sourced from commonly available NEMA 5-15 or 5-20 R receptacles. Vehicles must be able to accept 120 V AC. No pilot signal.

- Power sourced from 208-240 V AC single phase, up to 80 A. Pilot signal required.

- Under development. Fast charging, DC directly to battery packs, per NEC up to 600 V input. Output could potentially be up to 600 V, and >100 A. Pilot signal required.
EVSE and the J1772 ‘Pilot’ signal

In order to have a single protocol that can service many different vehicles a ‘pilot’ signal is defined in J1772. It performs the following functions:

- Verifies presence and connection of a vehicle
- Authorizes charger to energize contacts
- Allows the charging equipment to specify the available current (Amps) to the vehicle
- Continuously verifies presence of protective earth connection
- Establishes requirement for ventilation

This is accomplished through simple voltage ‘states’ and a variable duty cycle PWM signal.

Note that ‘ground monitoring’ and energization of contacts specified in J1772 are not relied upon for safety

The vehicle obeys the Pilot’s signal

(photo credit www.wired.com)
J1772 States (simplified, see J1772 for details)

<table>
<thead>
<tr>
<th>State</th>
<th>Description</th>
<th>Duty Cycle</th>
<th>Current available</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>12 V dc  Vehicle not detected</td>
<td>10% to 85%</td>
<td>% duty cycle X 0.6=Amps</td>
</tr>
<tr>
<td>B</td>
<td>9 V dc   Vehicle connected, not ready for charging</td>
<td>85% to 96%</td>
<td>% duty cycle -64X2.5=Amps</td>
</tr>
<tr>
<td>C</td>
<td>6 V dc   Vehicle connected and ready for charging</td>
<td>Examples:</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>3 V dc   Vehicle connected, ready for charge, and requires indoor ventilation</td>
<td>20%</td>
<td>12 A</td>
</tr>
<tr>
<td>E</td>
<td>0 V      EVSE does not have power or has malfunctioned</td>
<td>30%</td>
<td>18 A</td>
</tr>
<tr>
<td>F</td>
<td>-12 V dc EVSE not available or other EVSE problem</td>
<td>50%</td>
<td>30 A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>90%</td>
<td>65A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>96%</td>
<td>80A</td>
</tr>
</tbody>
</table>

Examples:
Subject UL 2594

- Covers EV cordsets and charging stations.
- Covers the basic safety hazards—fire, shock, mechanical, etc. in similar form to many other standards.
- Requires outdoor rated enclosure per UL 50E
- Requires EV connectors meet UL 2251
- Requires EV cables to comply with UL 62
- Requires CCID (Charging Circuit Interrupt Detection) per UL 2231-1 and UL 2231-2
- UL 2231-2 requires CCID circuits employing semiconductor devices for safety critical functions to meet UL 991
- UL 2231-2 requires CCID devices employing software to perform safety critical functions to comply with UL 1998
## Defined types of EVSE per UL 2594

<table>
<thead>
<tr>
<th>Type of product (Per UL Classification)</th>
<th>Installation</th>
<th>Connection, Input</th>
<th>Connection, Output</th>
<th>Environment</th>
<th>Minimum enclosure rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Movable charging station (5.7)</td>
<td>Intended to be moved from place to place</td>
<td>Cord and plug (6.2.1)</td>
<td>Non-locking NEMA receptacle, EV receptacle, or EV Connector (and cable)</td>
<td>Indoor Only or Indoor/outdoor</td>
<td>Indoors (7.7.3) only: 1.2.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Outdoors (7.7.4)</td>
</tr>
<tr>
<td>Permanent charging station (5.8)</td>
<td>Fixed in place, tools required to remove. Not intended to be routinely moved</td>
<td>Permanently wired (6.2.1)</td>
<td>Non-locking NEMA receptacle, EV receptacle, or EV Connector (and cable)</td>
<td>Indoor Only or Indoor/outdoor</td>
<td>Indoors (7.7.3) only: 1.2.5</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>Outdoors (7.7.4)</td>
</tr>
<tr>
<td>EV Cordset, Portable (5.10) (intended to be carried in vehicle)</td>
<td>Not mounted</td>
<td>Cord and plug (6.1.1)</td>
<td>EV Cable and EV connector</td>
<td>Indoor/outdoor</td>
<td>Outdoors (7.7.4)</td>
</tr>
<tr>
<td>EV Cordset, Stationary (5.11)</td>
<td>Fixed, but may be removed without the use of a tool</td>
<td>Cord and plug (6.1.1)</td>
<td>EV Cable and EV connector</td>
<td>Indoor only or indoor/outdoor</td>
<td>Indoors (7.7.3) only: 1.2.5</td>
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<td>Outdoors (7.7.4)</td>
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</table>
UL 2231-1: Standard for Personnel Protection Systems for EV Supply Circuits:

General Requirements

- **CCID**: Charging Circuit Interrupting Device is a device that continuously monitors the current differential between all current carrying conductors in a grounded system and opens the circuit if the differential current exceeds a threshold.

- **Ground Monitor/Interrupter**: Device that monitors grounding continuity in a charging circuit, opening in the event of a loss of ground, or not closing in the absence of ground.

- **Isolation Monitor/Interrupter**: Device that monitors insulation resistance between ground and isolated circuit and interrupts circuit if resistance drops below a threshold value.

- **CCID required for all grounded EVSE**: CCID5 or CCID20 with reliable ground

- **Ground Monitor/Interruptor required for all cord connected EVSE**

- **Isolation Monitor/Interrupter required for Class II (no protective earth) EVSE.**

- **Note**: The above is very simplified, see standard for full details.

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UL 2231-2

- Specifies test requirements for CCID
- Requirements similar to and based on GFCI requirements found in UL 943
- Two classes of CCID: 5mA (CCID5) and 20 mA (CCID20)
- Allows automatic retry in the event the circuit detects a ground fault
- Circuit may retry up to 4 times as long as the circuit does not close into an existing fault and provides a delay of at least 15 minutes between retries
- Automatic retry only allowed with automatic supervisory circuit
- Automatic or manual self testing
- Self test must test interrupting contacts
- Self test current ≤150% of nominal rated trip current

- CCID 5: 5mA +/- 1 mA *
- CCID 20: 20 mA +0/-5 mA *
- Trip curve (time): $T = \frac{(20/I)^{1.43}}{I}$ *
- I current in mA, T time in seconds
- Second Neutral Ground protection required for level 1 charging

* values given for 60Hz, min required trip time 20 ms
UL 2231-2 Environmental/Immunity Requirements

- Capacitor Switching Transient Test
- Surge per ANSI/IEEE 4, 1.2 x 50μs 6kV
- CCID tested under various conditions from -35°C (cold start up) to 66°C
- Shock and Vibration test (units intended to be carried in vehicle only)

- Unit shall operate normally following the test.
- Unit shall function as intended (both protection and charging) during exposure.
- Harmonic Distortion EN60204-1
- ESD per IEC 61000-4-2, 8kV contact, 15 kV air
- Radiated Immunity 61000-4-3, 20 V/m 80 MHz to 1 GHz
- Conducted immunity per 61000-4-6, 20 Vrms from 150KHz to 80 MHz
- EFT per 61000-4-4, Level 3, 2 kV
- Voltage dips and interrupts, 61000-4-11, 100% dip 10 ms, 60% dip 200 ms, 30% dip 1 s
- Magnetic Field Immunity 61000-4-8, 30A/m at 60Hz
• Power interruption must result in RA state
• For software with user interface, minimum 2 inputs required to leave RA state
• Analysis required for code, peer review by individuals other than those who wrote the software
• Detailed software testing and documentation of the results required
• Introduction of faults into the hardware, i.e., shorting, opening, grounding, or tying to Vcc any pin of any semiconductor device must result in RA state (UL 991)

UL 1998: Software in Programmable Components

- Documentation of software development process very important
- Standard sets requirements for:
  - Software Design—specific details such as variables being set to initial values before being used, software ends up in an RA (risk addressed) state in the event of a failure
  - Critical and Supervisory Sections of software: partitioning, recovery from memory usage error and addressing conflicts, fail safe procedure, protection of instructions and data, etc.
  - Mitigation of ‘microelectronic’ hardware failure modes: failure of CPU registers, execution, program counter, interrupt handling, clock, memory and memory addressing, data paths, etc.

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UL 1998: Documentation Package

- Software plan describing software development process and activities
- Risk analysis approach and results
- Configuration management plan
- Programmable system architecture
- Programmable component and software requirements specification
- Software design documentation
- Analysis and test documentation
- Documentation of any off the shelf (OTS) software including how it is used, provider, version, interface specification, documentation of any bugs and how they could affect the application, etc.
- Software changes and document control
- Identification of software version
UL 991: Tests for Safety-Related Controls employing Solid-State Devices

- This is a test standard and its requirements are called out from other end-product standards (UL 2231-2)
- Immunity tests not 'harmonized' with UL 2231-2
- FMEA to determine critical components
- 4 methods: Demonstrated, Computational, Electrical supervision, derating per military handbook 338 with additional considerations
- No loss of protective function or controlled shutdown resulting in RA state
- Tests for critical components:
  - Overvoltage and Undervoltage
  - Dips and interrupts
  - Transient Overvoltage
  - Voltage Variation
- Tests for critical components (continued)
  - Immunity tests: control shall perform its intended function or shut down without loss of protective function.
  - EFT
  - Radiated Immunity 25 MHz to 1GHz, level per end product standard
  - Keying interference
  - ESD
  - Thermal cycling
  - Shipping and Storage
  - Humidity Test
  - Vibration Test
  - Jarring Test
  - Power cycling

See standard for full details
Committees

• TC 69: IEC 61851 EV charging standard committee
• NEC: Article 625 Code Task Force
• evrTG: electric vehicle resource task group (CSA and Canada)
• SAE J1772 committee
End

- Questions?

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