EV Safety (Standard Regulation)
Whole Vehicle Safety Testing
Vehicle Electrical Safety

1. Why E-Mobility?
2. Overview of HV system
3. Electrical Safety Requirements
4. UNECE R100 Part I
5. UNECE R100 Part II, R12/R94, R95
Why E-Mobility?

- Eco-Driving
- Power Constant Range
- High Effective
- High Comfort Performance
- Energy Recoverable

Electric Energy ➔ Mechanical Energy

Presentation TÜV Rheinland 6/13/2019
Vehicle Electrical Safety

1. Why E-Mobility?
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5. UNECE R100 Part II, R12/R94, R95
System overview BEV, PHEV

LV Net Work
- CANBUS
- Current Sensor
- Voltage Sensor
- IR Sensor
- Temp. Sensor
- Crash Sensor
- Lamps...
- Pumps...

HV Components
- Vehicle Inlet
- REESS
- INVERTOR
- MOTER
- OBC
- PDU
- DC/DC
- PTC
- EACP...

HV system

HV system BEV, PHEV
- HV battery
- DC/DC converter HV/LV
- Ei. A/C compressor
- Ei. heater
- Inverter
- El. machine
- Power distribution box
- DC HV circuit
- On-board charger
- AC power supply circuit
- AC vehicle inlet
- DC connection box
- External DC power supply
- External AC power supply, low-voltage supply network

LV powernet
- HV cables

LV Network
- Current Sensor
- Voltage Sensor
- IR Sensor
- Temp. Sensor
- Crash Sensor
- Lamps...
- Pumps...
Circuit Diagram
Layout of High Voltage Parts

- Engine
- FR Power Drive Unit
- Electric A/C compressor
- Generator
- FR transaxle
- Vehicle chassis
- Service plug
- Battery pack
- Electric heater system
- FR motor
- RR motor
- 1500W inverter
- DC/DC converter & On board charger unit
- Junction box
- Vehicle Inlet
- RR MCU (motor control unit)
- 100V RR Outlet
- 100V FL Outlet
- 100V

Live Parts
Conductive Parts
Country Specific

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Vehicle Electrical Safety

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Example - Equipotential Bonding

- Equipotential Bonding
  - Indirect Protection
    - Electric Shock (On Vehicle)
    - Electric Shock (Charging)
  - LV PowerNet Failure
    - Current monitoring
    - Tem. Monitoring
    - VCU Function
    - ...

- Failed
- Failed
- Failed
- Accident
Regulation Requirements

The resistance between all exposed conductive parts and the electrical chassis shall be lower than 0.1 ohm when there is current flow of at least 0.2 A. It is more than a test to verify this.
Example - Equipotential Bonding

**Purpose**
2. Corresponding requirement for the vehicle system, a value for the electrical resistance of the equipotential bonding is required.

**Object**
All conductive covers or housings belonging to any HV components.

**Functions**
The requirements for the electrical resistance of the equipotential bonding shall be maintained until the end of the specified service life (EOL) of the HV component / vehicle.

**Requirements**
1. Low electrical resistance
2. Minimum cross-sectional areas
3. Fastening reliability
4. Electrochemical potential
Example - Equipotential Bonding
1. The HV component and the vehicle body shall be less than 40 mOhm;

2. The HV component and an adjacent conductive part is less than 20 mOhm;

3. Between two HV components which are simultaneously accessible for a person and are arranged in a distance up to 2.5 m in the vehicle shall be less than 100 mOhm;
Minimum cross-sectional areas

To ensure the EB conductor can withstand the current when overcurrent protection device of the HV battery in the event of short-circuit.

Means for equipotential bonding made of copper shall have a minimum cross-sectional area in accordance with Table:

<table>
<thead>
<tr>
<th>Cross-section of HV cable S mm²</th>
<th>Minimum cross-section of equipotential bonding means, conductor or ground strap S mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>S &lt; 4</td>
<td>4</td>
</tr>
<tr>
<td>4 ≤ S ≤ 16</td>
<td>S</td>
</tr>
<tr>
<td>16 &lt; S ≤ 35</td>
<td>16</td>
</tr>
<tr>
<td>S &gt; 35</td>
<td>0.5 x S</td>
</tr>
</tbody>
</table>

The specifications apply to copper.
Fastening Reliability

Fasteners in accordance with VDI 2862, specification of tightening torque;

Tapping screws shall not be used for the electrical connection of the equipotential bonding;

A screw shall be turned into a metal plate, a metal nut or a metal insert at least four complete turns deep;

To prevent work loose

Metal drawing technology, the thickness of the metal part shall not be lower at the joint than three turns of the screw thread.

Thread cutting screws are not permissible for the connection of the equipotential bonding.
Fastening Reliability

Coating

The coating of the contact point shall be **prevented** by appropriate measures.

The coating of the contact point shall subsequently be **removed** by means of a mounting process or process step.

Example - Equipotential Bonding
**Example - Equipotential Bonding**

**Electrochemical Potential**

The electrochemical potential of the material combination shall not exceed 0.6 V.

It is recommended to have the anode area 3 times larger than the cathode area.

**IEC 60950**

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**Equipotential Bonding Presentation TÜV Rheinland**

6/13/2019
There are much more to consider

Electrical Safety Requirements

- Direct Protective
  - MARKING
  - HV INTERLOCK
  - PROTECTION AGAINST DIRECT CONTACT
  - DELAYED ACCESS TO LIVE PART
  - HV CONTACTING AND REVERSE POLARITY PROTECTION

- Indirect Protective
  - EQUIPOTENTIAL BONDING
  - ISOLATION RESISTANCE
  - BEHAVIOR IN THE EVENT OF A CRASH

- System Detection
  - OVER CURRENT PROTECTION
  - FAILURE OF LV SUPPLY VOLTAGE
  - MEASURING THE HV VOLTAGE

- Insulation Protective
  - POTENTIAL SEPARATION OF HV & LV
  - CLEARANCES
  - CREEPAGE DISTANCES
  - SOLID INSULATING MATERIALS
  - WITHSTAND VOLTAGE

- Other:
  - RESIDUAL VOLTAGE
  - ACTIVE DISCHARGE
  - PASSIVE DISCHARGE

Presentation TÜV Rheinland

6/13/2019
Additional requirements for individual HV components

- Isolation monitoring
  - Detection of open HV cables
- Inverters
- HV battery
- Pre-charge
  - Overcurrent protection HV battery
  - Service disconnect function
- Switching equipment HV battery
### Additional requirements for connection to an external electric power supply

<table>
<thead>
<tr>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protective conductor (PE)</td>
</tr>
<tr>
<td>Protective conductor current</td>
</tr>
<tr>
<td>On-Board Charger</td>
</tr>
<tr>
<td>AC power supply wiring harness</td>
</tr>
<tr>
<td>Connection to a DC power supply</td>
</tr>
<tr>
<td>Overcurrent protection</td>
</tr>
<tr>
<td>Touch current</td>
</tr>
<tr>
<td>Requirements for the vehicle inlet</td>
</tr>
<tr>
<td>DC power supply wiring harness</td>
</tr>
<tr>
<td>Locking of the DC vehicle connector</td>
</tr>
</tbody>
</table>
Vehicle Electrical Safety

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UN Regulation 100

Uniform provisions concerning the approval of vehicles with regard to specific requirements for the electric power train

**Part I:**
Requirements of a vehicle with regard to its electrical safety

Safety requirements with respect to the electric power train of road vehicles of **categories M and N**, with a maximum design speed exceeding 25 km/h, equipped with one or more traction motor(s) operated by electric power and not permanently connected to the grid, as well as their high voltage components and systems which are galvanically connected to the high voltage bus of the electric power train.

**Part II:**
Requirements of a Rechargeable Energy Storage System (REESS) with regard to its safety
UNECE R100.02 Part I – Protection against Electrical Shock

Protection against direct contact

Protection against indirect contact

Resistance < 0.1Ω

Galvanically connected

Isolation resistance

Combined DC-AC bus

Separated DC-AC bus

Marking

IPXXD

IPXXB

Protection against indirect contact

Protection against indirect contact

Galvanically connected

Isolation resistance

Combined DC-AC bus

Separated DC-AC bus

Marking

IPXXD

IPXXB
UNECE R100.02 Part I – Protection against direct contact

Direct contact

High voltage
Live part

Should not be able to contact

Both inside and outside of passenger compartment

Z=1000 Ω
## UNECE R100.02 Part I – Protection against direct contact

### Access probe

<table>
<thead>
<tr>
<th></th>
<th>IP degree</th>
<th>Test equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><strong>IPXXD</strong></td>
<td><img src="image1.png" alt="Image of IPXXD" /></td>
</tr>
<tr>
<td></td>
<td>Diameter: 1mm, Length: 100mm (IEC 60529)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>・Live part inside passenger compartment and luggage compartment (R100)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td><strong>IPXXB</strong></td>
<td><img src="image2.png" alt="Image of IPXXB" /></td>
</tr>
<tr>
<td></td>
<td>Diameter: 12mm, Length: 80mm (IEC 60529)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>・Live part other than passenger compartment and luggage compartment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>・Live part inside passenger compartment and luggage compartment after crash</td>
<td></td>
</tr>
<tr>
<td></td>
<td>・Exposed conductive parts</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Barrier, Solid insulation, enclosure</td>
<td>Not removed without tool.</td>
</tr>
</tbody>
</table>
### UNECE R100.02 Part I – Protection against direct contact

#### Electrical safety: Connector

<table>
<thead>
<tr>
<th>Items</th>
<th>Requirements.</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>they comply with 5.1.1.1. and 5.1.1.2. when separated without the use of tools, or</td>
<td>Safety lock</td>
</tr>
<tr>
<td>(b)</td>
<td>they are located underneath the floor and are provided with a locking mechanism, or</td>
<td></td>
</tr>
<tr>
<td>(c)</td>
<td>they are provided with a locking mechanism and other components shall be removed with the use of tools in order to separate the connector, or</td>
<td></td>
</tr>
<tr>
<td>(d)</td>
<td>the voltage of the live parts becomes equal or below DC 60V or equal or below AC 30V (rms) within 1 second after the connector is separated.</td>
<td></td>
</tr>
<tr>
<td>Items</td>
<td>Requirements.</td>
<td>Interpretation</td>
</tr>
<tr>
<td>-------</td>
<td>---------------</td>
<td>----------------</td>
</tr>
<tr>
<td>1</td>
<td>For a service disconnect which can be opened, disassembled or removed without tools,</td>
<td>[Image of a service disconnect]</td>
</tr>
<tr>
<td>2</td>
<td>it is acceptable if protection degree IPXXB is satisfied under a condition where it is opened, disassembled or removed without tools.</td>
<td>[URL: <a href="http://www.te.com/ja/industries/hybrid-electric-mobility-solutions/service-disconnect.html">http://www.te.com/ja/industries/hybrid-electric-mobility-solutions/service-disconnect.html</a>]</td>
</tr>
</tbody>
</table>
Marking

The symbol shown in Figure 1 shall appear on or near the RESS. The symbol background shall be yellow, the bordering and the arrow shall be black.

The symbol shall also be visible on enclosures and barriers, which, when removed expose live parts of high voltage circuits. This provision is optional to any connector for high voltage buses. This provision shall not apply to any of the following cases:

(a) where barriers or enclosures cannot be physically accessed, opened, or removed; unless other vehicle components are removed with the use of tools

(b) where barriers or enclosures are located underneath the vehicle floor.

Cables for high voltage buses which are not located within enclosures shall be identified by having an outer covering with the colour orange.
UNECE R100.02 Part I – Protection against indirect contact

Exposed conductive parts (conductive cover)

Resistance value should be lower than 0.1Ω when there is at least 0.2A current flow (no need to measure if welded)

Electrical chassis
UNECE R100.02 Part I – Insulation resistance

**Insulation resistance**

**Step 1 to 3**
Measure $V_b, V_1, V_2$

**Step 4**
( in case $V_1 \geq V_2$ )

**Isolation resistance $R_i$ is**

$$R_i = R_0 \times V_b \times \left( \frac{1}{V_1} - \frac{1}{V_2} \right)$$

**Step 5**
If AC and DC buses are galvanically isolated from each other, isolation resistance shall be MIN. 500Ω/V for AC and MIN. 100Ω/V for DC buses of working voltage.

If AC and DC buses are galvanically connected, isolation resistance shall be MIN. 500Ω/V of working voltage.

NOT use internal power supply: Measure by ohmmeter

Use internal power supply: Measure as below procedure
Hazards when working with electric current

Hazards and effects

- Irritant effect on nerves, muscles and heart
- Decomposition of the body fluids, and hence poisoning symptoms, muscular paralysis, cardiac arrhythmia and ventricular fibrillation
- Internal and external burns

Indicative values for amperage and exposure time

- Harmless amperage in all areas < 0.5 mA
- Limit of perceptibility and hazard limit above approx. 3 mA
  - Let-go current approx. 6 mA
  - Respiratory muscle spasms above 20 mA
  - Ventricular fibrillation above approx. 50 mA
- Absolute life-threatening danger above approx. 500 mA
Hazards when working with electric current – effects on human body

Thermal effect
- Internal and external burns
- Protein coagulation (above 42° C)
- Bursting blood cells

Chemical effect
- Destruction of cells

Electrical trauma
Many people survive electrical trauma only to find a host of injuries including loss of consciousness, seizures, aphasia, visual disturbances, headaches, tinnitus, paresis, and memory disturbances.

Even without visible burns, electric shock survivors may be faced with long-term muscular pain and discomfort, fatigue, headache, problems with peripheral nerve conduction and sensation, inadequate balance and coordination, among other symptoms.

Electrical injury can lead to problems with neurocognitive function, affecting speed of mental processing, attention, concentration, and memory.
Hazards of electric current

Exposure time [ms]  10000  5000  2000  1000  500  200  100  50  20  10
0.1 0.2 0.5 1  2  5 10 20 50 100 200 500 1000 mA 5000

Tripping characteristic of residual current circuit breaker

Limit of perceptibility  Let-go current  Fibrillation threshold

Fatal electric shock probable

Current [mA] through the human body

Range  Body reactions
1  No effects on the body
2  No hazardous effect
3  Risk of ventricular fibrillation
4  Ventricular fibrillation possible

Presentation TÜV Rheinland 6/13/2019
# Comparison to engineering rules - Protection against Electrical Shock

## Indirect Contact - Isolation Resistance

<table>
<thead>
<tr>
<th>Standard / Regulation</th>
<th>min. Resistance</th>
<th>Measurement voltage</th>
</tr>
</thead>
</table>
| ECE R 100.02          | DC-HV-Buses: 100 Ohm/V  
                       | AC-HV-Buses: 500 Ohm/V | At least half of the voltage in powertrain |
| ISO 23273             | 100 Ohm/V       | Max. voltage in powertrain at least 500V |
| ISO 6469              | Class I: 1000 Ohm/V  
                       | Class II: 5000 Ohm/V | 1.5 times the maximum voltage in the power train at least 500V |
Vehicle Electrical Safety

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5. UNECE R100 Part II, R12/R94, R95
### UNECE R100.02 Part II
- Rechargeable Energy Storage System (REESS) safety requirement

<table>
<thead>
<tr>
<th>Clause</th>
<th>Test Item</th>
<th>Test Procedure</th>
<th>Acceptance Criteria (no evidence of...)</th>
<th>Test Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.2</td>
<td>Vibration</td>
<td>Annex 8A</td>
<td>Electrolyte leakage, rupture, fire, explosion, insulation decrease</td>
<td>REESS or REESS sub-system</td>
</tr>
<tr>
<td>6.3</td>
<td>Thermal Shock &amp; Cycling</td>
<td>Annex 8B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.4.1.1</td>
<td>Mechanical Shock</td>
<td>ECE R12 or ECE R94 and ECE R95</td>
<td>Electrolyte leakage, fire, explosion, mounting damage, REESS components outside of REESS boundaries, insulation decrease</td>
<td>Vehicle Based Test</td>
</tr>
<tr>
<td>6.4.1.2</td>
<td></td>
<td>Annex 8C</td>
<td></td>
<td>REESS or REESS sub-system</td>
</tr>
<tr>
<td>6.4.2.1.1</td>
<td>Mechanical Integrity, only for M1 &amp; N1</td>
<td>Vehicle based dynamic test ECE R12 or ECE R94 and ECE R95</td>
<td>Electrolyte leakage, fire, explosion, insulation decrease</td>
<td>Vehicle Based Test</td>
</tr>
<tr>
<td>6.4.2.1.2</td>
<td></td>
<td>Annex 8D, crush force replaced by contact force of ECE</td>
<td></td>
<td>REESS or REESS sub-system</td>
</tr>
<tr>
<td>6.4.2.2</td>
<td></td>
<td>Annex 8D</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.5</td>
<td></td>
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<td>6.6</td>
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<td>6.7</td>
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<td>6.8</td>
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<tr>
<td>6.9</td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

R100 does not cover post crash safety requirement
UNECE R12/R94, R95

R12 Steering mechanism: Annex 7
R94 Frontal collision protection: Annex 11
R95 Lateral collision protection: Annex 9

Post crash safety requirement against electrical shock

One of four criteria to be met

- Absence of High voltage
- Low electrical energy
- Physical protection
- Isolation resistance
- Electrolyte spillage
Absence of high voltage

- Detect impact and disconnect
- Capacitance remains
- Detect impact and close

Voltage shall be equal or less than 30V AC or 60V DC not earlier than 5 sec. and not later than 60 sec. after impact

Voltage remains

“Absence of high voltage“ only applicable to load side from disconnect device

UNECE R12/R94, R95 – Protection against electrical shock after crash
**UNECE R12/R94, R95 – Protection against electrical shock after crash**

### Low electrical energy

- **Detect impact and disconnect**
- **Detect impact and close**
- **Close after impact not earlier than 5 sec and before 60 sec.**

**Cx, Cy1, Cy2: Specify by manufacturer**

**Battery pack**

**Automatic disconnect device**

**Service plug**

**Measure Vb and Ie b/w 5 sec and 60 sec.**

**Low electrical energy**

- High voltage remains
- “Absence of high voltage“ only applicable to load side from disconnect device

### Equations

\[ TE = \int_0^t V_b \times I_c \, dt \quad \text{or} \]
\[ TE = \frac{1}{2} \times C_x \times 10^{-6} \times (V_b^2 - 3600) \]

\[ TE_{y1} = \frac{1}{2} \times C_{y1} \times 10^{-6} \times (V_1^2 - 3600) \]

\[ TE_{y2} = \frac{1}{2} \times C_{y2} \times 10^{-6} \times (V_2^2 - 3600) \]

**Less than 2.0 Joules**

**Less than 2.0 Joules**
UNECE R12/R94, R95 – Protection against electrical shock after crash

**Physical protection**

**Direct contact**
- High voltage
- Live part
- IPXXB

**Should not be able to contact**
- Both inside and outside of passenger compartment

**Indirect contact**
- Exposed conductive parts (conductive cover)
- Electrical chassis

**Resistance value should be lower than 0.1Ω when there is at least 0.2A current flow (no need to measure if welded)**
UNECE R12/R94, R95 – Protection against electrical shock after crash

**Insulation resistance**

**NOT use internal power supply:** Measure by ohmmeter

**Use internal power supply:** Measure as below procedure

**Step 1 to 3**
Measure $V_b, V_1, V_2$

**Step 4**
( in case $V_1 \geq V_2$ )

**Isolation resistance $R_i$ is**

$$R_i = R_0 \times V_b \times \left( \frac{1}{V_1} - \frac{1}{V_2} \right)$$

**Step 5**

If AC and DC buses are galvanically isolated from each other, isolation resistance shall be MIN. 500Ω/V for AC and MIN. 100Ω/V for DC buses of working voltage.

If AC and DC buses are galvanically connected, isolation resistance shall be MIN. 500Ω/V of working voltage.

**Power system**

- $V_b$
- $V_1$
- $V_2$
- $R_0$

**Ohm meter:** Hioki 3453

R0: 100Ω resistance per 1V of working voltage

**6/13/2019**

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### Electrolyte spillage

#### During 30 mins after impact
- **Inside passenger compartment:** No spill of electrolyte
- **Outside passenger compartment:**
  - Except open type traction battery: No more than 7%
  - Open type traction battery: No more than 7% With MAX. 5.0 litters

### REESS retention

#### REESS location and status
- **Inside passenger compartment:** Shall remain in installed location
- **Outside passenger compartment:** No part shall enter passenger compartment
Thank you for your attention!

Kazushi Arima

General Manager
Deputy Head of Technical Service, North East Asia
Mobility

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