LV 123
UNDERSTAND TEST REQUIREMENTS AND IMPLEMENT THEM EFFORTLESSLY. ELECTRICAL NORMATIVE BASICS AND PRACTICAL CHALLENGES FOR VEHICLE COMPONENTS AND SYSTEMS
/ Electrical requirements and tests of LV 123

Electrical Characteristics and Electrical Safety of High-Voltage Components in Road Vehicles

/ Terms and definitions
/ Electrical requirements and tests of HV components

/ Definition:
LV123 is a harmonized document of test requirements of all German OEMs:
Audi, BMW, Daimler, Porsche and VW

/ Advantages:
/ Systematic approach and transparent definition of test parameter
/ Possibility of interchanging qualification results
/ Comparability of product qualifications, even across OEM borders
OVERVIEW LV 123 STANDARDS

/ LV 123
   / Electrical Characteristics and Electrical Safety of High-Voltage Components in Road Vehicles
   / Requirements and Tests

/ BMW   GS 95023   Edition: 2016-11
/ Mercedes MBN LV 123   Edition: 2014-03
/ Volkswagen VW 80303   Edition: 2014-06
The HV system of a vehicle with an electric drive system consists of several HV components.

Operating voltages
DC: 60 V - 1500 V
AC: 30 V - 1000 V (rms)
The HV operating status apply to HV components.

<table>
<thead>
<tr>
<th>HV Status</th>
<th>Description of HV – operating status</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>B0</strong></td>
<td>The HV components are <em>operational</em> and there is <em>no power demand</em>.</td>
</tr>
<tr>
<td><strong>B1</strong></td>
<td>The HV components are <em>fully operational</em>, and provide their intended performance.</td>
</tr>
<tr>
<td><strong>B2</strong></td>
<td>The HV components are still <em>fully operational</em>. The HV components provide a performance within the <em>deviations permissible</em> for operating status <em>B2</em>. When the HV components <em>revert</em> to operating status <em>B1</em>, they shall automatically provide their <em>intended performance</em>.</td>
</tr>
</tbody>
</table>
| **B3**    | The HV components are *still operational*, shall *not assume any undefined states* and, in particular, shall not cause any malfunctions in other HV components.  
- The HV components may *reduce their output* for self-protection purposes.  
- When the HV components *revert* to operating status *B1* or *B2*, they shall automatically provide their *intended performance*. |
| **B4**    | The HV components are still operational and shall not assume any undefined states.  
- The HV components may *switch off their output*.  
- When the HV components *revert* to operating status *B1*, *B2* or *B3*, they shall provide their *intended performance* by means of a *reset* or a simple intervention (e.g. change of ignition status, restart vehicle). |

Table 2: HV operating status
The HV- voltage ranges are represented with the following four voltage ranges.

<table>
<thead>
<tr>
<th>HV- voltage ranges</th>
<th>HV- operating range</th>
<th>Unit</th>
<th>HV_1</th>
<th>HV_2a</th>
<th>HV_2b</th>
<th>HV_3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overvoltage at load dump</td>
<td>B3 / B4</td>
<td>V pk</td>
<td>220</td>
<td>410</td>
<td>500</td>
<td>800</td>
</tr>
<tr>
<td>Upper HV circuit limit voltage</td>
<td>B3 / B4</td>
<td>V pk</td>
<td>220</td>
<td>410</td>
<td>500</td>
<td>800</td>
</tr>
<tr>
<td>Maximum operating voltage</td>
<td>B2</td>
<td>V d.c.</td>
<td>200</td>
<td>360</td>
<td>470</td>
<td>770</td>
</tr>
<tr>
<td>Upper limited operating capability</td>
<td>B2</td>
<td>V d.c.</td>
<td>&gt;190-200</td>
<td>&gt;340-360</td>
<td>&gt;450 -470</td>
<td>&gt;750 -770</td>
</tr>
<tr>
<td>Unlimited operating capability</td>
<td>B1</td>
<td>V d.c.</td>
<td>90 -190</td>
<td>170 -340</td>
<td>250 -450</td>
<td>520 -750</td>
</tr>
<tr>
<td>Lower limited operating capability</td>
<td>B2</td>
<td>V d.c.</td>
<td>80 -&lt;90</td>
<td>160 -&lt;170</td>
<td>200 -&lt;250</td>
<td>450 -&lt;520</td>
</tr>
<tr>
<td>Highly limited operating capability</td>
<td>B2 a / B3 b</td>
<td>V d.c.</td>
<td>60 -&lt;80</td>
<td>120 -&lt;160</td>
<td>150 -&lt;200</td>
<td>-</td>
</tr>
<tr>
<td>Undervoltage</td>
<td>B3</td>
<td>V d.c.</td>
<td>0 -&lt;60</td>
<td>0 -&lt;120</td>
<td>0 -&lt;150</td>
<td>0 -&lt;450</td>
</tr>
</tbody>
</table>

Table 3: HV voltage ranges
The change of the DC HV circuit voltage over time shall be limited to the specified maximum generated voltage dynamics (slope) for every HV component that is controlled by power electronics; see Table 4 "Dynamic parameters". The requirement shall be fulfilled for all HV operating statuses in accordance with Table "HV operating status".

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>HV_1</th>
<th>HV_2a</th>
<th>HV_2b</th>
<th>HV_3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generated voltage dynamics (slope) between two different steady-state voltage levels (holding time &gt; 2 s), robustness during operation in DC HV circuit (i.e. operating voltage without ripple)</td>
<td>V/ms</td>
<td>± 15</td>
<td>± 15</td>
<td>± 15</td>
<td></td>
</tr>
<tr>
<td>Present voltage dynamics (slope) between two different steady-state voltage levels (holding time &gt; 2 s), robustness during operation in DC HV circuit (i.e. operating voltage without ripple)</td>
<td>V/ms</td>
<td>± 20</td>
<td>± 20</td>
<td>± 20</td>
<td></td>
</tr>
<tr>
<td>Present and generated voltage ripple with HV battery switched on (at specified continuous output)</td>
<td>Vpk</td>
<td>± 8</td>
<td>± 8</td>
<td>± 8</td>
<td></td>
</tr>
<tr>
<td>Present and generated voltage ripple with HV battery switched off (at specified continuous output)</td>
<td>Vpk</td>
<td>± 15</td>
<td>± 15</td>
<td>± 15</td>
<td></td>
</tr>
</tbody>
</table>

Table 4: Dynamic parameters
HV components shall meet the HV operating status B3 or B4 in accordance with table 4 "HV operating status" in the event of overvoltage due to load dump. See OEM's requirements documentation for information on the HV operating status.

Further, HV components shall be designed for the maximum voltage dynamics in accordance with table 5 "Maximum voltage dynamics" in the event of overvoltage due to load dump.

The respective HV component shall detect the occurrence of load dump and initiate the measures for voltage limiting.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>HV - operating status</th>
<th>Unit</th>
<th>HV_1</th>
<th>HV_2a</th>
<th>HV_2b</th>
<th>HV_3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum voltage dynamics (slope), load dump</td>
<td>B3</td>
<td>V/ms</td>
<td>± 250</td>
<td>± 250</td>
<td>± 250</td>
<td></td>
</tr>
</tbody>
</table>

Table 5: Maximum voltage dynamics
10 TESTS OVERVIEW

HV System voltage range
The tests are based on the requirements for HV components with regard to their electric behavior in DC HV circuits; see Section 6 "Electrical operating ranges of the HV system".

<table>
<thead>
<tr>
<th>Test</th>
<th>Product validation</th>
<th>100% standard production test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range of unlimited operating capability</td>
<td>Xp</td>
<td>N/A</td>
</tr>
<tr>
<td>Range of upper limited operating capability</td>
<td>Xp</td>
<td>N/A</td>
</tr>
<tr>
<td>Range of lower limited operating capability</td>
<td>Xp</td>
<td>N/A</td>
</tr>
<tr>
<td>Range of highly limited operating capability</td>
<td>Xp</td>
<td>N/A</td>
</tr>
<tr>
<td>Voltage dynamics</td>
<td>Xp</td>
<td>N/A</td>
</tr>
<tr>
<td>Voltage ripple</td>
<td>Xp</td>
<td>N/A</td>
</tr>
<tr>
<td>Overvoltage</td>
<td>Xp</td>
<td>N/A</td>
</tr>
<tr>
<td>Undervoltage</td>
<td>Xp</td>
<td>N/A</td>
</tr>
<tr>
<td>Load dump and voltage limiting</td>
<td>Xp</td>
<td>Xs</td>
</tr>
<tr>
<td>Voltage offset</td>
<td>Xp</td>
<td>N/A</td>
</tr>
<tr>
<td>Interactions between LV and HV system</td>
<td>Xp</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Xp: Test scope for product validation
Xs: Test scope for 100% standard production test

Product validation
The tests apply to the operation of the HV components in HV circuits and to electrical safety for vehicles with HV systems.

100% standard production testing

Table 20: Tests regarding the voltage ranges of the HV system
### Electrical characteristics and HV safety

The tests are based on the requirements regarding electrical characteristics and electrical safety for HV components in accordance with **Section 7 “Requirements for electrical characteristics and HV safety”**.

<table>
<thead>
<tr>
<th>Test</th>
<th>Product validation</th>
<th>100% standard production test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marking</td>
<td>Xp</td>
<td>Xs</td>
</tr>
<tr>
<td>Protection against direct contact</td>
<td>Xp</td>
<td>Xs</td>
</tr>
<tr>
<td>Equivalent bending</td>
<td>Xp</td>
<td>Xs</td>
</tr>
<tr>
<td>Overcurrent protective</td>
<td>Xp</td>
<td>Xs</td>
</tr>
<tr>
<td>Potential separation of HV system and LV ponents</td>
<td>Xp</td>
<td>N/A</td>
</tr>
<tr>
<td>Isolation resistance</td>
<td>Xp</td>
<td>Xs</td>
</tr>
<tr>
<td>Insulation coordination</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• General, clearances and creepage distances, and solid insulating materials</td>
<td>Xp</td>
<td>N/A</td>
</tr>
<tr>
<td>• Withstand voltage</td>
<td>Xp</td>
<td>Xs</td>
</tr>
<tr>
<td>Residual voltage</td>
<td>Xp</td>
<td>Xs</td>
</tr>
<tr>
<td>Active discharge</td>
<td>Xp</td>
<td>Xs</td>
</tr>
<tr>
<td>Passive discharge</td>
<td>Xp</td>
<td>Xs</td>
</tr>
<tr>
<td>X capacitance</td>
<td>Xp</td>
<td>Xs</td>
</tr>
<tr>
<td>Y capacitance</td>
<td>Xp</td>
<td>Xs</td>
</tr>
<tr>
<td>Isolation bridging parts</td>
<td>Xp</td>
<td>Xs</td>
</tr>
<tr>
<td>HV contacting</td>
<td>Xp</td>
<td>Xs</td>
</tr>
<tr>
<td>HV interlock</td>
<td>Xp</td>
<td>Xs</td>
</tr>
<tr>
<td>Delayed access to live parts</td>
<td>Xp</td>
<td>Xs</td>
</tr>
<tr>
<td>Behaured in the event of a crash</td>
<td>Xp</td>
<td>Xs</td>
</tr>
<tr>
<td>Measuring the HV voltage</td>
<td>Xp</td>
<td>Xs</td>
</tr>
<tr>
<td>Failure of LV supply voltage</td>
<td>Xp</td>
<td>N/A</td>
</tr>
<tr>
<td>Electrical equivalent circuit diagrams</td>
<td>Xp</td>
<td>N/A</td>
</tr>
<tr>
<td>Installation areas and ambient conditions</td>
<td>Xp</td>
<td>N/A</td>
</tr>
<tr>
<td>Pre-assembly and mounting</td>
<td>Xp</td>
<td>N/A</td>
</tr>
<tr>
<td>Disassembly and disposal</td>
<td>Xp</td>
<td>N/A</td>
</tr>
<tr>
<td>Underhood factors for HV parts</td>
<td>Xp</td>
<td>N/A</td>
</tr>
<tr>
<td>Documentation</td>
<td>Xp</td>
<td>N/A</td>
</tr>
</tbody>
</table>

**Xp**: Test scope for product validation  
**Xs**: Test scope for 100% standard production test

Table 22: Tests regarding el. characteristics and HV safety for HV components
### Additional requirements for individual HV components

The tests are based on the requirements for HV components in accordance with Section 8 "Additional requirements for individual HV components".

<table>
<thead>
<tr>
<th>Test</th>
<th>Product validation</th>
<th>100% standard production test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isolation monitoring</td>
<td>Xp</td>
<td>Xs</td>
</tr>
<tr>
<td>Service Disconnect function</td>
<td>Xp</td>
<td>Xs</td>
</tr>
<tr>
<td>Pre-charge</td>
<td>Xp</td>
<td>Xs</td>
</tr>
<tr>
<td>Detection of open HV cables</td>
<td>Xp</td>
<td>Xs</td>
</tr>
<tr>
<td>Requirements for HV battery</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Switching equipment</td>
<td>Xp</td>
<td>Xs</td>
</tr>
<tr>
<td>• Overcurrent protection device</td>
<td>Xp</td>
<td>Xs</td>
</tr>
<tr>
<td>Requirements for DC/DC converter HV/LV</td>
<td>Xp</td>
<td>Xs</td>
</tr>
<tr>
<td>Requirements for inverters</td>
<td>Xp</td>
<td>Xs</td>
</tr>
<tr>
<td>Requirements for HV wiring harness</td>
<td>Xp</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Table 22: Tests regarding the additional requirements for HV components

### Additional requirements for connection to an external electric voltage supply

The tests are based on the additional requirements for HV components in accordance with Section in accordance with Section 9 "Additional requirements for the connection to an ext. el. Power supply".

<table>
<thead>
<tr>
<th>Test</th>
<th>Product validation</th>
<th>100% standard production test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protective conductor current and touch current</td>
<td>Xp</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Table 23: Tests regarding additional requirements for connection to an external electric power supply

Xp: Test scope for product validation
Xs: Test scope for 100% standard production test
Unless otherwise specified, the values in accordance with Table 26 ”Standard values“ shall be selected.

<table>
<thead>
<tr>
<th>Test parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room temperature</td>
<td>TRT = 23 °C ± 5 °C</td>
</tr>
<tr>
<td>Humidity</td>
<td>Frel = 25 % to 75 % RH</td>
</tr>
<tr>
<td>Ambient test temperature</td>
<td>TRT</td>
</tr>
<tr>
<td>Internal resistance HV voltage source (Ri)</td>
<td>Ri ≤ 100 mOhm</td>
</tr>
<tr>
<td>LV voltage for test</td>
<td>14 V / 28 V</td>
</tr>
</tbody>
</table>

Table 26: Standard values

The sampling rate and bandwidth and resolution of the measuring system shall be adapted for the respective test. All measured values with all maximum values (peaks) shall be recorded.
STANDARD TOLERANCES

Unless otherwise specified, the tolerances in accordance with Table "Standard tolerances" apply. Tolerances of envelopes must always be considered unilaterally as otherwise the requirement is mitigated.

**Voltage**
- up to 1000 V
  - DC to 1 kHz: ± 1.5%
  - 1 kHz to 5 kHz: ± 2.0%
  - 5 kHz to 20 kHz: ± 3.0%
  - 20 kHz and above: ± 5.0%
- 1000 V and above
  - DC to 20 kHz: ± 3.0%
  - 20 kHz and above: ± 5.0%

**Current**
- up to 5 A
  - AC to 60 Hz: ± 1.5%
  - 60 Hz to 5 kHz: ± 2.5%
  - 5 kHz to 20 kHz: ± 3.5%
  - 20 kHz and above: ± 5.0%
- 5 A and above
  - DC to 5 kHz: ± 2.5%
  - 5 kHz to 20 kHz: ± 3.5%
  - 20 kHz and above: ± 5.0%

**Power (50/60 Hz)**
- to 1 W: ± 20.0 mW
- above 1 W and to 3 kW: ± 3.0%
- above 3 kW: ± 5.0%

**Resistance**
- 1 mOhm to 100 mOhm: ± 5.0%
- 1 MOhm to 1 TOhm: ± 5.0%
- above 1 TOhm: ± 10.0%
- All others: ± 3.0%

**Temperature**
- below 100 °C: ± 2.0 °C
- 100 °C to 500 °C: ± 3.0%

**Time**
- 10 ms to 200 ms: ± 5.0%
- 200 ms to 1 s: ± 10.0 ms
- 1 s and above: ± 1.0%

**Relative Humidity**
- 30% to 95% RH: ± 6.0% RH
LV 123 does not provide detailed specifications for the test set-up for HV test components. In general it is required that the test set-up is to be documented in detail with all its components.

The standard **VW 80300** describes the same tests as **LV 123**, with further helpful hints for the test setup.
AC / DC sources with recuperation properties are suitable for testing HV components. Thus, the source is also able to absorb energy from the device under test by means of regenerative energy. For voltage levels above 500 V, it is possible to double the DC voltage with two phases. The sources are potential-free against the ground, which must be taken into account during the test setup and the measurements.
**NETWAVE 3-PHASE: NEW DATASHEET**

- Automotive testing standards added:
  LV 123, BMW GS 95023, MBN LV 123, VW 80300, VW 80303, PSA B21 7110
- Max. output power changed to 270 kVA AC
- Max. output voltages changed to 690 VAC / ±1120 VDC
- New info box about Automotive applications (p.2)
- NetWave 20.3, 30.3, 60.3 & 90.3 models added
- New Option → DC EXTENDED VOLTAGE RANGE (p.7)
- New accessories: FILTER BOX L-BOX 1-32A / 100A (p.8)
  → For MIL-STD-704 LDC : 50 μH decoupling coils with integrated 10 μF capacitor
- New Automotive options:
  - AMP 200N1.1
  - CN200N1, 100, 200, 300

**AUTOMOTIVE APPLICATIONS**

THE COMPLETE SOLUTION FOR HV COMPONENTS TESTING

With the NetWave it is possible for the first time to check HV components up to 1000 VDC according to LV 123. The additional LF amplifier AMP 200N1 uses the CN 200N to couple voltage ripples up to 450 kHz to the supply lines. With the closed loop method, the network control software measures the voltage ripple and continuously controls the amplitude.
Doubles the DC voltage range for arbitrary waveform programming

Technically this is done by using Phase 1 as +DC and Phase 2 as −DC pole

The control signal is split by a new “split PCB” which applies the analogue signal to both Phase 1 & 2 symmetrically

NW 20, 30, 60 : 425 VDC → 850 VDC
NW 20.2, 30.2, 60.2, 90.2 : 500 VDC → 1’000 VDC
NW 20.3, 30.3, 60.3, 90.3 : 560 VDC → 1’120 VDC

Existing NetWave sources can be upgraded
Upgrade requires skilled personnel (Instructions available)
NEW: NETWAVE 20.3 / 30.3 / 60.3 / 90.3

- New Top Range version of 3 PH NetWave sources
- Features extended AC voltage range from 360 VAC → $400 \text{VAC}_{L-N} / 690 \text{VAC}_{L-L}$
- Option PowerRecovery included
- Option DC Extended Voltage Range included (Opt-3 DC-EVR) → ± 1120 VDC
- Upgrades from xx.2 to xx.3 are not planned
- net.control V2.0 required

- Example: NetWave 30.3

<table>
<thead>
<tr>
<th>NETWAVE 30.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output voltage</td>
</tr>
<tr>
<td>0 V - 3*400 V AC (p-n)</td>
</tr>
<tr>
<td>0 V - 3*690 V AC (p-p)</td>
</tr>
<tr>
<td>0 V - +/- 1120 V DC</td>
</tr>
<tr>
<td>Output current (@ max. 300 V AC/360 V DC)</td>
</tr>
<tr>
<td>33 A (RMS) continuous</td>
</tr>
<tr>
<td>66 A (RMS) short-term (max. 3 s)</td>
</tr>
<tr>
<td>250 A repetitive peak</td>
</tr>
<tr>
<td>PowerRecovery 30</td>
</tr>
<tr>
<td>included</td>
</tr>
</tbody>
</table>
NEW: NETWAVE 270.3

- First sold at large customer in Germany
- Built out of three NetWave 90.3 & 3 x Parallel Mode
- 270 kVA / 324 kW
- Max nominal current: 300 A / Phase
10.4.1 TEST RANGE OF UNLIMITED OPERATING CAPABILITY

/ Requirement: see section 6.3.3.2 "Range of unlimited operating capability"
/ Test type: Product validation, 3 cycles, 3 samples
/ Test method: Measurement

For HV_1 a: 90V, b: 190V -> c= 140V
The slopes are in the ms range, tr1, tr2: 3.33ms, tf1: 6.66ms
### 10.4.2 TEST RANGE OF UPPER LIMITED OPERATION

/ Requirement: see section 6.3.3.3 "Range of upper limited operating capability"
/ Test type: Product validation, 3 cycles, 3 samples
/ Test method: Measurement

#### HV_1
- Minimum value: 200 V
- Maximum value: 770 V

#### HV_2a
- Minimum value: 195 V
- Maximum value: 460 V

#### HV_2b
- Minimum value: 190 V
- Maximum value: 450 V

#### HV_3
- Minimum value: 140 V
- Maximum value: 635 V

For HV_2 a: 170V, b: 340V -> c= 255V
d: 360V -> e= 350V
tr1: 5.66ms, tr2, tf1: 1min
10.4.3 TEST RANGE OF LOWER LIMITED OPERATING CAPABILITY

 Requirement: see section 6.3.3.4 "Range of lower limited operating capability"
 Test type: Product validation, 3 cycles, 3 samples
 Test method: Measurement

<table>
<thead>
<tr>
<th>Min. / Max. value</th>
<th>Lower limited operating capability</th>
<th>Minimum value</th>
<th>Maximum value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min. / Max. value</td>
<td>Lower limited operating capability</td>
<td>Minimum value</td>
<td>Maximum value</td>
</tr>
<tr>
<td>Min. / Max. value</td>
<td>Lower limited operating capability</td>
<td>Minimum value</td>
<td>Maximum value</td>
</tr>
</tbody>
</table>

HV_1 | HV_2a | HV_2b | HV_3 |
--- | --- | --- | --- |
190 V | 340 V | 450 V | 750 V |
140 V | 255 V | 350 V | 635 V |
90 V | 170 V | 250 V | 520 V |
85 V | 165 V | 225 V | 485 V |
80 V | 160 V | 200 V | 450 V |
10.4.4 TEST RANGE OF HIGHLY LIMITED OPERATING CAPABILITY

/ Requirement: see section 6.3.3.5 "Range of highly limited operating capability"
/ Test type: Product validation, 3 cycles, 3 samples
/ Test method: Measurement

<table>
<thead>
<tr>
<th>Min. / Max. value</th>
<th>Lower limited operating capability</th>
<th>Min. / Max. value</th>
<th>Highly limited operating capability</th>
<th>Minimum value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HV_1</td>
<td>HV_2a</td>
<td>HV_2b</td>
<td>HV_3</td>
</tr>
<tr>
<td>90 V</td>
<td>170 V</td>
<td>250 V</td>
<td>520 V</td>
<td></td>
</tr>
<tr>
<td>85 V</td>
<td>165 V</td>
<td>225 V</td>
<td>485 V</td>
<td></td>
</tr>
<tr>
<td>80 V</td>
<td>160 V</td>
<td>200 V</td>
<td>450 V</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>70 V</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>60 V</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
10.4.5 TEST VOLTAGE DYNAMICS

/ Requirement: see section 6.3.4.2 "Voltage dynamics"
/ Test type: Product validation, 10 cycles, 3 samples
/ Test method: Measurement

It shall be verified that the HV operating status of the HV component in the respective operating voltage range does not change due to generated voltage dynamics (slope).

/ Test Generated voltage dynamics
Compliance with the maximum generated/present voltage dynamics (slope) shall be verified for all operating modes.

The test pulse in accordance with Figure 19 "Test pulse generated voltage dynamics" and the specifications for voltage dynamics in Table 4 "Dynamic parameters“ shall be used.

Figure 19 Test pulse generated voltage dynamics

Generated voltage dynamics (slope) between two different steady state voltage levels (holding time > 2 s), generated by individual HV component:
Value: +/- 15 V/ms for HV_1, HV_2a/b and HV_3
10.4.5 TEST VOLTAGE DYNAMICS

/ Requirement: see section 6.3.4.2 "Voltage dynamics"
/ Test type: Product validation, 10 cycles, 3 samples
/ Test method: Measurement

Present voltage dynamics
The test shall be verified in HV operating mode B1, B2, B3
Robustness with regard to the maximum present voltage dynamics (slope) shall be verified for all HV components by means of appropriate measurements. The specifications for the voltage dynamics in Table 4 "Dynamic parameters" shall be used.

It shall be verified that the HV operating status of the HV component in the respective operating voltage range does not change due to present voltage dynamics (slope).

Generated voltage dynamics (slope) between two different steady state voltage levels (holding time > 2 s), generated by individual HV component:
Value: +/- 20 V/ms for HV_1, HV_2a/b and HV_3
10.4.6 TEST VOLTAGE RIPPLE

/ Requirement: see section 6.3.4.3 "Voltage ripple"
/ Test type: Product validation, 1 cycles, 3 samples
/ Test method: Measurement

Test generated voltage ripple

For every HV component controlled by power electronics, evidence shall be provided that the generated voltage ripple in HV system operation with and without HV battery (switching equipment HV battery switched on and off) in accordance with Table 4 "Dynamic parameters" is fulfilled.

The frequency response shall be documented by the supplier.

The test set-up shall be documented in detail, including line inductances, line capacitances, on-board electrical system equivalent capacitances and line resistances.

### Parameter
<table>
<thead>
<tr>
<th>Parameter</th>
<th>All HV voltage operating ranges HV_1, HV_2a/2b, HV_3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present and generated Voltage ripple with HV battery switched on</td>
<td>± 8 V pk</td>
</tr>
</tbody>
</table>

### HV Component

<table>
<thead>
<tr>
<th>HV Component</th>
<th>Operating mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC/ DC-converter HV/LV</td>
<td>Boost Mode / Buck Mode</td>
</tr>
<tr>
<td>Drive system power electronics</td>
<td>Engine- / Generator mode</td>
</tr>
<tr>
<td>On-board charger, HV battery</td>
<td>HV-System (ext. el. Power supply)</td>
</tr>
<tr>
<td>Other HV component, HV battery</td>
<td>Load mode</td>
</tr>
</tbody>
</table>
10.4.6 TEST VOLTAGE RIPPLE

/ Requirement: see section 6.3.4.3 “Voltage ripple”
/ Test type: Product validation, 1 cycles, 3 samples
/ Test method: Measurement

/ Test generated voltage ripple
For every HV component, robustness and stable operation shall be provided when there is a voltage ripple present during the operation of the HV system with and without an HV battery (switching equipment switched on/off) in accordance with Table 4 "Dynamic parameters". The present HV voltage $U$ without ripple is at the relevant upper limit of each HV voltage range.

Test duration: 30 min
Frequency range: 15 Hz – 20 kHz
Wobble period: 2 min
Wobble type: triangular logarithmic
Upp: 16 Vpp or 30 Vpp

<table>
<thead>
<tr>
<th>Parameter Tabelle 4</th>
<th>All HV voltage ranges HV_1, HV_2a/2b, HV_3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present and generated Voltage ripple with HV battery switched on</td>
<td>± 8 V pk</td>
</tr>
<tr>
<td>Present and generated Voltage ripple with HV battery switched off</td>
<td>± 15 V pk</td>
</tr>
</tbody>
</table>

The test setup for superposed voltage ripple requires a dc supply and an additional LF amplifier and a coupling device for superpose the voltage ripple to the dc power lines.
The standard VW 80300 requires for high frequency test a separate test setup with a shielded box for the measurement, decoupling and ripple transformer.
10.4.7 TEST OVERVOLTAGE

/ Requirement: see section 6.3.5.1 “Overvoltage"
/ Test type: Product validation, Cycles to be determined from the specified number of overvoltage events, 3 samples
/ Test method: Measurement

It shall be verified that the required HV operating status for the range of unlimited operating capability is reestablished if the DC HV voltage exceeds the max. operating voltage and then falls again below the maximum operating voltage.

For the HV battery the voltage increase for the test pulse overvoltage shall be effected with the max. slope 20V/ms in accordance with Table 4 "Dynamic parameters" up to the time when the switching equipment switches off. Then, i.e. with the switching equipment switched on, the voltage increase and decrease shall be performed with the maximum voltage dynamics with 250V/ms in accordance to Table 5 "Maximum voltage dynamics".
10.4.8 TEST UNDERVOLTAGE

/ Requirement: see section 6.3.5.2 “Undervoltage“
/ Test type: Product validation, 2 cycles, 3 samples
/ Test method: Measurement

Compliance with the HV operating status B3 shall be verified.

The test shall be used to verify that the maximum intended performance or the HV operating status B1 and B2 is complied with again when the DC HV voltage falls within the range of unlimited operating capability again after a deviating characteristic.
10.4.9 LOAD DUMP AND VOLTAGE LIMITING

/ Requirement: see section section 6.3.5.3 “Load dump and voltage limiting"
/ Test type: product validation, 2 cycles, 3 samples
/ Test method: Measurement

/ a) Product validation
The test for the required behavior of an HV component during present overvoltage during load dump is covered by the “Overvoltage” test. No separate test is required. The test for control measures for voltage limitation during load dump shall be carried out for the HV components by the OEM.
The effectiveness of the voltage limiting function shall be verified for operation at maximum load and subsequent load dump.
An appropriate test procedure shall be documented by the supplier and agreed upon with the OEM.

/ b) 100 % standard production test
The control measures for voltage limiting during load dump shall be verified within the scope of functional tests. This test may be performed within the scope of the agreed functional test.
An appropriate test procedure shall be specified by the supplier and agreed upon with the OEM.
10.4.10 TEST VOLTAGE OFFSET

/ Requirement: see section 6.3.8 “Voltage offset“
/ Test type: product validation, 2 cycles, 3 samples
/ Test method: Measurement

/ Test step 1a:
A test voltage U with the value of the upper voltage of the unlimited operating capability shall be applied between the positive DC HV potential of the HV component and the electrical ground of the test setup for a period of at least 600 s.
The negative DC HV potential of the HV component shall be connected with the electrical ground of the test setup.

/ Test step 1b:
A test voltage U with the value of the upper HV circuit limit voltage shall be applied between the positive DC HV potential of the HV component and the electrical ground of the test setup for a period of at least 10 s or a period agreed between the supplier and the OEM.
The negative DC HV potential of the HV component shall be connected with the electrical ground of the test setup.
10.5 Testing for electrical characteristics and HV safety

10.5.1 Test: Marking
10.5.2 Test: Protection against direct contact
10.5.3 Test: Equipotential bonding
10.5.4 Test: Overcurrent protection
10.5.5 Test: Potential separation of HV system and LV powernet
10.5.6 Test: Isolation resistance
10.5.7 Test: Insulation coordination
10.5.7.1 Test: General, clearances and creepage distances and solid insulating materials
10.5.7.2 Test: Withstand voltage
10.5.8 Test: Residual voltage
10.5.9 Test: Active discharge
10.5.10 Test: Passive discharge
10.5.11 Test: X capacitors
10.5.12 Test: Y capacitors
10.5.13 Test: Isolation-bridging parts
10.5.14 Test: HV contacting
10.5.15 Test: HV interlock
10.5.16 Test: Delayed access to live parts
10.5.17 Test: Behavior in the event of a crash
10.5.18 Test: Measuring the HV voltage
10.5.19 Test: Failure of LV supply voltage
10.5.20 Test: Electrical equivalent circuit diagrams
10.5.21 Test: Installation areas and ambient conditions
10.5.22 Test: Pre-assembly and mounting
10.5.23 Test: Disassembly and disposal
10.5.24 Test: Underload factors for HV parts
10.5.25 Test: Documentation
10.5.26 Test sequence plan

10.6 Testing for additional requirements for individual HV components

10.6.1 Test: Isolation monitoring
10.6.2 Test: Service disconnect function
10.6.3 Test: Pre-charge circuit
10.6.4 Test: Detection of open HV cables
10.6.5 Test: Additional requirements for HV battery
10.6.5.1 Test: Switching equipment HV battery
10.6.5.2 Test: Overcurrent protection HV battery
10.6.6 Test: Additional requirements for DC/DC converter HV/LV
10.6.7 Test: Additional requirements for inverters
10.6.8 Test: Additional requirements for HV wiring harness

10.7 Tests regarding additional requirements for connection to an external electrical power supply

10.7.1 Test: Protective conductor current and touch current
MANY THANKS FOR YOUR ATTENTION

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