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AMETEK®
COMPLIANCE TEST SOLUTIONS

LV 123

UNDERSTAND TEST REQUIREMENTS AND IMPLEMENT THEM EFFORTLESSLY. ELECTRICAL NORMATIVE BASICS AND PRACTICAL CHALLENGES FOR VEHICLE COMPONENTS AND SYSTEMS

FRANK NIECHCIAL

06.06.2017

THE WORLD'S SPEED IS OUR BEAT

CONTENTS

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 componnets

- **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



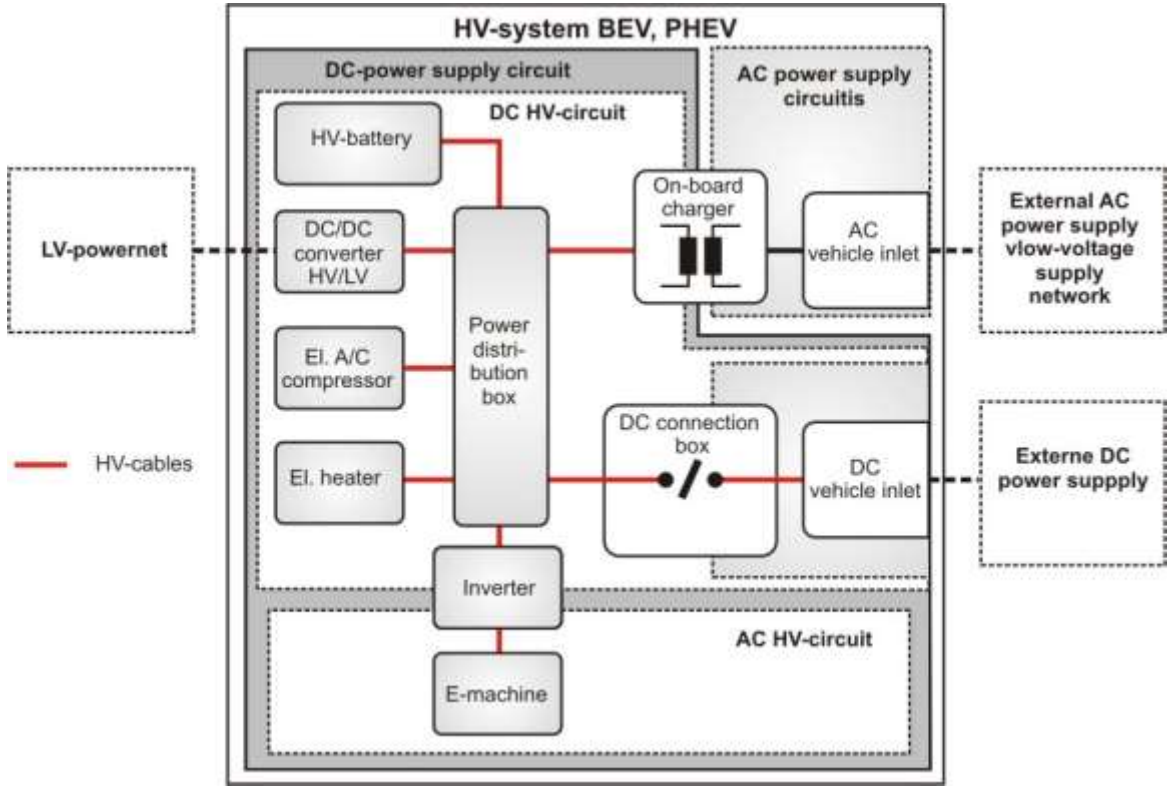


BMW	GS 95023	Edition: 2016-11
Mercedes	MBN LV 123	Edition : 2014-03
Volkswagen	VW 80303	Edition : 2014-06

OVERVIEW HV SYSTEM

/ 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)



HV – OPERATING STATUS

/ The HV operating status apply to HV components.

HV Status	Description of HV – operating status
B0	The HV components are operational and there is no power demand.
B1	The HV components are fully operational, and provide their intended performance.
B2	The HV components are still fully operational. The HV components provide a performance within the **deviations permissible** for operating status **B2**. When the HV components **revert** to operating status **B1**, they shall automatically provide their **intended performance**.
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

HV – VOLTAGE RANGES

The HV- voltage ranges are represented with the following four voltage ranges.

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

Table 3: HV voltage ranges

DYNAMIC PARAMETERS (TABLE 4)

- 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".

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

Table 4: Dynamic parameters

LOAD DUMP AND VOLTAGE LIMITING (TABLE 5)

- 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.

Parameter	HV - operating status	Unit	HV_1	HV_2a HV_2b	HV_3
Maximum voltage dynamics (slope), load dump	B3	V/ms	± 250	± 250	± 250

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".

Test	Product validation	100% standard production test
Range of unlimited operating capability	Xp	N/A
Range of upper limited operating capability	Xp	N/A
Range of lower limited operating capability	Xp	N/A
Range of highly limited operating capability	Xp	N/A
Voltage dynamics	Xp	N/A
Voltage ripple	Xp	N/A
Overvoltage	Xp	N/A
Undervoltage	Xp	N/A
Load dump and voltage limiting	Xp	Xs
Voltage offset	Xp	N/A
Interactions between LV and HV system	Xp	N/A
Xp: Test scope for product validation Xs: Test scope for 100% standard production test		

Table 20: Tests regarding the voltage ranges of the HV system

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

10 TESTS

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".*

Test	Product validation	100% standard production test
Marking	Xp	Xs
Protection against direct contact	Xp	Xs
Equipotential bonding	Xp	Xs
Overcurrent protection	Xp	Xs
Potential separation of HV system and LV powernet	Xp	N/A
Isolation resistance	Xp	Xs
Insulation coordination		
• General, clearances and creepage distances, and solid insulating materials	Xp	N/A
• Withstand voltage	Xp	Xs
Residual voltage	Xp	Xs
Active discharge	Xp	Xs
Passive discharge	Xp	Xs
X capacitors	Xp	Xs
Y capacitors	Xp	Xs
Isolation-bridging parts	Xp	Xs
HV contacting	Xp	Xs
HV interlock	Xp	Xs
Delayed access to live parts	Xp	Xs
Behavior in the event of a crash	Xp	Xs
Measuring the HV voltage	Xp	Xs
Failure of LV supply voltage	Xp	N/A
Electrical equivalent circuit diagrams	Xp	N/A
Installation areas and ambient conditions	Xp	N/A
Pre-assembly and mounting	Xp	N/A
Disassembly and disposal	Xp	N/A
Underload factors for HV parts	Xp	N/A
Documentation	Xp	N/A

Table 22:
Tests regarding el. characteristics and HV safety for HV components

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

10 TESTS

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".*

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

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".*

Test	Product validation	100% standard production test
Protective conductor current and touch current	Xp	N/A

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

STANDARD VALUES

/ Unless otherwise specified, the values in accordance with Table 26 "Standard values“ shall be selected

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

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

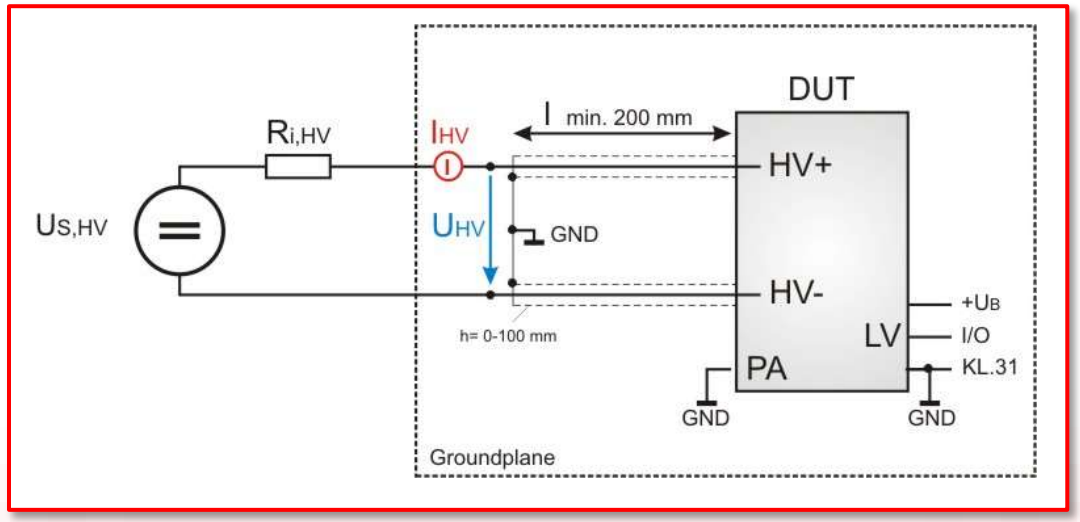
- Unless otherwise specified, the tolerances in accordance with Table "Standard tolerances" apply. Tolerances of envelopes must always be considered unilaterally as otherwise the requirement is mitigated.

- **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 und 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 und 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 %

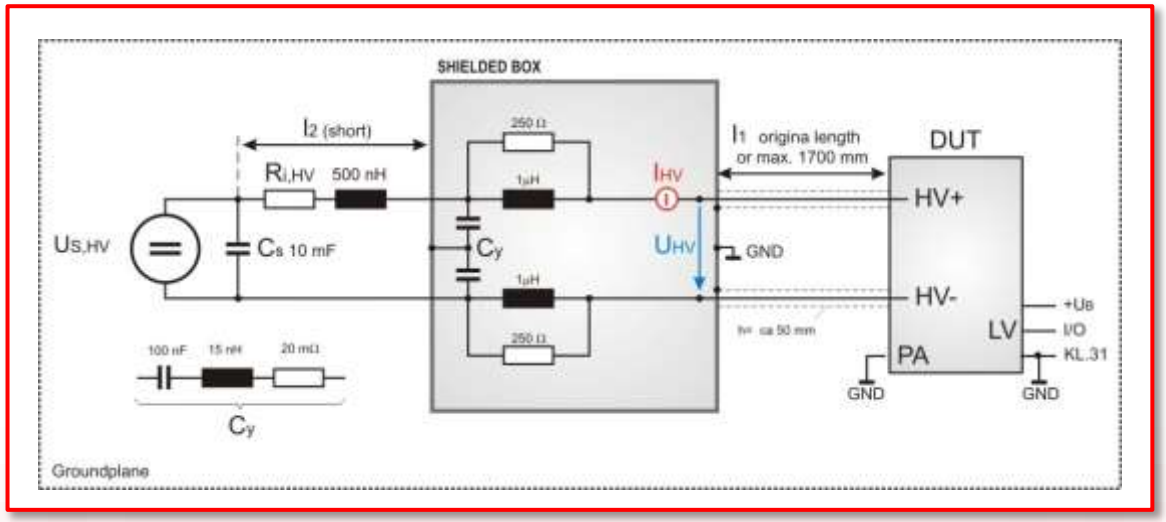
- **Power** (50/60 Hz)
  - to 1 W: ± 20,0 mW
  - above 1 W and to 3 kW: ± 3,0 %
  - above 3 kW: ± 5,0 %
- **Resistance**
  - 1 mOhm to 100 mOhm: ± 5,0 %
  - 1 MOhm to 1 TOhm: ± 5,0 %
  - above 1 TOhm: ± 10,0 %
  - All others: ± 3,0 %
- **Temperature**
  - below100 °C: ± 2,0 °C
  - 100 °C to 500 °C: ± 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

TEST SETUP

- 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.



HV Test setup Type 1 for slow events

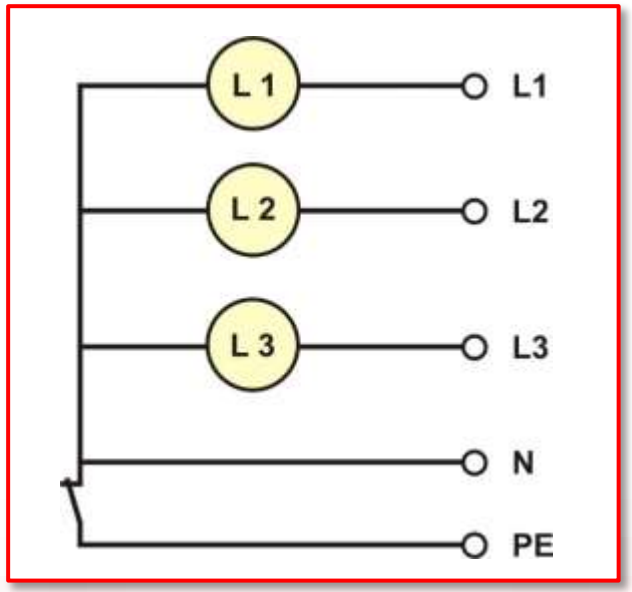


HV Test setup Type 2 for fast events

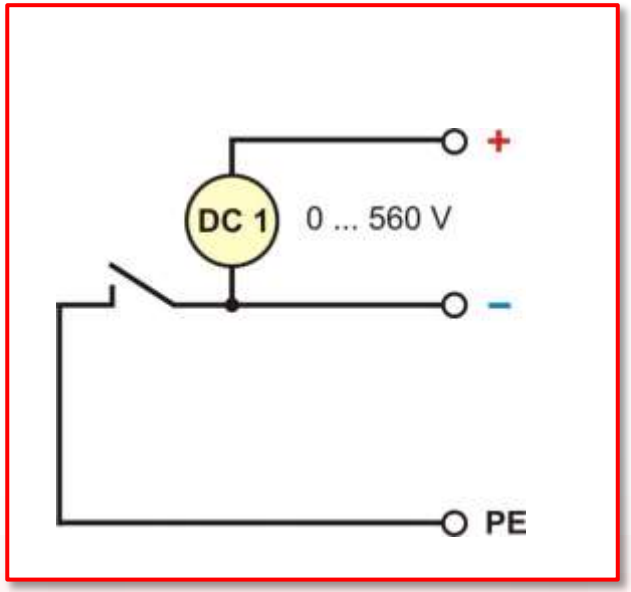
TEST SETUP DC SOURCE

- 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.

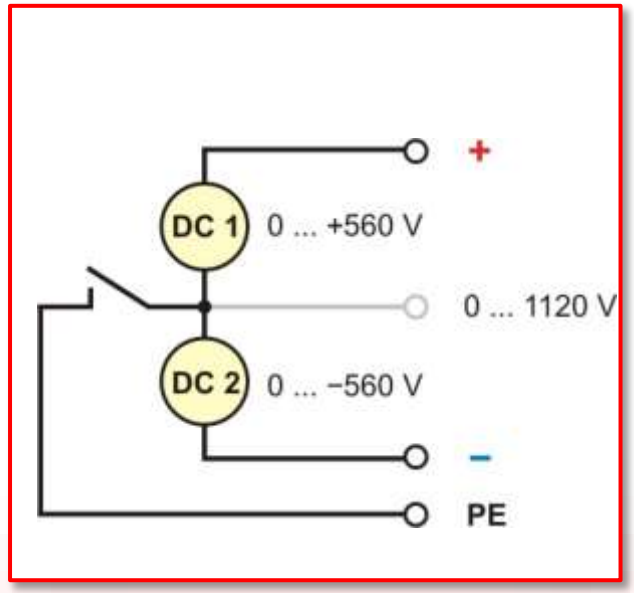
Setup for a 3-phase source for DC applications



AC / DC source Netwave 3-ph Serie



Setup for HV_1, HV_2



Setup for HV_3

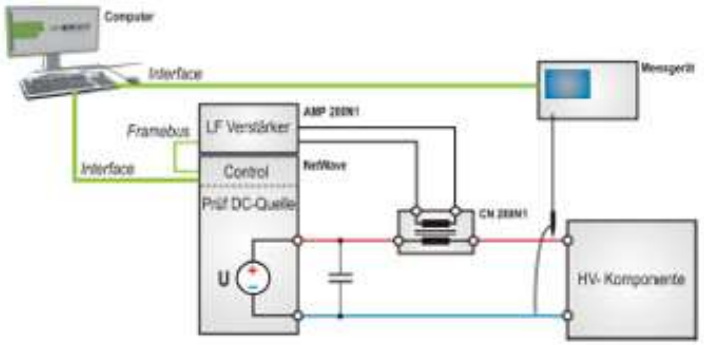
NETWAVE 3-PHASE: NEW DATASHEET

- **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 netwave.control software measures the voltage ripple and continuously controls the amplitude.



NETWAVE OPT DC-EVR : DC EXTENDED VOLTAGE RANGE OPTION

- 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

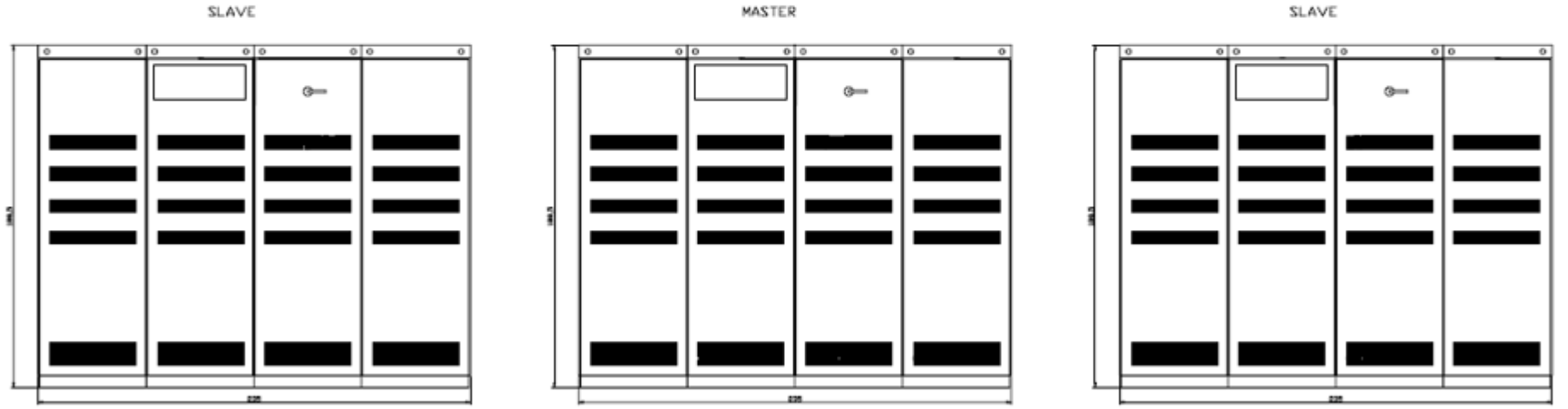
- New Top Range version of 3 PH NetWave sources
- Features extended AC voltage range from 360 VAC → 400 VAC_{L-N} / 690 VAC_{L-L}
- Option PowerRecovery included
- Option DC Extended Voltage Range included (Opt-3 DC-EVR) → ± 1120 VDC
- Upgrades from xx.2 to xx.3 are not planned
- net.control V2.0 required

- Example : NetWave 30.3

NETWAVE 30.3	
Output voltage	0 V - 3*400 V AC (p-n) 0 V - 3*690 V AC (p-p) 0 V - +/- 1120 V DC
Output current (@ max. 300 V AC/ 360 V DC)	33 A (RMS) continuous 66 A (RMS) short-term (max. 3 s) 250 A repetitive peak
PowerRecovery 30	included

NEW: NETWAVE 270.3

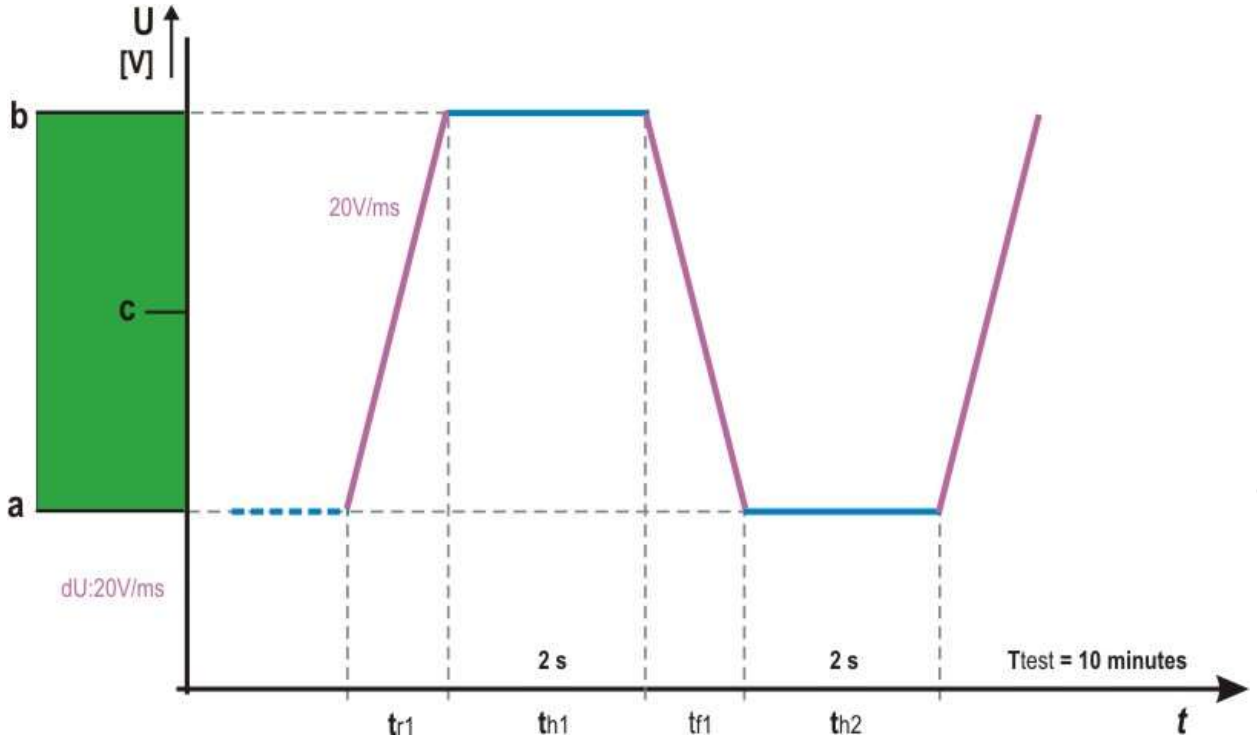
- First sold at large customer in Germany
- Built out of three NetWave 90.3 & 3 x Parallel Mode
- 270 kVA / 324 kW
- Max nominal current: 300 A / Phase



L2 L1 L3

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



	HV_1	HV_2a	HV_2b	HV_3
Maximum value	190 V	340 V	450 V	750 V
Unlimited operating capability	140 V	255 V	350 V	635 V
Minimum value	90 V	170 V	250 V	520 V

For HV_1 a: 90V, b: 190V -> c= 140V
The slopes are in the ms range,
tr1, tr2: 3.33ms, tf1: 6.66ms

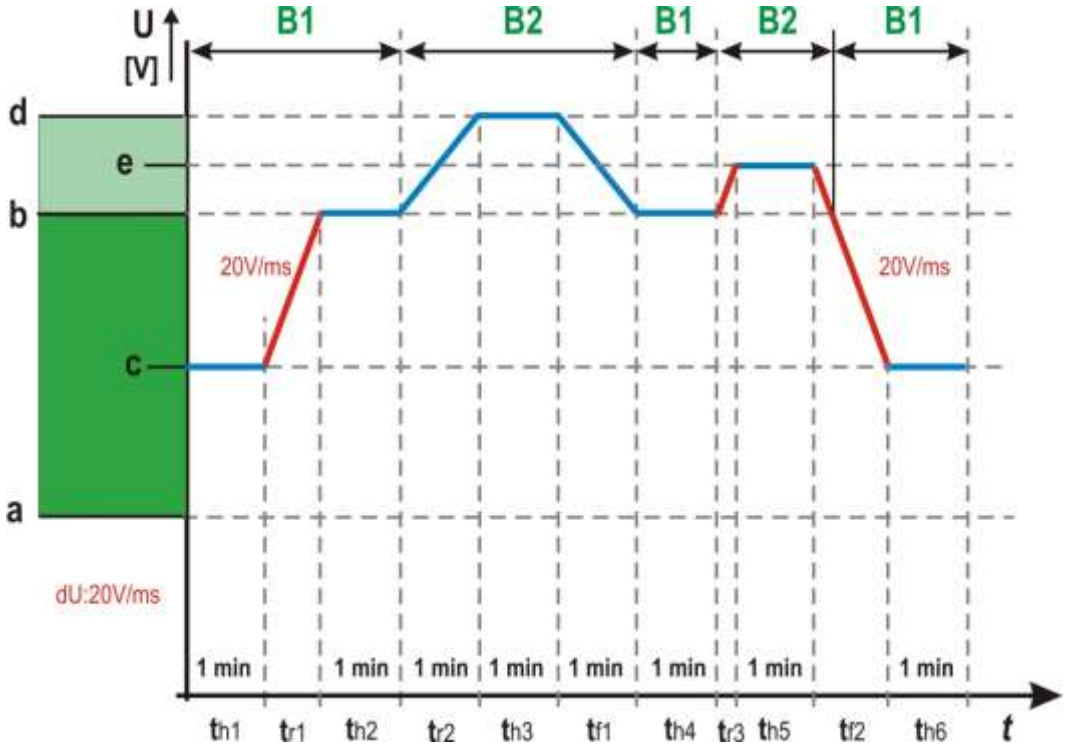
10.4.2 TEST RANGE OF UPPER LIMITED OPERATION

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

Maximum value
Upper limited operating capability
Min. / Max. value

Unlimited operating capability

Minimum value

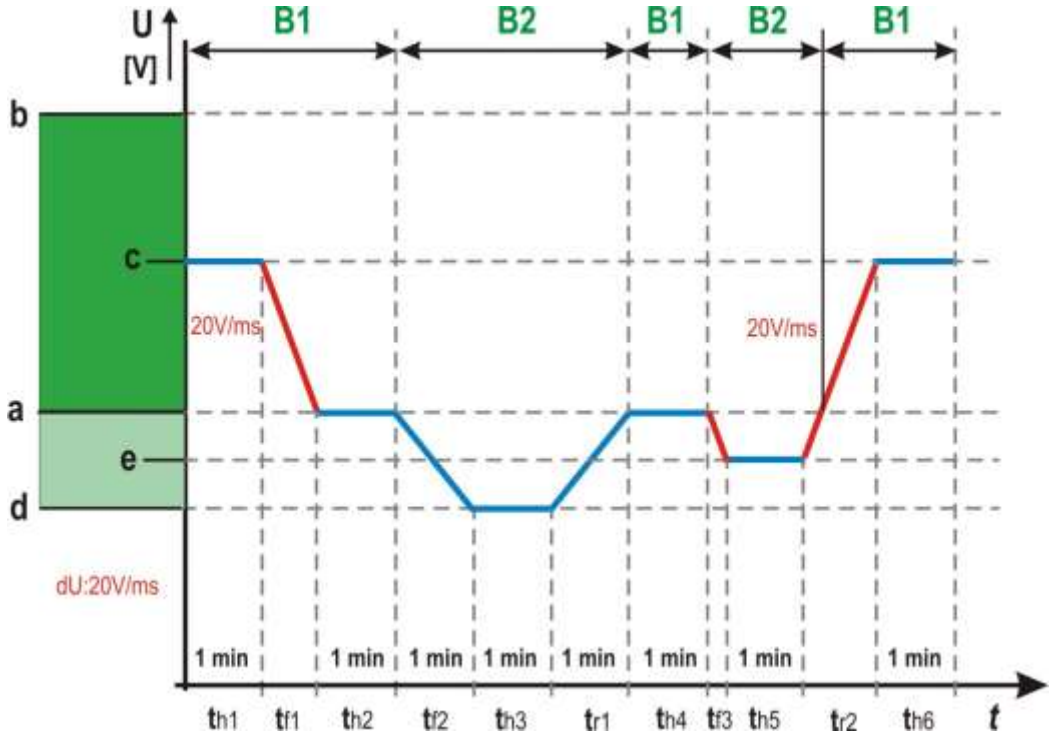


	HV_1	HV_2a	HV_2b	HV_3
	200 V	360 V	470 V	770 V
	195 V	350 V	460 V	760 V
	190 V	340 V	450 V	750 V
	140 V	255 V	350 V	635 V
	90 V	170 V	250 V	520 V

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

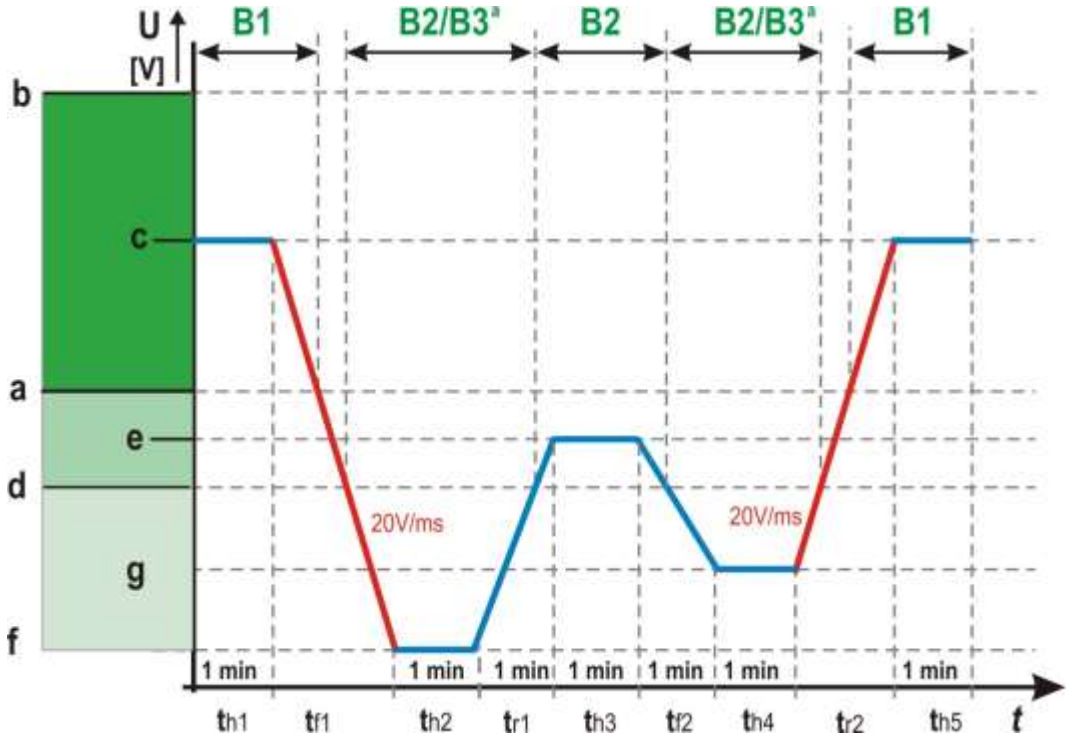
- Requirement: see section 6.3.3.4 "Range of lower limited operating capability"
- Test type: Product validation, 3 cycles, 3 samples
- Test method: Measurement



	HV_1	HV_2a	HV_2b	HV_3
Maximum value	190 V	340 V	450 V	750 V
Unlimited operating capability	140 V	255 V	350 V	635 V
Min. / Max. value	90 V	170 V	250 V	520 V
Lower limited operating capability	85 V	165 V	225 V	485 V
Minimum value	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



	HV_1	HV_2a	HV_2b	HV_3
Maximum value	190 V	340 V	450 V	750 V
Unlimited operating capability	140 V	255 V	350 V	635 V
Min. / Max. value	90 V	170 V	250 V	520 V
Lower limited operating capability	85 V	165 V	225 V	485 V
Min. / Max. value	80 V	160 V	200 V	450 V
Highly limited operating capability	70 V	140 V	175 V	-
Minimum value	60 V	120 V	150 V	-

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.

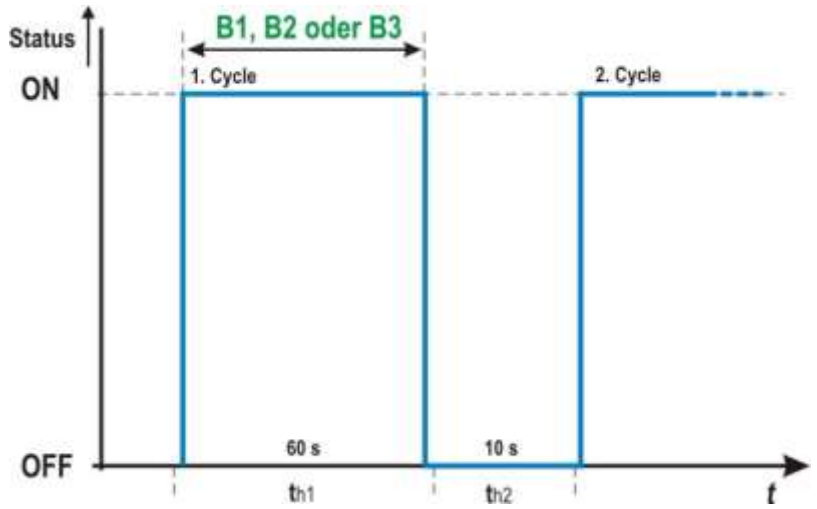


Figure 19 Test pulse generated voltage dynamics

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

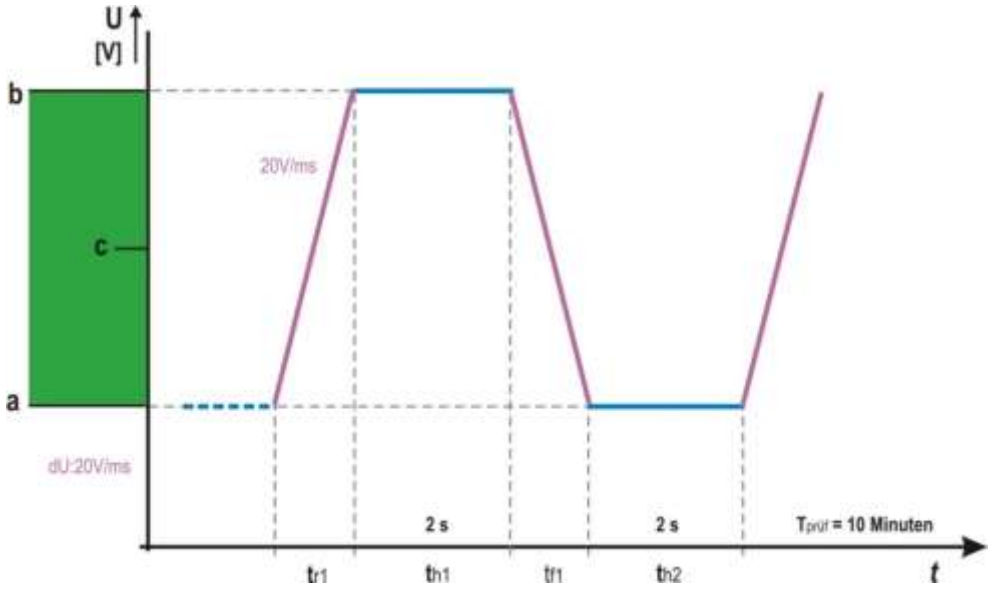
- Requirement: see section 6.3.4.2 “Voltage dynamics"
- Test type: Product validation, 10 cycles, 3 samples
- Test method: Measurement

- **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

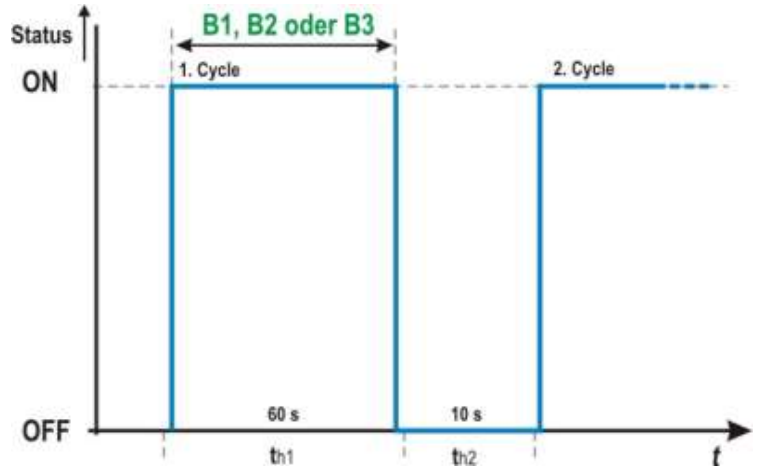
Parameter	All HV voltage operating ranges HV_1, HV_2a/2b, HV_3
Present and generated Voltage ripple with HV battery switched on	**± 8 V pk**

- **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.



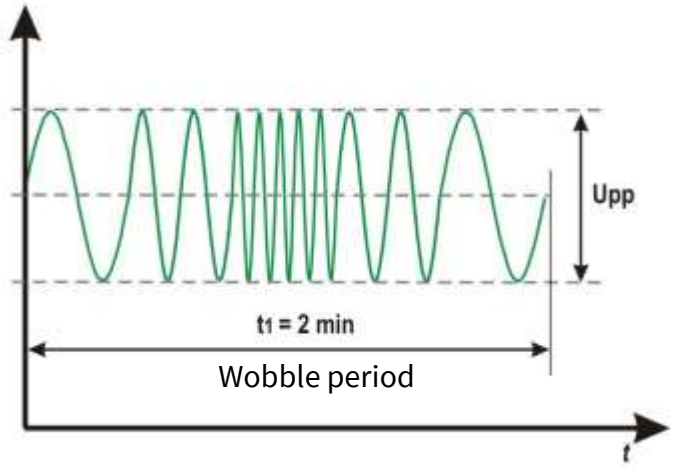
HV Component	Operating mode
DC/ DC-converter HV/LV	Boost Mode / Buck Mode
Drive system power electronics	Engine- / Generator mode
On-board charger,	HV-System (ext. el. Power supply)
Other HV component, HV battery	Load mode

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.

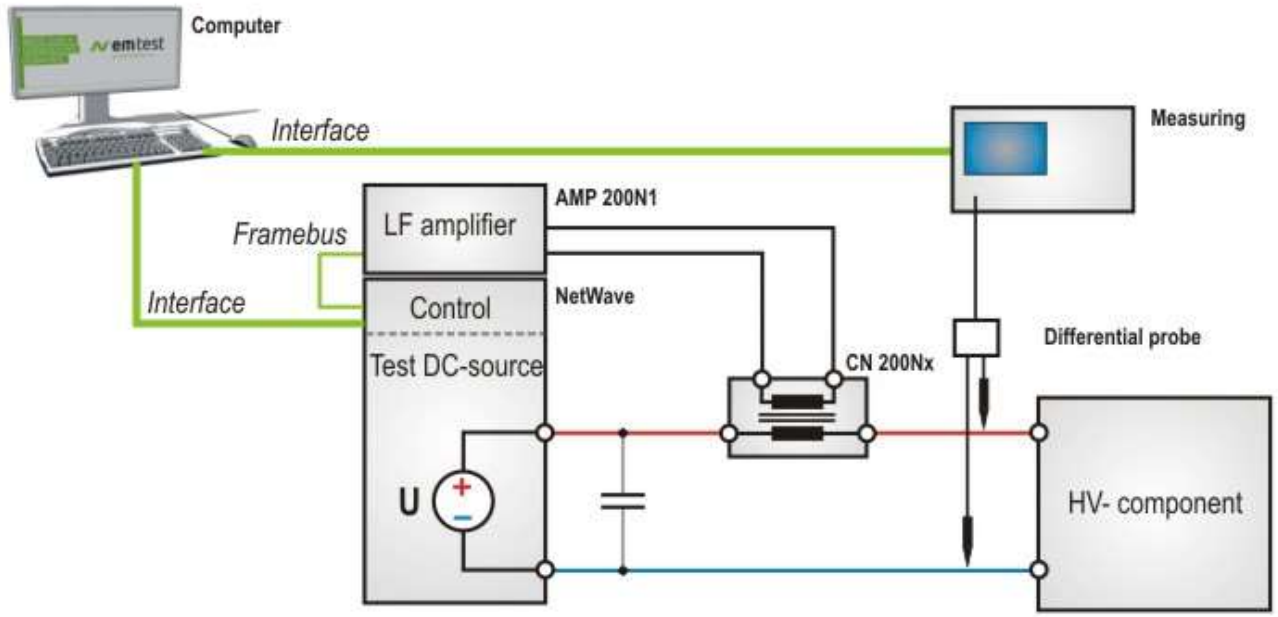
  Test duration: 30 min
  Frequency range: 15 Hz – 20 kHz
  Wobble period: 2 min
  Wobble type: triangular logarithmic
  Upp: 16 Vpp or 30 Vpp



Parameter Tabelle 4	All HV voltage ranges HV_1, HV_2a/2b, HV_3
Present and generated Voltage ripple with HV battery switched on	**± 8 V pk**
Present and generated Voltage ripple with HV battery switched off	**± 15 V pk**

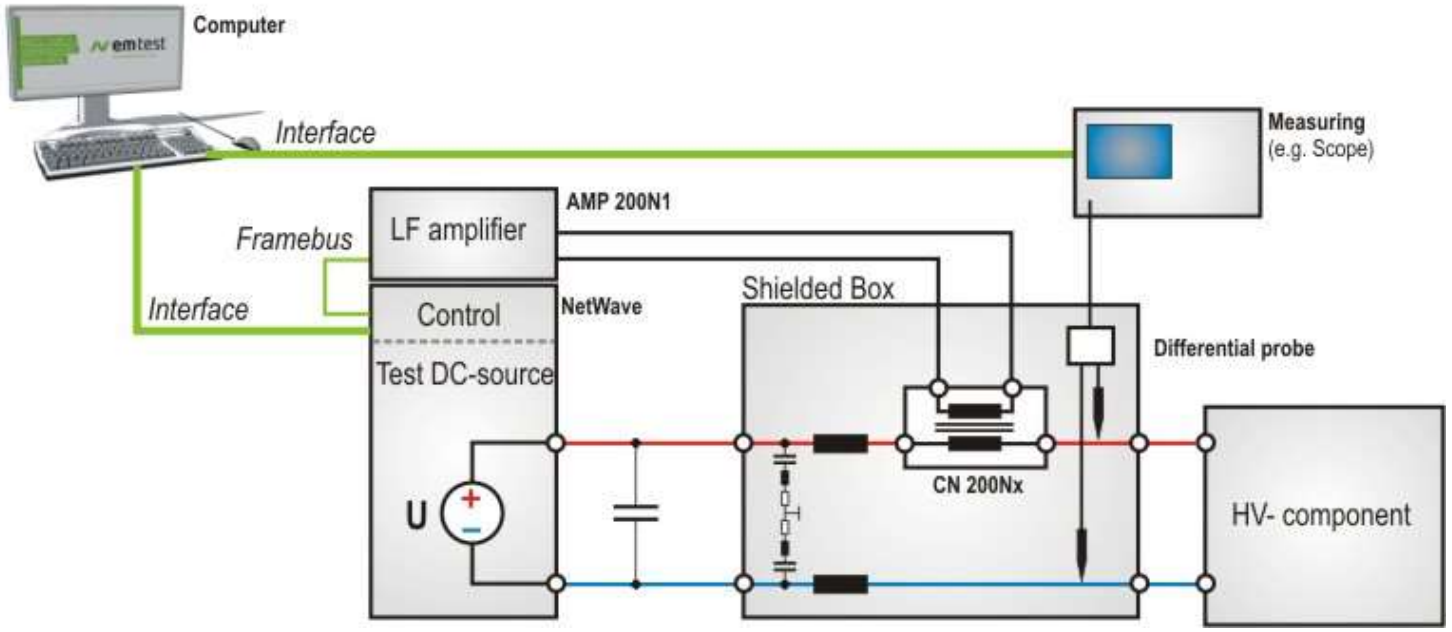
10.4.6 TEST VOLTAGE RIPPLE

- 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.



TEST VOLTAGE RIPPLE

- The standard VW 80300 requires for high frequency test a separate test setup with a shielded box for the measurement, decoupling and ripple transformer.

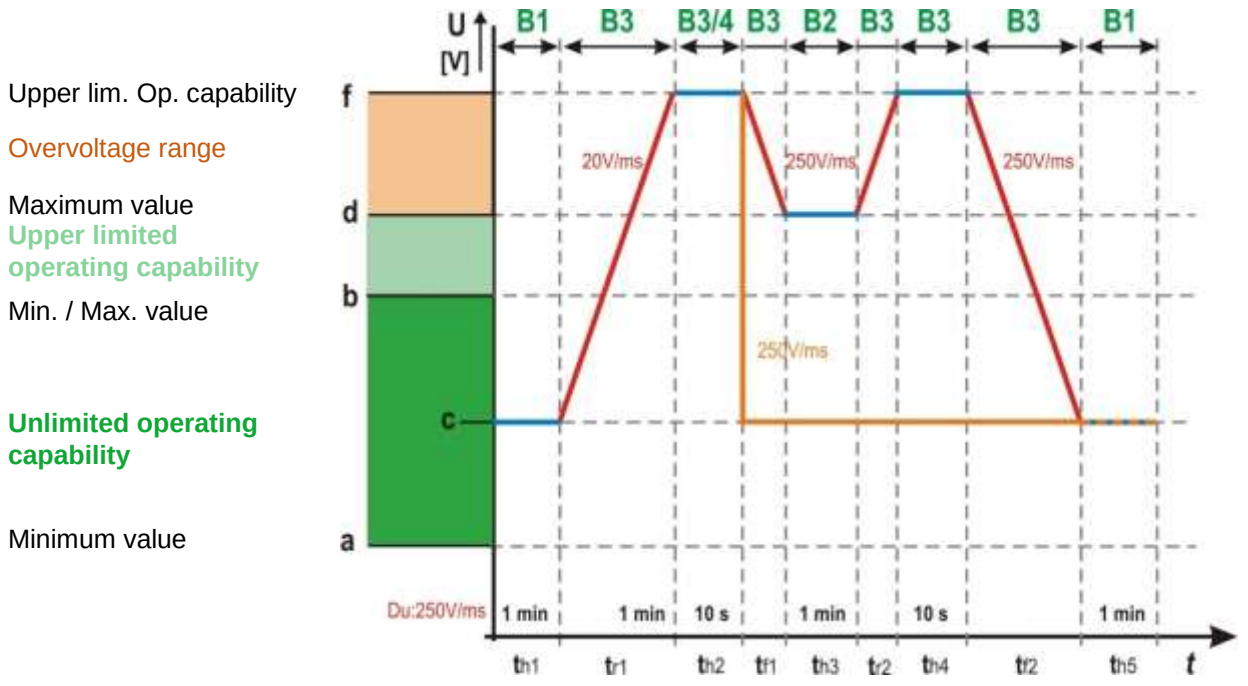


10.4.7 TEST OVERVOLTAGE

- 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".

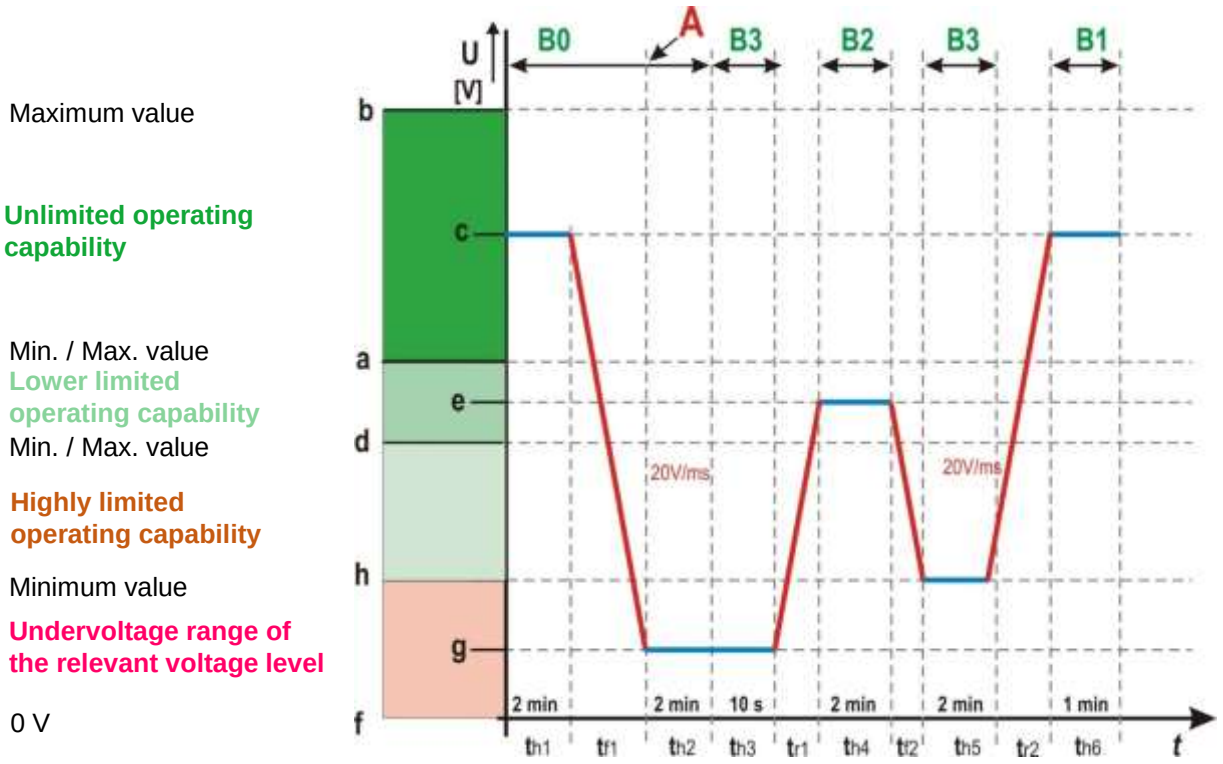


10.4.8 TEST UNDERVOLTAGE

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

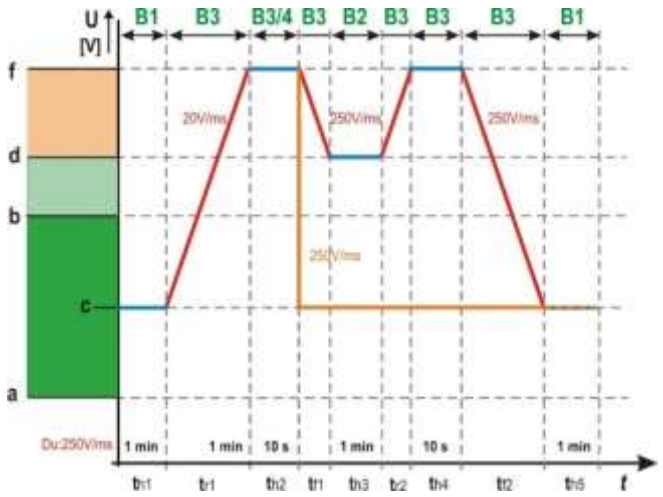
Compliance with the HV operating status **B3** shall be verified.

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



Test «Overvoltage"

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.

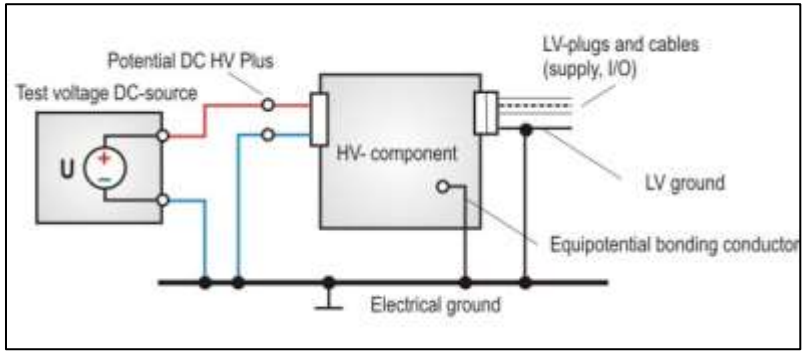
10.4.10 TEST VOLTAGE OFFSET

- 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.

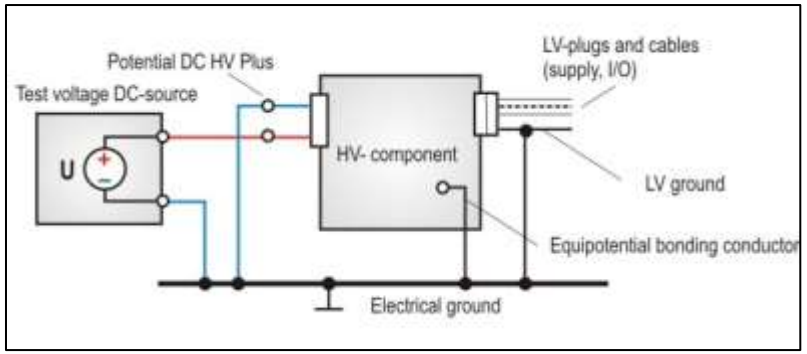
  The negative DC HV potential of the HV component shall be connected with the electrical ground of the test setup.



- **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.



OTHER TESTINGS FOR ELECTRICAL CHARACTERISTICS AND HV SAFETY

- 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

AMETEK CTS Germany GmbH
Lünener Str. 211
59174 Kamen, Germany

Phone: +49 (0) 2307 / 260700
Fax: +49 (0) 2307 / 17050

www.ametek-cts.com

info.cts@ametek.de