TESTING FOR THE VERIFICATION OF COMPLIANCE OF PV INVERTER WITH :

VDE-AR-N 4105:2018-11 + CORRECTION 1: 2020-10: GENERATORS CONNECTED TO THE LOW-VOLTAGE DISTRIBUTION NETWORK – TECHNICAL REQUIREMENTS FOR THE CONNECTION TO AND PARALLEL OPERATION WITH

LOW-VOLTAGE DISTRIBUTION NETWORKS

Procedure: PE.T-LE-62

Test Report Number ....:	**230033RECO03**
Trademark..:	TENTEK Catch Every Sunbeam
Tested Model..:	Tiger-2KW4E1P
Variant Models ....:	Tiger-1.6KW4E1P, Tiger-1.8KW4E1P
APPLICANT	
Name ....:	**SGS Tecnos, S.A. (Certification Body)**
Address...:	C/ Trespaderne, 29 - Edificio Barajas 1 28042 Madrid (Spain)
HIRED BY	
Name ....:	**Shenzhen Tentek New Energy Technology Co., Ltd.**
Address...:	8th Floor, B-A1, New Era Gongrong Industrial Zone, #2 Shihuan Rd, Shiyan Town, Shenzhen, P.R. China
TESTING LABORATORY	
Name ....:	**SGS Tecnos, S.A. (Electrical Testing Laboratory)**
Address...:	C/ Trespaderne, 29 - Edificio Barajas 1 28042 MADRID (Spain)
Conducted (tested) by.................................:	Michael Tong (Project Engineer)
Reviewed & Approved by............................:	Miguel Rodriguez Garcia (Technical Reviewer) SGS Tecnos, S.A. Laboratorio de Ensayos E&E
Date of issue ....:	2023/03/25
Number of pages ....:	82
Supplementary Report and pages...............:	230033RECO03 Supplementary Report including 9 pages
Totla Number of pages ....:	91

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Data Provided By The Client:

The following data has been provided by the applicant:

1. Any information regarding technical characteristics of the equipment (ratings, operation modes, software and hardware versions, dimensions and weight).

2. Equipment operation & construction information (manuals, electrical diagrams, information about components, operation procedures).

3. Documental information (brand and models names, address or other information about applicant, company or manufacturer).

4. Other information remarked within this report.

SGS TECNOS declines any responsibility with respect to the information provided by the applicant and that it may affect to the validity of results. It is not covered by ENAC accreditation.

Test Report Historical Revision:

Test Report Version	Date	Resume
230033RECO03	2023/03/25	First issuance

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1 SCOPE

SGS Tecnos, S.A. (Electrical Testing Laboratory) has been contracted by SGS Tecnos, S.A. (Certification body), in order to perform the testing according to:

- VDE-AR-N 4105:2018-11:” Generators connected to the low-voltage distribution network - Technical requirements for the connection to and parallel operation with low-voltage distribution networks” and including “Correction 1:2020-10”.

As Test procedure, the following Standard has been used for some of the applicable tests of the Standard above:

- VDE V 0124-100:2020-06: Grid integration of generator plants Low-voltage – Test requirements for generation units, intended for connection and parallel operation on the low-voltage grid.

2 GENERAL INFORMATION

2.1 Testing Period and Climatic conditions

The necessary testing has been performed between the 23rd of November of 2022 and the 24th of February of 2023.

All the tests and checks have been performed at climatic conditions:

Temperature	25 ± 5 ºC
Relative Humidity	50 ± 10 %
Pressure	96 ± 10 kPa

SITE TEST

Name.. : **Dongguan BALUN Testing Technology Co., Ltd.**

Address .... : Room 104, 204, 205, Building 1, No. 6, Industrial South Road, Songshan Lake District, Dongguan, Guangdong, China.

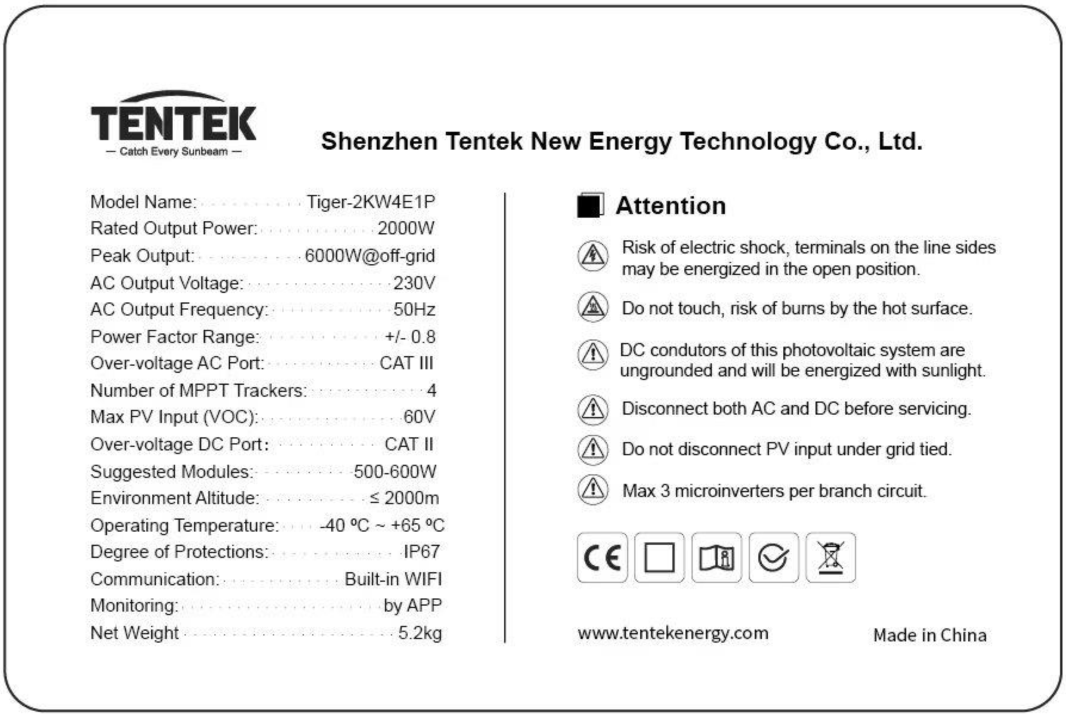
2.2 Equipment under Testing

Apparatus type ....: Microinverter
Installation ....: Fixed (permanent connection)
Manufacturer ....: Shenzhen Tentek New Energy Technology Co., Ltd.
Trademark...: TENTEK – Catch Every Sunbeam –
Model / Type reference ....: Tiger-2KW4E1P
Serial Number..: TJ0123A15A0358
Software Version ....: TJ01V1.002
Rated Characteristics.................................: DC input: 25~60 V_{MPPT} (Max.60 V), 4*15 A
AC output: L/N/PE, 230 V_{ac}, 50 Hz, 8.7A (Max.8.7 A),
2 kW (Max. 2 kVA)

Date of manufacturing: 2023

Input ....: PV
Output ....: AC, L/N/PE
Class of protection against electric shock...: Class I
Degree of protection against moisture........: IP 67
Type of connection to the main supply ....: Single phase – Fixed installation
Cooling group ....: Natural Convection-No Fans
Modular ....: No
Internal Transformer ....: Yes

Copy of marking plate (representative):



Note:

1. The above markings are the minimum requirements required by the safety standard. For the final production samples, the additional markings which do not give rise to misunderstanding may be added.
2. Label is attached on the side surface of enclosure and visible after installation.
3. Labels of other models are as the same with **Tiger-2KW4E1P**'s except the parameters of rating.

Equipment Under Testing:

- **Tiger-2KW4E1P**

Variant models:

- Tiger-1.6KW4E1P
- Tiger-1.8KW4E1P

The variants models have been included in this test report without tests because the following features don´t change regarding to the tested model:

- Same connection system and hardware topology
- Same control algorithm
- Output power within 1/√10 and 2 times of the rated output power of the EUT or Modular inverters.
- Same Firmware Version

The models of Tiger-1.6KW4E1P, Tiger-1.8KW4E1P and Tiger-2KW4E1P are identical on topological schematic circuit diagram and control solution codes except for input/output rating.

The results obtained apply only to the particular sample tested that is the subject of the present test report.

The most unfavourable result values of the verifications and tests performed are contained herein.

Throughout this report a point (~~comma~~) is used as the decimal separator.

Following table shows the full ratings of all the models referenced in this report, marked in **bold letters** the ones subjected to testing:

Model	Tiger-1.6KW4E1P	Tiger-1.8KW4E1P	**Tiger-2KW4E1P**
DC Input			
Max. input voltage	60 V		
Start-up operating voltage	20 V		
Rated input voltage	38 V		
MPPT operating voltage range	25 V ~ 60 V		
Full power MPPT voltage range	38 V ~60 V		
Max. input current	60 A		
Max. short current	72 A		
AC Output			
Nominal grid voltage	L/N/PE, 230 V (187-278V)		
Nominal grid frequency	50 Hz		
Rated AC power	1.6 kW	1.8 kW	2 kW
Max. AC power	1.6 kVA	1.8 kVA	2 kVA
Rated AC current	6.95 A	7.83 A	8.7 A
Max. AC current	6.95 A	7.83 A	8.7 A
Output power factor	>0.99 Default, 0.8 Leading / 0.8 Lagging		
General Data			
Operating temperature range	-40 ºC ~ +65 ºC		
Protection degree	IP67		
Protective class	Class III		
Cooling method	Natural Convection-No Fans		
Topology	Transformer		

2.3 Reference Values

The values presented in the following table have been used for calculation of referenced values (p.u.; %) through the report.

Reference Values for Model: Tiger-2KW4E1P	
Rated power, **Pn** (**P_{rE}**) in kW	2
Rated apparent power, **Sn** (**S_{rE}**) in kVA	2
Max. power, **Pmax** (**P_{Amax} | P_{Emax}**) in kW	2
Max. apparent power, **Smax** (**S_{Amax} | S_{Emax}**) in kVA	2
Rated wind speed (only WT), **vn** in m/s	Not applicable
Rated current (determined), **In** in A	8.7
Max. current (determined), **Imax** in A	8.7
Rated output voltage, (phase to neutral) **Un** in Vac	230
Note: In this report p.u. values are calculated as follows: -For Active & Reactive Power p.u values are reference to **Pn** -For Currents p.u values, the reference is always **In** -For Voltages p.u values, the reference is always **Un=230V_{L-N}**	

2.4 Manufacturer and Factory Information

Manufacturer Name:

Name .... : Shenzhen Tentek New Energy Technology Co., Ltd.

Address... : 8th Floor, B-A1, New Era Gongrong Industrial Zone, #2 Shihuan Rd, Shiyan Town, Shenzhen, P.R. China.

Factory Location:

Name .... : Shenzhen F&R Technologies Co., Ltd.

Address... : 8/F, 5/F, Building 1, Jiuzhou Industrial Park, No.10 Of Shijiuhao Road, Tongguan Road, Tianliao Community, Gongming, Guangming District, Shenzhen, Guangdong, P.R. China

2.5 Test Equipment List

From	No.	Equipment Name	Trademark / Model No.	Equipment No.	Calibration Period
Balun	1	Power analyzer	YOKOGAWA/ WT3000E	91V208962	2022/06/16 to 2023/06/15
	2	Power analyzer	YOKOGAWA/ WT1800	C3SA15008E	2022/04/06 to 2023/04/05
	3	Digital oscilloscope	Tektronix/ MSO4054B	BZ-DGD- L064	2022/03/01 to 2023/02/28
	4	Current probe	HIOKI/ CT6863-05	BZ-DGD- L026-3	2022/09/07 to 2023/09/06
	5	Current probe	CYBERTEK/ CP8150A	BZ-DGD-L067	2022/03/01 to 2023/02/28
	6	Voltage probe	CYBERTEK/ VP5200A	BZ-DGD- L241	2022/03/01 to 2023/02/28
	7	Temperature & Humidity meter	CEM/ DT-322	BZ-DGD- L005	2022/03/01 to 2023/02/28
	8	Power analyzer	DEWETRON / DEWE2-A4	BZ-DGD-L119	2022/11/03 to 2023/11/02
SGS	9	True RMS Multimeter	Fluke/187	GZE012-16	2022/05/21 to 2023/05/20

Note: Voltage direct measurement through power analyzer, the voltage probes were used with the digital oscilloscope. All measurement equipment was used inside their corresponding calibration period. Copy of all calibration certificates are available at the laboratory for reference.

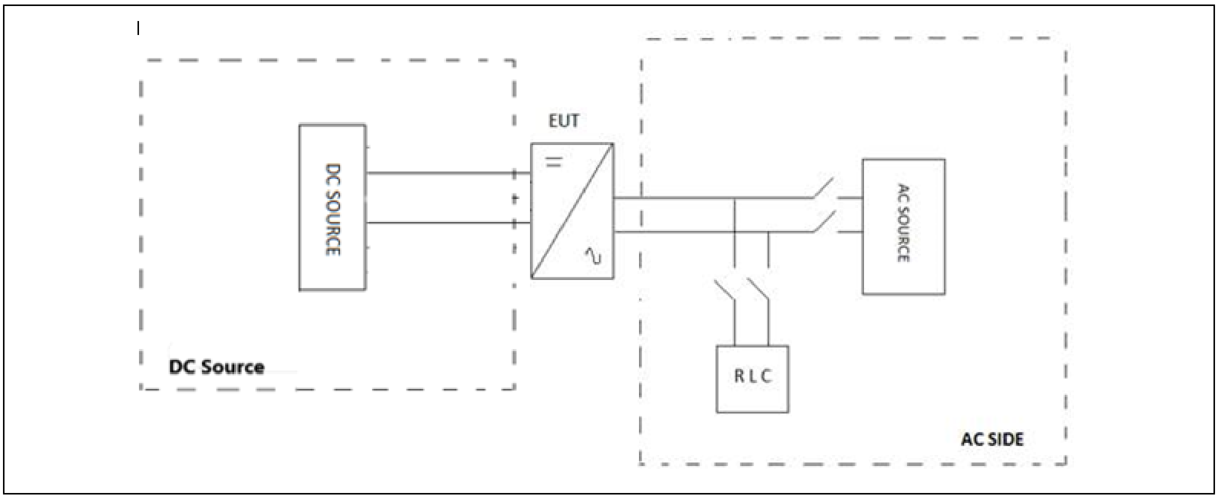
2.6 Measurement Uncertainty

Associated uncertainties through measurements showed in this this report are the maximum allowable uncertainties.

Magnitude	Uncertainty
Voltage measurement	±1.5 %
Current measurement	±2.0 %
Frequency measurement	±0.2 %
Time measurement	±0.2 %
Power measurement	±2.5 %
Phase Angle	±1º
CosφTemperature	±0.013º C
Note1: Measurement uncertainties showed in this table are maximum allowable uncertainties. The measurement uncertainties associated with other parameters measured during the tests are in the laboratory at disposal of the petitioner. Note2: Where the standard requires lower uncertainties that those in this table. Most restrictive uncertainty has been considered.	

2.7 Test set up of the different standard

Below is the simplified construction of the test set up.



Tests requiring batteries were performed using a DC source simulating the behaviour of the battery.

Different equipment has been used to take measures as it shows in chapter 2.5 Current have been connected to the inverter input / output for all the tests.

All the tests described in the following pages have used this specified test setup.

The test bench used includes:

EQUIPMENT	MARK / MODEL	RATED CHARACTERISTICS	OWNER / SN.
AC source	Kewell / KACM-75-33	75 kVA max. 45-65 Hz	BZ-DGD-L193
PV source	WKDY-30KVA	30kVA max.	BZ-DGD-L068
RLC load	QunLing / 93H000845	68 kW,68 kvar	BZ-DGD-L063

Test Conditions		
Condition	**Value**	**Comments**
Point of measurement	EUT Output (Low Voltage)	Equipment enounced in section 2.4 of this report has been used in the point of measurement
Short circuit ratio at the measurement point (S_k /Sn)	The value of S_{Emax}/S_{kv} used for the analysis has been 20.	
If the PGU is connected directly to the medium-voltage grid and a step-up transformer is installed between the PGU and the grid (which is not part of the PGU), a standard transformer must be used, the rated apparent power of which corresponds at least to the rated apparent power of the PGU being evaluated.	Connect to LV grid only	
MV Tansformer: Short circuit Power	--	Not applicable measured in Low voltage side
MV Tansformer: Network impedance Phase Angle	--	Not applicable measured in Low voltage side
MV Transformer : Service voltage Uc	--	Not applicable measured in Low voltage side
LV Isolation transformer : Nominal Power (kVA)	--	Transformerless
LV Isolation transformer : Short circuit voltage U_k (%)	--	Transformerless
LV Isolation transformer : Tap possition	--	Transformerless
MV Side: Additional impedance	--	Not applicable measured in Low voltage side
LV Side: Additional impedance	Active 0 Ω Reactive 0 Ω	
The THDSU of the voltage which includes all integer harmonics up to the 50th order must be smaller than 5%. It is measured as the 10-minute mean at the PGU terminals while the PGU is not generating any power.	See section 4.1.3. of this report	
The voltage, measured as a 10-minute mean at the PGU terminals, must lie within a range of ±10% of the rated voltage	0.20%	Single-phase
The voltage unbalance, measured as a 10-minute mean at the PGU terminals, must be less than 2%.	--	Single-phase

Test Conditions		
Condition	**Value**	**Comments**
The grid frequency, measured as a 0.2 second mean, must lie within a range of ±1% of the rated frequency around the rated frequency. The rate of change of the grid fre-quency, measured as a 0.2 second mean, must be smaller than 0.2% of the rated fre-quency per 0.2 seconds.	Tested Max. Value: 49.997 Hz Tested Min. Value: 49.990 Hz Tested Avg. Value: 49.994 Hz	
Note 1: These test conditions have been used in all the test performed in Sections 4 of this report. Note 2: See also the test bench information table in this section		

2.8 Definitions

In	Nominal Current	P	Power
p.u	Per unit	I	Current
Pn	Nominal Power	M	Change for real power
Sn	Apparent Power	N	Change for reactive power
PGU	Power Generation Unit	F	Frequency
Pst	Short-term flicker strength	Q_f	Quality factor
Plt	Long-term flicker strength	NS	Network and System
$C_{\Psi K}$	Flicker coefficient for continuous operation	Un	Nominal Voltage
S_r	Apparent Power Rated	PWHD	Partial weight harmonic distortion
S_k	Short-circuit Apparent Power	THD	Total harmonic distortion
K_{imax}	Maximum switching current factor	Z_{test}	Test circuit impedance at which the emission test
Z_{ref}	The reference impedance	EUT	Equipment under test
P_{rE}	rated active power	S_{rE}	rated apparent power
S_{Amax}	maximum apparent power of a power generation system	S_{Emax}	maximum apparent power of a power generation unit
P_{Amax}	maximum active power of the power generation system	P_{Emax}	maximum active power of the power generation unit
P_{mom}	instantaneous active power	$P_{AV, E}$	agreed active power of a connection for feed-in

3 RESUME OF TEST RESULTS

INTERPRETATION KEYS

Test object does meet the requirement .... **P** Pass

Test object does not meet the requirement................. **F** Fails

Test case does not apply to the test object................. **N/A** Not applicable

To make a reference to a table or an annex. .... See additional sheet

To indicate that the test has not been realized............ **N/R** Not realized

TEST REPORT SECTION	VDE V 0124-100:2020-06 CLAUSE	STANDARD REQUIREMENTS VDE-AR-N 4105:2018-11		RESULT
		CLAUSE	TEST	
4.1	**5.2**	**5.4**	**Network connection**	**-**
4.1.1	5.2.2	--	Rapid Voltage Changes	P
4.1.2	5.2.3	--	Flickers	P
4.1.3	5.2.4	--	Harmonics and interharmonics	P
4.1.4	5.2.5	--	Commutation notches	P
4.1.5	5.2.6	--	Direct current feed	P
4.2	**5.3**	**5.6**	**Verification of the symmetry behaviour of converters**	**N/A**
4.2.1	5.3.2	--	Calculation of asymmetry of three-phase converters	N/A
4.2.2	5.3.3	--	Symmetrical operation with a symmetry device	N/A
--	**5.4**	**5.7**	**Behaviour of the power generation system at the network**	**N/A**
4.3	--	5.7.1	General *(Normal frequency operating range)*	P
4.4	--	5.7.1	General *(RoCoF)*	P
4.5.1	5.4.8.2	5.7.2.2	Reactive power supply at ΣS_{Emax}	P
4.5.2	--	5.7.2.3	Reactive power supply smaller than P_{Emax}	P
4.6.1	5.4.8.4	5.7.2.4 a) / 5.7.2.5	Reactive power voltage characteristic curve Q(U) / Requirements for reactive power methods of type 2 systems (inverters only) and type 1 systems	N/A
4.6.2	5.4.8.3	5.7.2.4 b) / 5.7.2.5	Displacement factor/active power characteristic curve cos ϕ (P) / Requirements for reactive power methods of type 2 systems (inverters only) and type 1 systems	P
4.6.3	--	5.7.2.4 c) / 5.7.2.5	Displacement factor cos ϕ / Requirements for reactive power methods of type 2 systems (inverters only) and type 1 systems	P
4.7	5.8	5.7.3	Dynamic network stability	N/A
4.8.1	5.4.3.4	5.7.4.1	Active power output – General *(P gradient)*	P
4.8.2	--	5.7.4.1	Active power output – General *(Ceasing of P)*	P
4.8.3	5.4.3.3	5.7.4.2.2	Active power steps	P
4.8.4.1	5.4.4	5.7.4.2.3	Active power adjustment as a function of grid frequency *(Overfrequency, generator)*	P
4.8.4.2	5.4.6	5.7.4.2.3	Active power adjustment as a function of grid frequency *(Underfrequency, generator)*	P
4.8.5	--	5.7.4.4	Voltage-dependent active power reduction	N/A
4.9	--	5.7.5	Short circuit contribution	P

Table continue on next page

--	**5.5**	**6.5**	**Protection devices and protection settings**	**P**
4.10	5.5.7	6.5.2	Protective functions	P
4.11	5.5.10	6.5.3	Islanding detection	P
4.12	**5.6**	**8.3**	**Connection conditions and synchronisation**	**P**

Note: Decision rule of the declaration of conformity evaluated according to the ILAC G8: 09/2019 & IEC 115 Guidelines (Proc. 2 “Accuracy Method” based on OD-5014).

Decision rule used: Binary with simple acceptance. (Safety Zone with respect to the limit w = 0).

Specific risk: Probability of False Acceptance or Rejection less than 50%, (PFA / PFR <50%). For more information see ILAC Guide G8 / 09.

4 TEST RESULTS

4.1 System perturbations

System perturbations have been measured with tests procedures from chapter 5.2 of the VDE V 0124-100:2020-06 standard to verify requirements specified in form E.5 of VDE AR-N 4105:2018-11.

4.1.1 Rapid voltage changes

The point 5.2.2 of VDE V 0124-100:2020-06 refers to the standard DIN EN 61000-3-3 for the verification of the rapid voltage changes in equipment with a nominal current ≤ 16 A.

Test results offered have a reference grid impedance Z_{ref} of **32º**.

		d_c (%)	d_{max} (%)	T_{max} (ms)
Limits set under DIN EN 61000-3-3		3.3	4.0	500
33% Pn	Measured values at test impedance	0.23	0.99	0
66% Pn	Measured values at test impedance	0.18	0.96	0
100% Pn	Measured values at test impedance	0.18	0.77	0

Graphics of the results are same with the flickers, refer to the section paragraph 4.1.2 of this report.

4.1.2 Flickers

The Flickers test has been performed according to the paragraph 5.4.3 of VDE-AR-N 4105:2018-11 and the paragraph 5.2.3 of VDE V 0124-100:2020-06. It has been taken the EN 61000-3-3 as reference standard due to the output current ≤ 16 A of the inverter. In addition of the requirements of this reference standard, VDE-AR-N 4105: 2011 requires a Plt value less or equal to 0.5.

In table below are offered the values measured:

	Limit	33% Pn	66% Pn	100% Pn
Pst	≤ 1.0	0.30	0.25	0.24
Plt	≤ 0.5	0.25	0.20	0.16
dc [%]	≤ 3.30	0.23	0.18	0.18
dmax [%]	4.0	0.99	0.96	0.77

As it can be seen in the next screenshots, this test has 12 steps and each step for 10min. The values took of Pst, Plt, dc and dmax are the most unfavourable of the 12 steps.

According to the standard, the flicker coefficient *c*Ψk must be determined for the impedance angle 32°.

The flicker coefficient is determined on the basis of the previously measured P_{st} values in accordance with the following formula:

$$c_{\Psi k} = P_{st} \times (S_k/P_n).$$

Whereby the following applies:

P_{st} Short-term flicker value measured on the network substitute element;

S_k Short circuit power of the network substitute element (during determination of the corresponding P_{st} values).

Checking the datasheet of the AC source (Chroma / 61860):

Sk,fic =60 kVA   Imax=300A, and Pn=2 kW

Which leads us to the following relation:

$$S_k / Pn = 30$$

These tests are only based on a 32° network impedance angle.

Z_{test} impedance test (Test method refer to IEC 61000-3-3):

R_A = 0.24 W; X_A = j 0.15 W at 50 Hz.
R_N = 0.16 W; X_N = j 0.10 W at 50 Hz.

The impedance test Z_{test} is the same that the reference impedance Z_{ref}.

It has also been calculated the flicker coefficient in function of different network impedance phase angles. These calculations are offered in the table below.

Network impedance phase angle, Ψk	32°
Average active power	Flicker coefficient, C (Ψk, P)
P = 33%Pn	9.0
P = 66% Pn	7.5
P = 100% Pn	7.2

Power=33% Pn

Flicker Mode Uover:- - - -
IEC61000-4-15 Ed1.1 Iover:- - - - Flicker:Complete 2:00:00

YOKOGAWA ◆

Count 12/12
Interval 10m00s/10m00s

Element 3
Volt Range 300V/50Hz
Un (U3) 231.229 V
Freq(U3) 50.000 Hz

Element3 Judgement: Pass
Total Judgement: Pass
(Element3)

	dc[%]	dmax[%]	d(t)[ms]	Pst	Plt
Limit	3.30	4.00	500 3.30(%)	1.00	0.65 N:12
No. 1	0.21 Pass	0.64 Pass	0 Pass	0.23 Pass	
2	0.12 Pass	0.61 Pass	0 Pass	0.20 Pass	
3	0.13 Pass	0.47 Pass	0 Pass	0.20 Pass	
4	0.11 Pass	0.60 Pass	0 Pass	0.21 Pass	
5	0.12 Pass	0.46 Pass	0 Pass	0.21 Pass	
6	0.19 Pass	0.81 Pass	0 Pass	0.25 Pass	
7	0.22 Pass	0.97 Pass	0 Pass	0.28 Pass	
8	0.19 Pass	0.96 Pass	0 Pass	0.27 Pass	
9	0.23 Pass	0.99 Pass	0 Pass	0.30 Pass	
10	0.15 Pass	0.46 Pass	0 Pass	0.23 Pass	
11	0.17 Pass	0.93 Pass	0 Pass	0.26 Pass	
12	0.19 Pass	0.71 Pass	0 Pass	0.27 Pass	
Result	Pass	Pass	Pass	Pass	0.25

Flicker Form
Measurement
Flicker dmax
Initialize Exec
Start
Reset
Flicker Settings

Update 3600 2022/12/27 12:24:03

Power=66% Pn

Flicker Mode Uover:- - - -
IEC61000-4-15 Ed1.1 Iover:- - - - Flicker:Complete 2:00:00

YOKOGAWA ◆

Count 12/12
Interval 10m00s/10m00s

Element 3
Volt Range 300V/50Hz
Un (U3) 231.390 V
Freq(U3) 50.000 Hz

Element3 Judgement: Pass
Total Judgement: Pass
(Element3)

	dc[%]	dmax[%]	d(t)[ms]	Pst	Plt
Limit	3.30	4.00	500 3.30(%)	1.00	0.65 N:12
No. 1	0.18 Pass	0.86 Pass	0 Pass	0.21 Pass	
2	0.14 Pass	0.67 Pass	0 Pass	0.21 Pass	
3	0.16 Pass	0.82 Pass	0 Pass	0.20 Pass	
4	0.17 Pass	0.72 Pass	0 Pass	0.20 Pass	
5	0.16 Pass	0.75 Pass	0 Pass	0.19 Pass	
6	0.17 Pass	0.60 Pass	0 Pass	0.18 Pass	
7	0.17 Pass	0.96 Pass	0 Pass	0.20 Pass	
8	0.17 Pass	0.55 Pass	0 Pass	0.17 Pass	
9	0.17 Pass	0.80 Pass	0 Pass	0.21 Pass	
10	0.15 Pass	0.67 Pass	0 Pass	0.19 Pass	
11	0.15 Pass	0.71 Pass	0 Pass	0.19 Pass	
12	0.15 Pass	0.91 Pass	0 Pass	0.25 Pass	
Result	Pass	Pass	Pass	Pass	0.20

Flicker Form
Measurement
Flicker dmax
Initialize Exec
Start
Reset
Flicker Settings

Update 3600 2022/12/26 19:56:04

Power=100% Pn

Flicker Mode Uover:- - - -
IEC61000-4-15 Ed1.1 Iover:- - - - Flicker:Complete 2:00:00

YOKOGAWA ◆

Count 12/12
Interval 10m00s/10m00s

Element 3
Volt Range 300V/50Hz
Un (U3) 230.235 V
Freq(U3) 49.999 Hz

Element3 Judgement: Pass
Total Judgement: Pass
(Element3)

	dc[%]	dmax[%]	d(t)[ms]	Pst	Plt
Limit	3.30	4.00	500 3.30(%)	1.00	0.65 N:12
No. 1	0.18 Pass	0.50 Pass	0 Pass	0.13 Pass	
2	0.06 Pass	0.65 Pass	0 Pass	0.14 Pass	
3	0.07 Pass	0.48 Pass	0 Pass	0.13 Pass	
4	0.06 Pass	0.62 Pass	0 Pass	0.14 Pass	
5	0.09 Pass	0.51 Pass	0 Pass	0.14 Pass	
6	0.12 Pass	0.64 Pass	0 Pass	0.14 Pass	
7	0.11 Pass	0.45 Pass	0 Pass	0.14 Pass	
8	0.12 Pass	0.59 Pass	0 Pass	0.14 Pass	
9	0.12 Pass	0.77 Pass	0 Pass	0.17 Pass	
10	0.10 Pass	0.71 Pass	0 Pass	0.24 Pass	
11	0.11 Pass	0.70 Pass	0 Pass	0.17 Pass	
12	0.13 Pass	0.65 Pass	0 Pass	0.15 Pass	
Result	Pass	Pass	Pass	Pass	0.16 Pass

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4.1.3 Harmonics and interharmonics

The current harmonics, interharmonics and supraharmonics have been measured according to chapter 5.2.4 of VDE V 0124-100:2020-06, at the required power values.

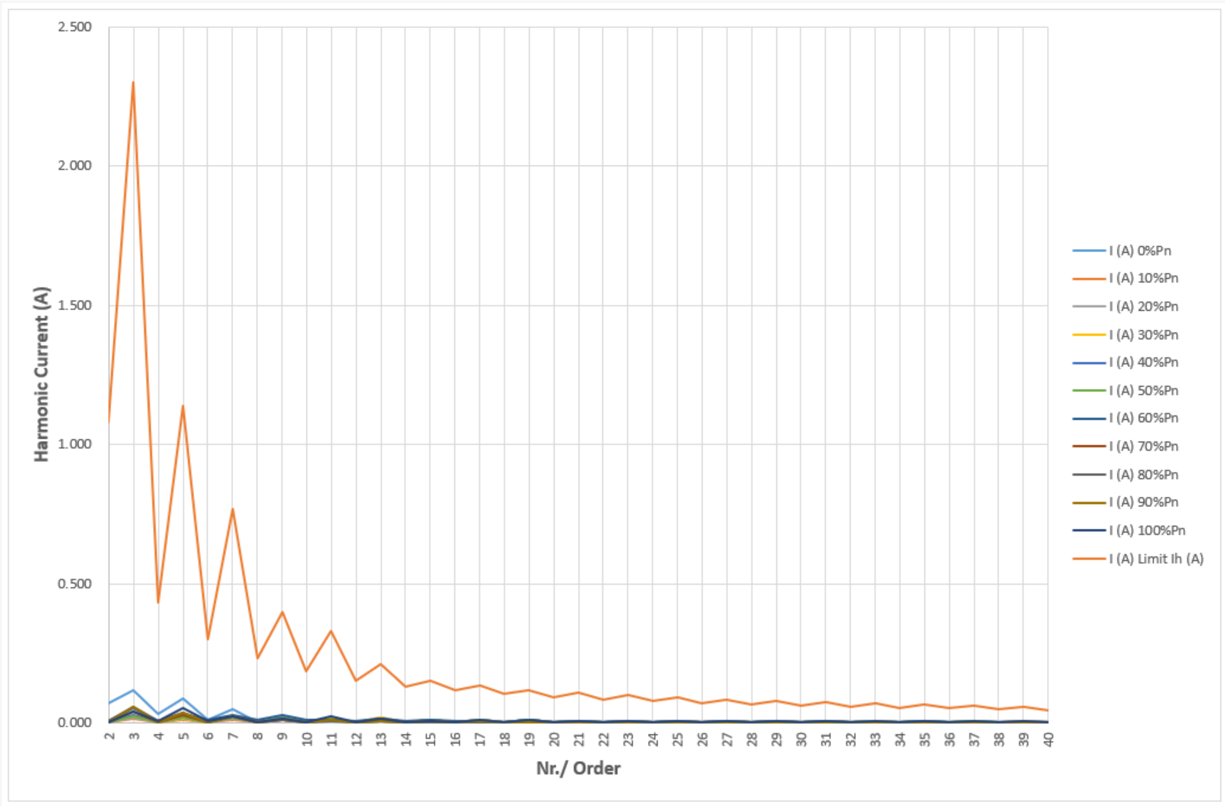
4.1.3.1 Harmonics

Standard EN 61000-3-2 has been taken as reference for harmonic limits.

The arithmetic average is formed over the 10 minutes record for each harmonic component of the current.
Values measured of the 50th current harmonics is offered in the following table and graphs:

P (%P_n)	0	10	20	30	40	50	60	70	80	90	100	Limit
Nr. / Order	**I (A)**	**I (A)**	**I (A)**	**I (A)**	**I (A)**	**I (A)**	**I (A)**	**I (A)**	**I (A)**	**I (A)**	**I (A)**	**I (A)**
2	0.821	0.016	0.015	0.020	0.028	0.024	0.088	0.032	0.058	0.041	0.037	1.080
3	1.319	0.170	0.226	0.314	0.334	0.288	0.602	0.441	0.638	0.640	0.460	2.300
4	0.355	0.014	0.016	0.022	0.023	0.027	0.088	0.030	0.055	0.042	0.070	0.430
5	1.018	0.099	0.169	0.149	0.203	0.219	0.382	0.330	0.431	0.413	0.628	1.140
6	0.128	0.013	0.018	0.020	0.026	0.023	0.103	0.028	0.033	0.029	0.046	0.300
7	0.564	0.104	0.158	0.198	0.209	0.227	0.302	0.260	0.259	0.289	0.263	0.770
8	0.014	0.014	0.017	0.019	0.025	0.023	0.104	0.026	0.025	0.027	0.029	0.230
9	0.111	0.111	0.132	0.147	0.214	0.217	0.312	0.141	0.121	0.153	0.178	0.400
10	0.015	0.015	0.016	0.020	0.020	0.026	0.096	0.024	0.030	0.030	0.018	0.184
11	0.135	0.135	0.093	0.176	0.139	0.185	0.143	0.113	0.088	0.115	0.269	0.330
12	0.013	0.013	0.016	0.020	0.022	0.024	0.084	0.024	0.035	0.029	0.015	0.153
13	0.103	0.103	0.195	0.195	0.173	0.076	0.180	0.066	0.055	0.055	0.177	0.210
14	0.013	0.013	0.016	0.017	0.022	0.021	0.070	0.026	0.036	0.027	0.013	0.131
15	0.080	0.080	0.127	0.127	0.127	0.127	0.120	0.034	0.037	0.053	0.061	0.150
16	0.013	0.013	0.015	0.016	0.019	0.020	0.054	0.024	0.036	0.032	0.021	0.115
17	0.089	0.089	0.100	0.100	0.100	0.100	0.066	0.024	0.029	0.046	0.110	0.132
18	0.013	0.013	0.014	0.016	0.017	0.020	0.041	0.021	0.034	0.034	0.025	0.102
19	0.082	0.082	0.103	0.103	0.103	0.103	0.100	0.017	0.037	0.035	0.100	0.118
20	0.012	0.012	0.014	0.015	0.018	0.019	0.028	0.019	0.031	0.028	0.028	0.092
21	0.074	0.074	0.092	0.092	0.092	0.092	0.090	0.013	0.035	0.037	0.092	0.107
22	0.012	0.012	0.014	0.014	0.018	0.017	0.018	0.020	0.026	0.024	0.032	0.084
23	0.075	0.075	0.080	0.080	0.080	0.080	0.080	0.023	0.037	0.035	0.088	0.098
24	0.012	0.012	0.014	0.014	0.016	0.016	0.014	0.019	0.021	0.028	0.030	0.077
25	0.047	0.047	0.069	0.069	0.069	0.069	0.070	0.023	0.034	0.035	0.080	0.090
26	0.012	0.012	0.013	0.014	0.016	0.016	0.015	0.016	0.023	0.026	0.026	0.071
27	0.053	0.053	0.075	0.075	0.075	0.075	0.060	0.014	0.018	0.020	0.070	0.083
28	0.012	0.012	0.013	0.014	0.016	0.016	0.016	0.015	0.019	0.019	0.022	0.066
29	0.058	0.058	0.063	0.063	0.063	0.063	0.056	0.011	0.023	0.022	0.068	0.078
30	0.012	0.012	0.013	0.014	0.016	0.016	0.019	0.015	0.018	0.017	0.015	0.061
31	0.047	0.047	0.063	0.063	0.063	0.063	0.050	0.018	0.022	0.025	0.065	0.073
32	0.012	0.012	0.014	0.014	0.016	0.015	0.020	0.015	0.017	0.019	0.010	0.058
33	0.050	0.050	0.052	0.052	0.052	0.052	0.045	0.023	0.023	0.023	0.063	0.068
34	0.012	0.012	0.014	0.014	0.016	0.016	0.019	0.015	0.017	0.019	0.007	0.054
35	0.039	0.039	0.052	0.052	0.052	0.052	0.050	0.022	0.023	0.023	0.055	0.064
36	0.012	0.012	0.013	0.014	0.016	0.016	0.017	0.016	0.017	0.018	0.007	0.051
37	0.041	0.041	0.052	0.052	0.052	0.052	0.045	0.012	0.023	0.019	0.051	0.061
38	0.012	0.012	0.013	0.014	0.017	0.016	0.015	0.016	0.017	0.019	0.007	0.048
39	0.048	0.048	0.035	0.035	0.035	0.035	0.040	0.012	0.013	0.023	0.048	0.058
40	0.012	0.012	0.014	0.014	0.016	0.017	0.015	0.016	0.018	0.015	0.008	0.046

Current Harmonics



4.1.3.2 Interharmonics

This test is not applicable according to paragraph 5.2.4.1 of standard VDE V 0124-100:2020-06, which states that inverters >75 A will have to perform current interharmonics test.

4.1.3.3 Higher Frequency

This test is not applicable according to paragraph 5.2.4.1 of standard VDE V 0124-100:2020-06, which states that inverters >75 A will have to perform current higher frequencies (between 2 kHz and 9 kHz) test.

4.1.4 Commutation notches

The point 5.2.5 of VDE V 0124-100:2020-06 requires verification of the commutation voltage dips in line-commutated inverters.

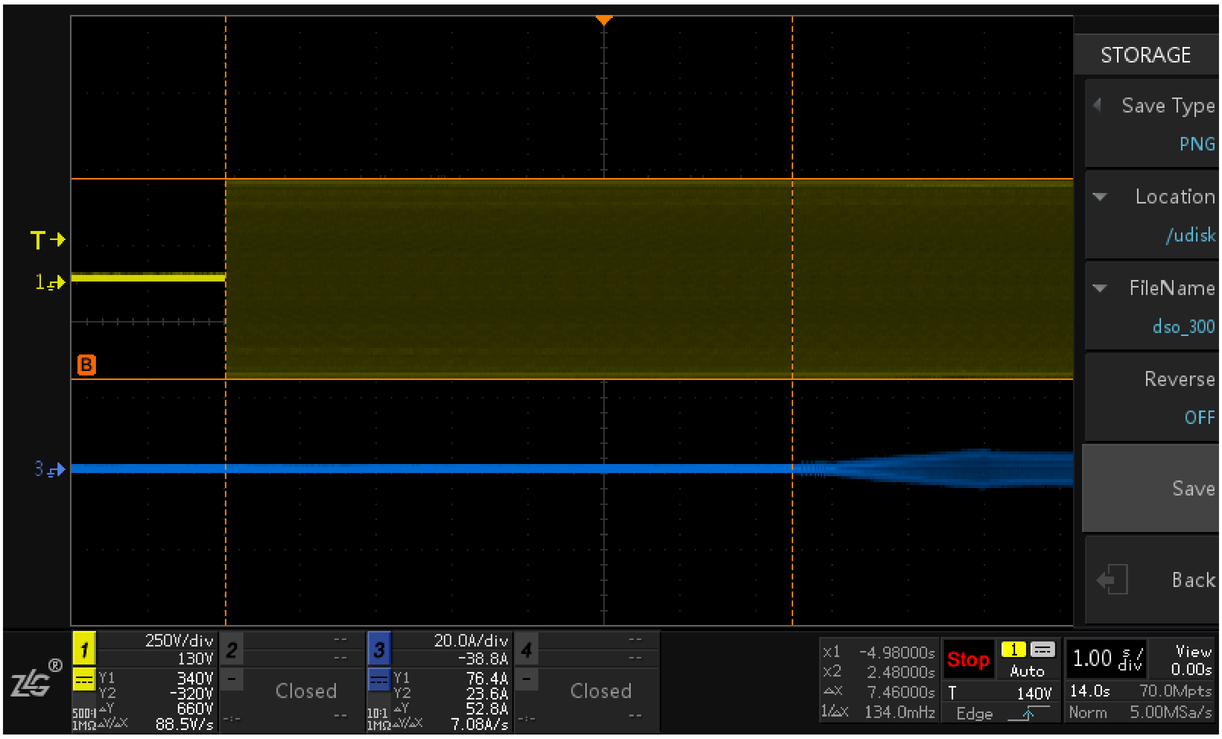
The equipment shall be operated in three operation points, and three 100ms oscillograms from each operation point shall be measured to check the commutation dips.

Limits and success criteria are specified in VDE-AR-N 4100:2019-04, section 5.4.

Most unfavourable test results for each operation point are presented in the following table:

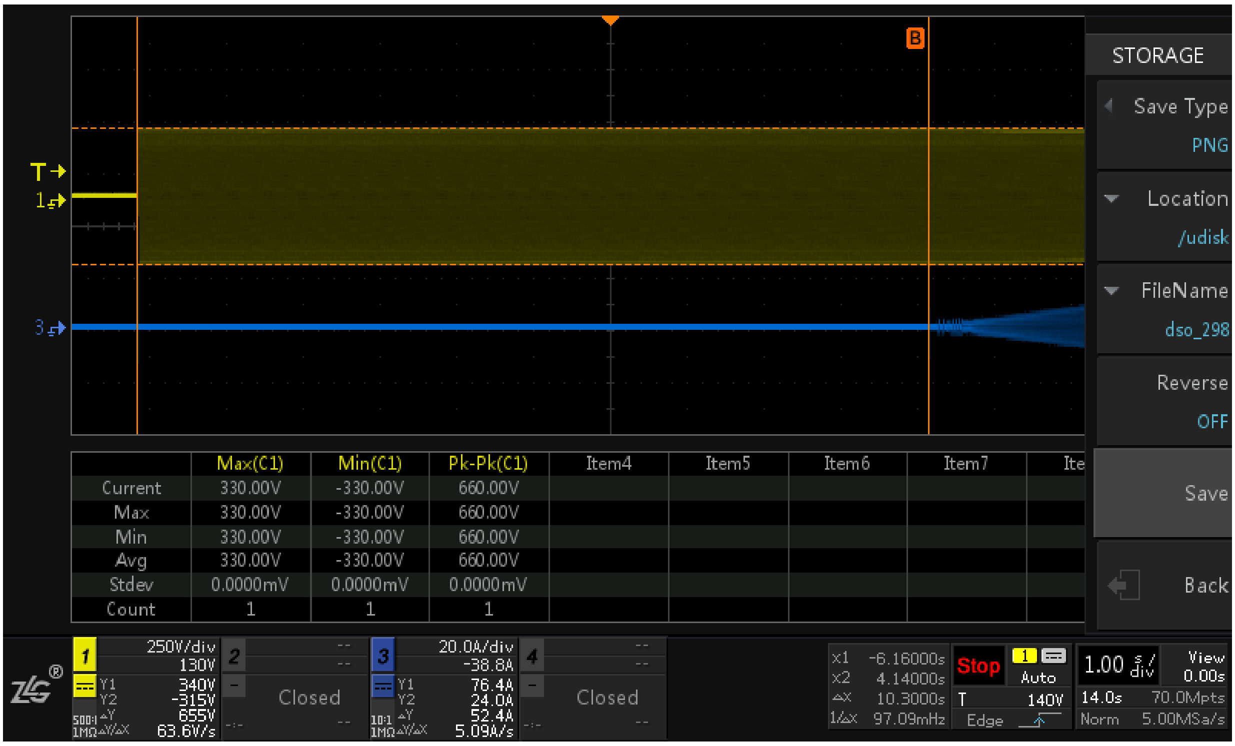
Operating point	P measured (%P_{Emax})	V measured (V)	$\hat{U}_n$ (V)	ΔU_{com} (V)	d_{com} limit (%)	d_{com} measured (%)
25%P_{Emax}<P<35%P_{Emax}	30.6	340.0	240.5	10.5		4.5
65%P_{Emax}<P<75%P_{Emax}	69.4	340.0	240.5	10.5	5.0	4.5
90%P_{Emax}<P	98.2	340.0	240.5	10.5		4.5

Commutation notches test (25%P_{Emax}<P<35%P_{Emax})



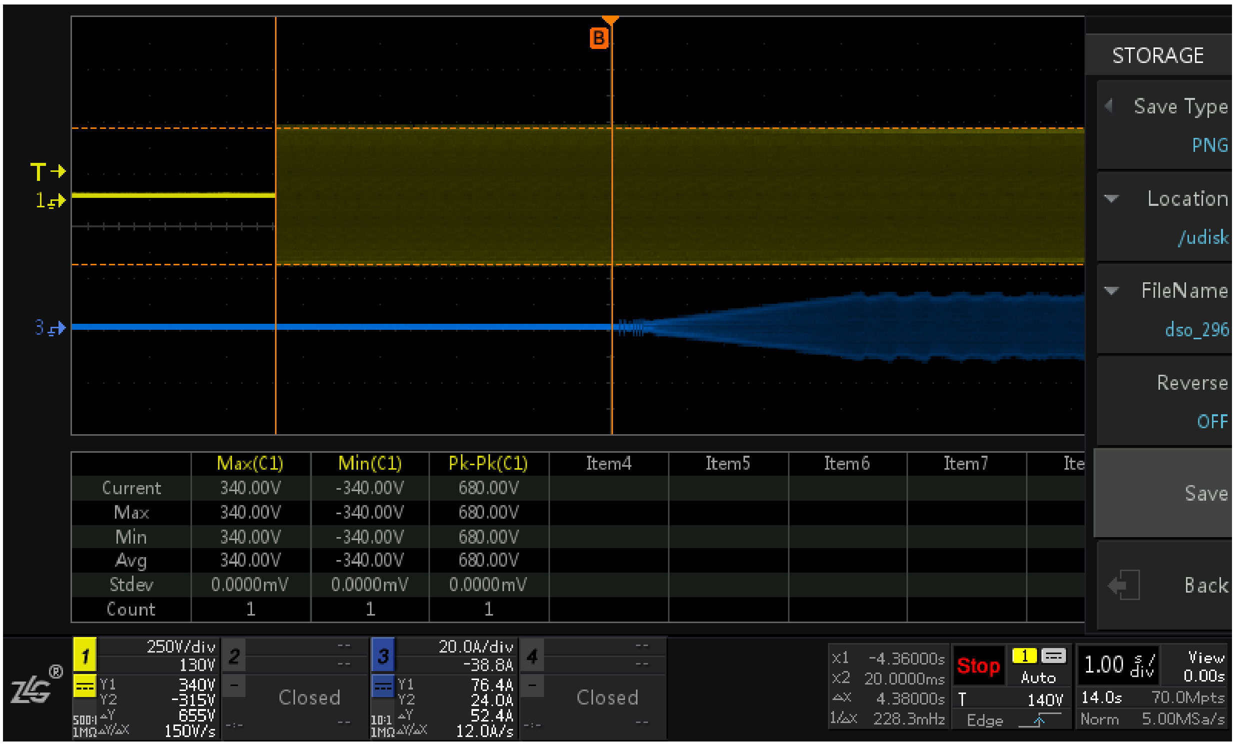
d_{com} = (((340/1.414) – 230) / 230) * 100% = 4.5%

$65\%P_{Emax}<P<75\%P_{Emax}$



d_{com} = (((340/1.414) – 230) / 230) * 100% = 4.5%

$90\%P_{Emax}<P$



d_{com} = (((340/1.414) – 230) / 230) * 100% = 4.5%

4.1.5 DC current injection

The point 5.2.6 of VDE V 0124-100:2020-06 refers to the standard DIN EN 61000-4-7 for the verification of the DC current feed into the low-voltage grid.

This test is only required for inverters without internal transformer.

The equipment shall be operated in the following points at the following active power levels:

- 30.0% P_{Emax} < P < 40.0% P_{Emax}
- 60.0% P_{Emax} < P < 70.0% P_{Emax}
- P > 95.0% P_{Emax}

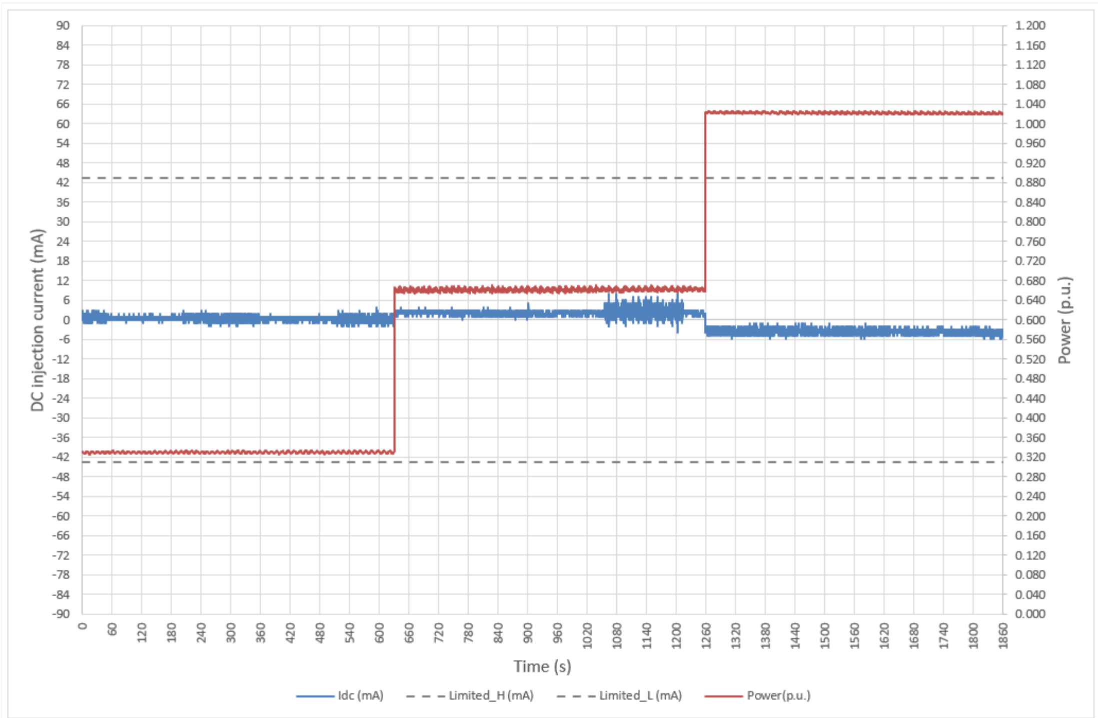
The network or network simulator used for the tests shall meet the following conditions:

- U = U_n ± 5.0%
- f = 50.00 ± 0.20 Hz
- Voltage THD < 2.5%
- DC component of the voltage < 0.1%

Limits given in VDE-AR-N 4100:2019-04 for direct current feed in are 0.5% of the rated current, or 20 mA, whichever is higher.

Operating point	P measured (p.u)	U measured (p.u.)	f measured (Hz)	Iac measured (p.u)	Idc limit (mA)	Idc measured (mA)
30%P_{Emax}<P<40%P_{Emax}	0.330	1.001	50.00	0.046	43	4
60%P_{Emax}<P<70%P_{Emax}	0.662	1.002	50.00	0.092		8
P>95%P_{Emax}	1.022	1.003	50.00	0.069		6

DC component emission test



4.2 THREE-PHASE INVERTER SYSTEMS

This chapter has been done taking into consideration requirements from chapter 5.6 and information of Annex A.4 of the VDE AR-N 4105:2018-11 standard. Chapter 5.3 of the VDE V 0124-100:2020-06 has been used as a testing procedure.

4.2.1 Calculation of asymmetry of three-phase converters

This test is not applicable according to the section 5.3.2 of the standard VDE V 0124-100:2020-06 due to this testing is only applied to three-phase converters.

4.2.2 Symmetrical operation with a symmetry device

This test is not applicable according to the section 5.3.3 of the standard VDE V 0124-100:2020-06 due to this testing is only applied to EZE and storage operating with a symmetry device.

4.3 NORMAL FREQUENCY OPERATING RANGE

According to the paragraph 5.7.1 of the VDE-AR-N 4105:2018-11, in the frequency range of 47.5 Hz to 51.5 Hz, power generation systems shall be capable of network parallel operation in compliance with the time-related minimum requirements given in Table 1.

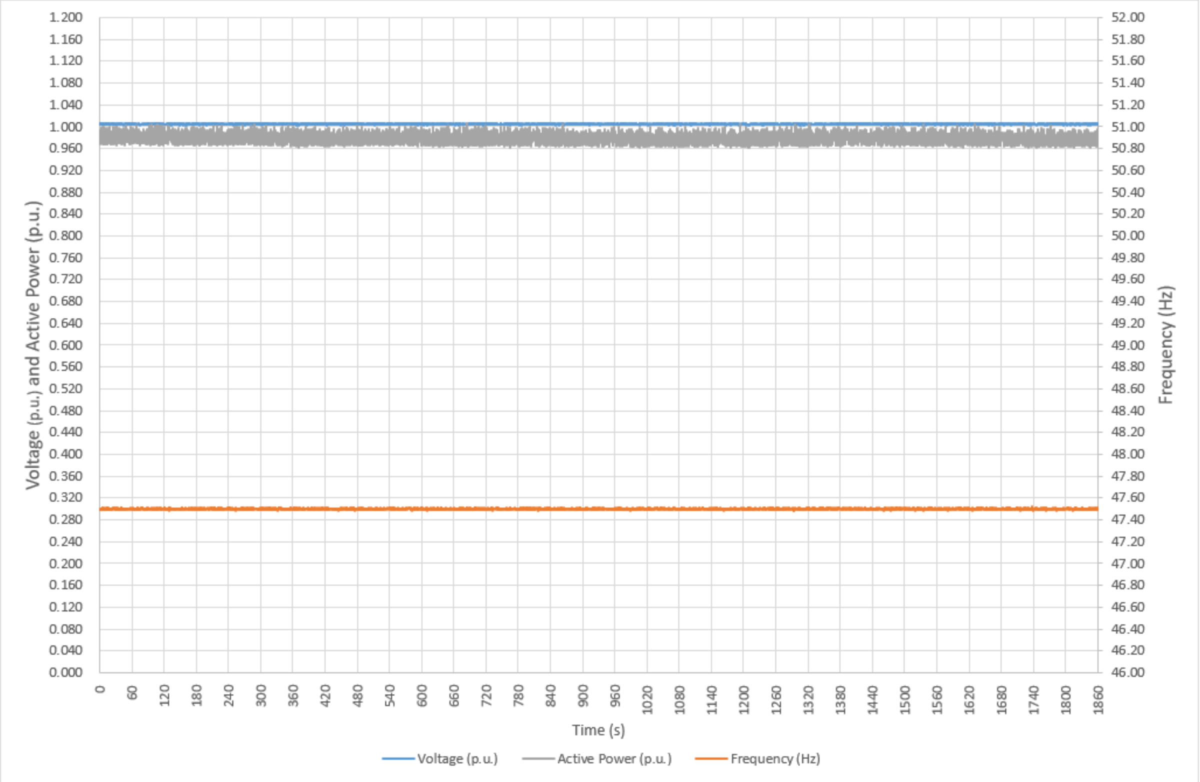
Table 1 – Frequency/time ranges for the proper operation of power generation systems

Frequency range	Operating period
47,5 Hz to 49,0 Hz	≥ 30 min
49,0 Hz to 51,0 Hz	unlimited
51,0 Hz to 51,5 Hz	≥ 30 min

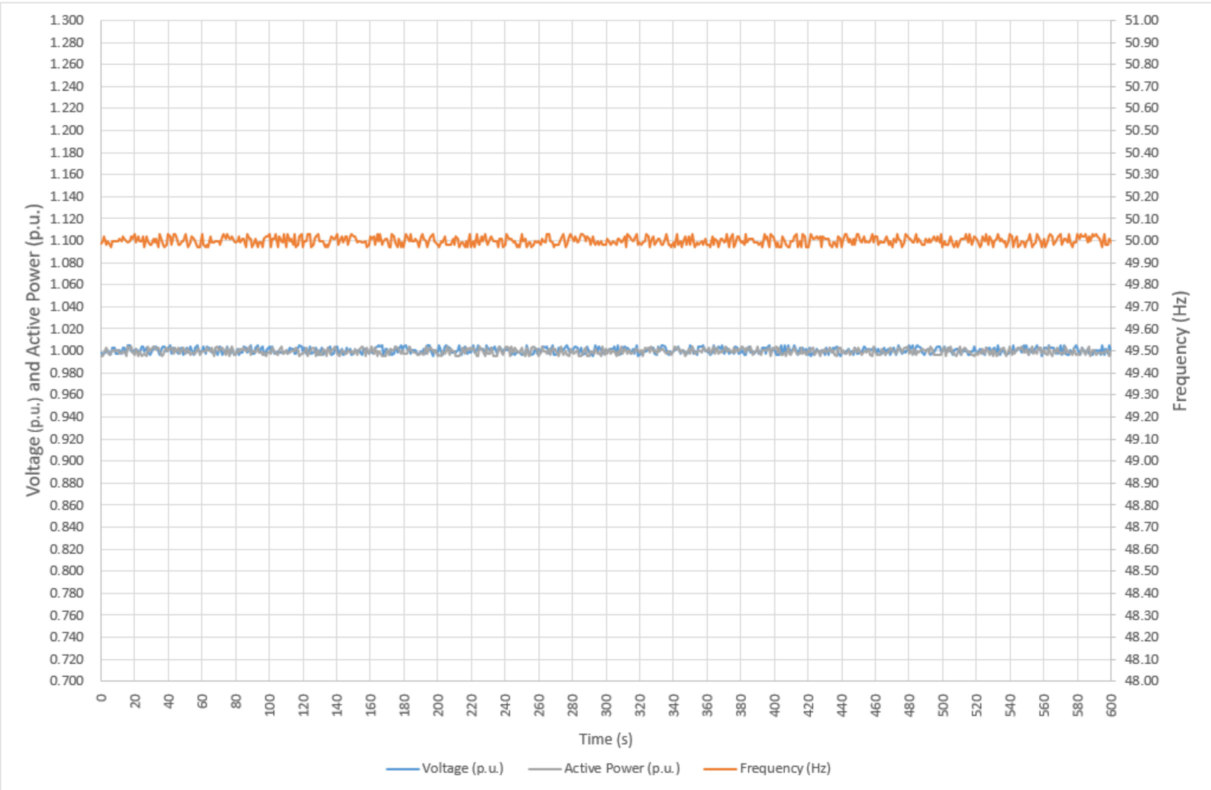
Test results are offered in the following tables and graphs:

Test no.	Voltage setpoint (%Un)	Voltage measured (%Un)	Frequency setpoint (Hz)	Frequency measured (Hz)	Min. time required (min)	Time measured (min)	Active power measured (%Pn)	Disconnection
1	100.0	100.5	47.50	47.50	≥30	31.4	97.8	☐ Yes ☒ No
2	100.0	100.0	50.00	50.00	unlimited	10.0	99.9	☐ Yes ☒ No
3	100.0	100.3	51.50	51.48	≥30	32.0	99.8	☐ Yes ☒ No

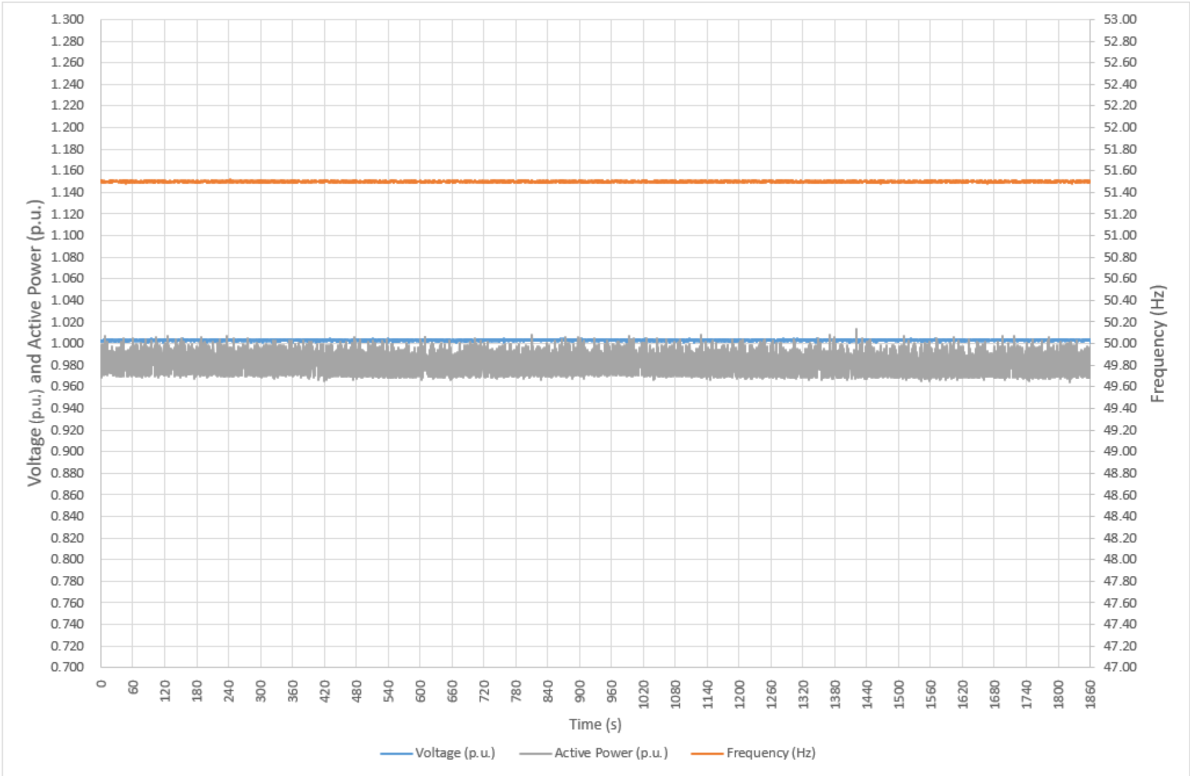
Test 1 (V = 100%Un and F = 47.5 Hz)



Test 2 (V = 100%Un and F = 50.0 Hz)



Test 3 (V = 100%Un and F = 51.5 Hz)



4.4 RoCoF

This test has been done according to chapter 5.7.1 of the VDE AR-N 4105:2018-11 standard to verify that the EUT does not disconnect when submitted to frequency jumps.

For verification of this requirement, different tests have been done regarding different frequency jumps and different mobile time windows in the range 47.5 Hz – 51.5 Hz, at 100 %Pn:

- ± 2 Hz/s for a mobile time window of 0.5 s
- ± 1.5 Hz/s for a mobile time window of 1 s
- ± 1.25 Hz/s for a mobile time window of 2 s

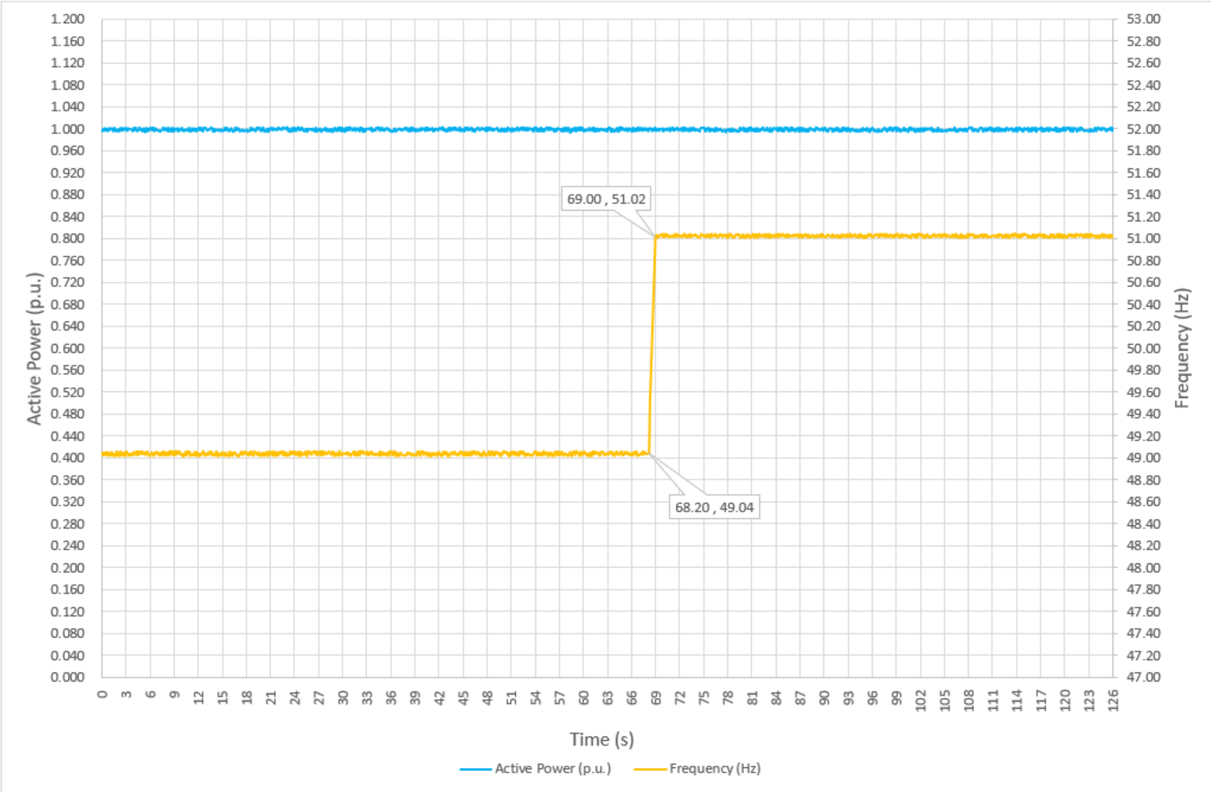
Test results are offered in the following tables and graphs:

Test 1: ± 2 Hz/s					
	Start frequency (Hz)	**Change desired (Hz/s)**	**Final Value (Hz)**	**Ramp (Hz/s)**	**Disconnection**
Positive frequency drift	49.04	+2.00	51.02	+2.48	☒ NO ☐ YES
Negative frequency drift	51.04	-2.00	49.00	-2.58	☒ NO ☐ YES

Test 2: ± 1.5 Hz/s					
	Start frequency (Hz)	**Change desired (Hz/s)**	**Final Value (Hz)**	**Ramp (Hz/s)**	**Disconnection**
Positive frequency drift	49.26	+1.50	50.76	+1.87	☒ NO ☐ YES
Negative frequency drift	50.75	-1.50	49.25	-1.88	☒ NO ☐ YES

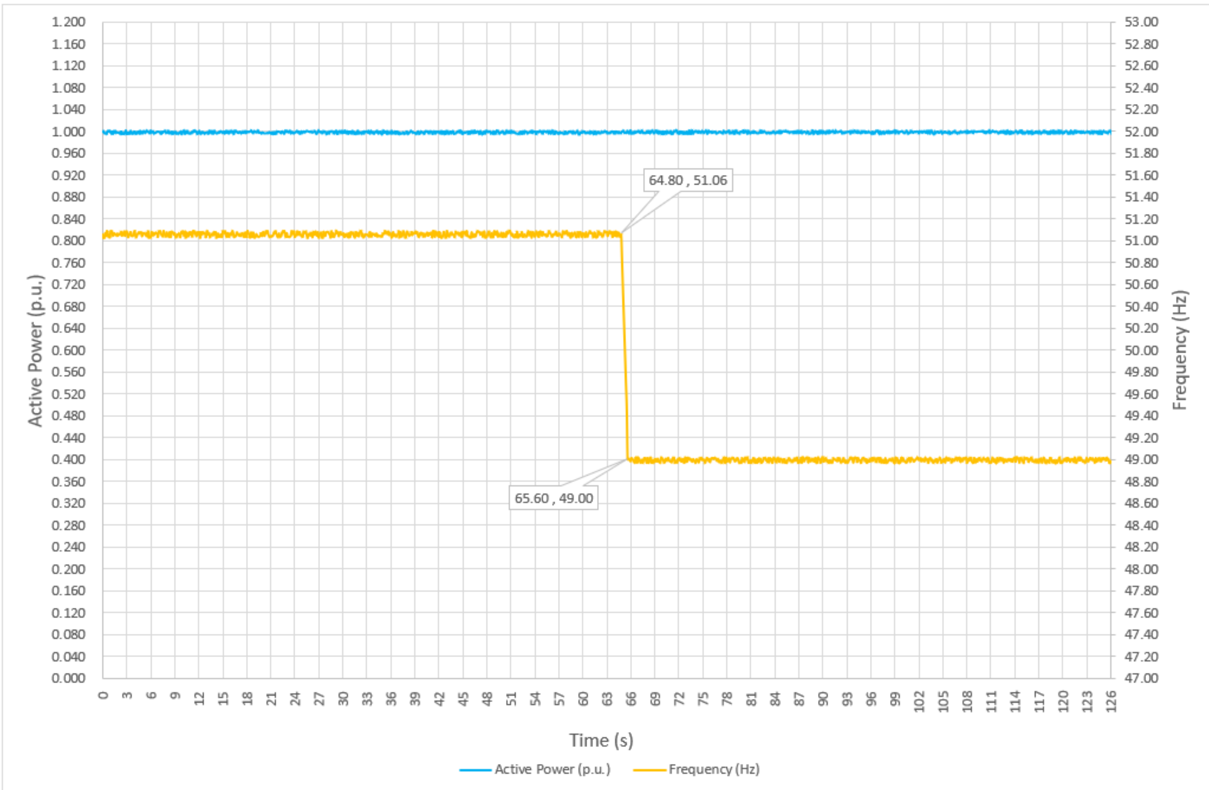
Test 3: ± 1.25 Hz/s					
	Start frequency (Hz)	**Change desired (Hz/s)**	**Final Value (Hz)**	**Ramp (Hz/s)**	**Disconnection**
Positive frequency drift	48.74	+1.25	51.21	+1.30	☒ NO ☐ YES
Negative frequency drift	51.26	-1.25	48.75	-1.32	☒ NO ☐ YES

Test 1 (+2 Hz/s) - Positive frequency drift



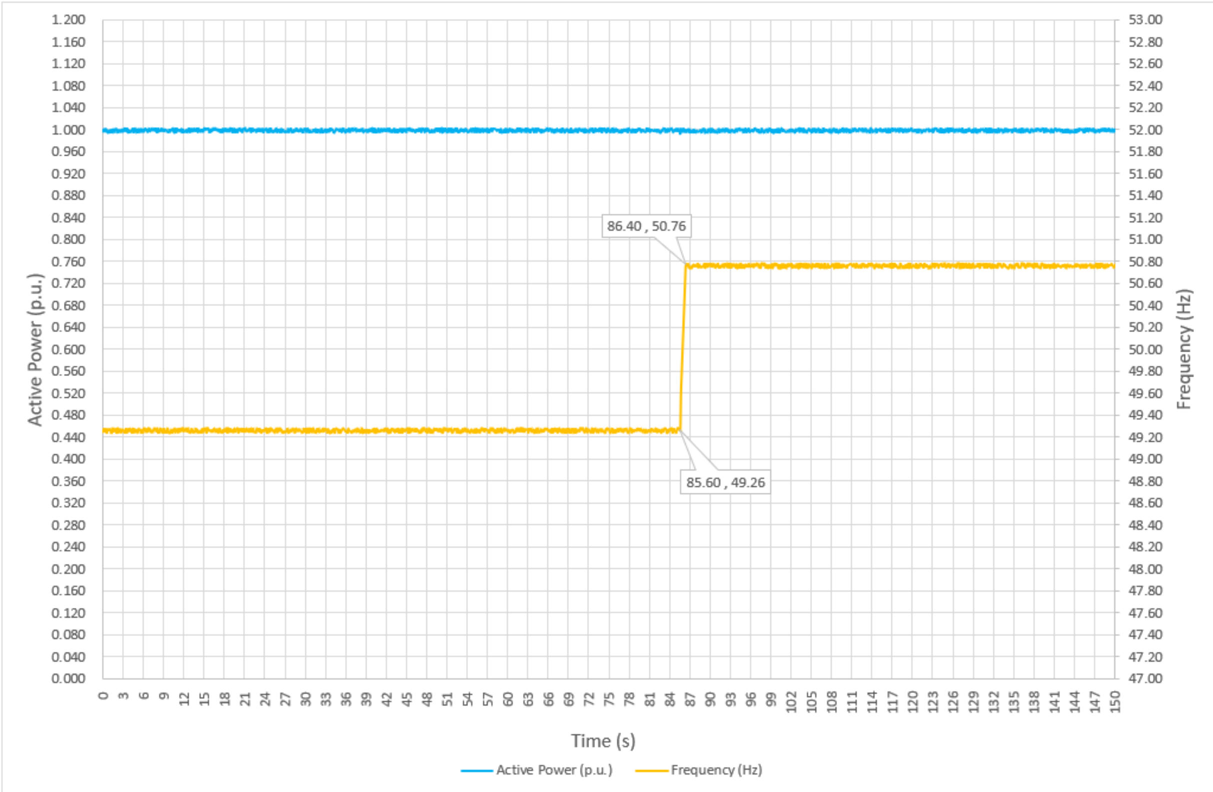
Time of change measured: 800 ms

Test 1 (-2 Hz/s) - Negative frequency drift



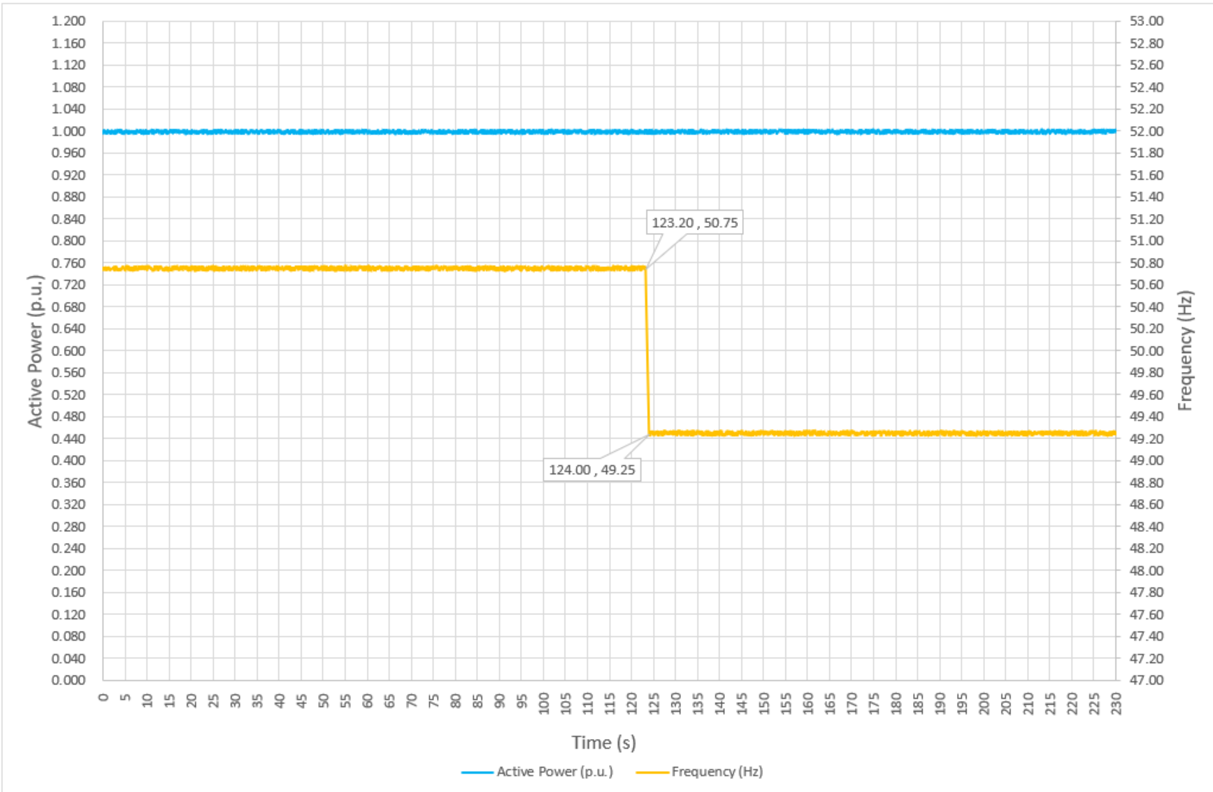
Time of change measured: 800 ms

Test 2 (+1.5 Hz/s) - Positive frequency drift



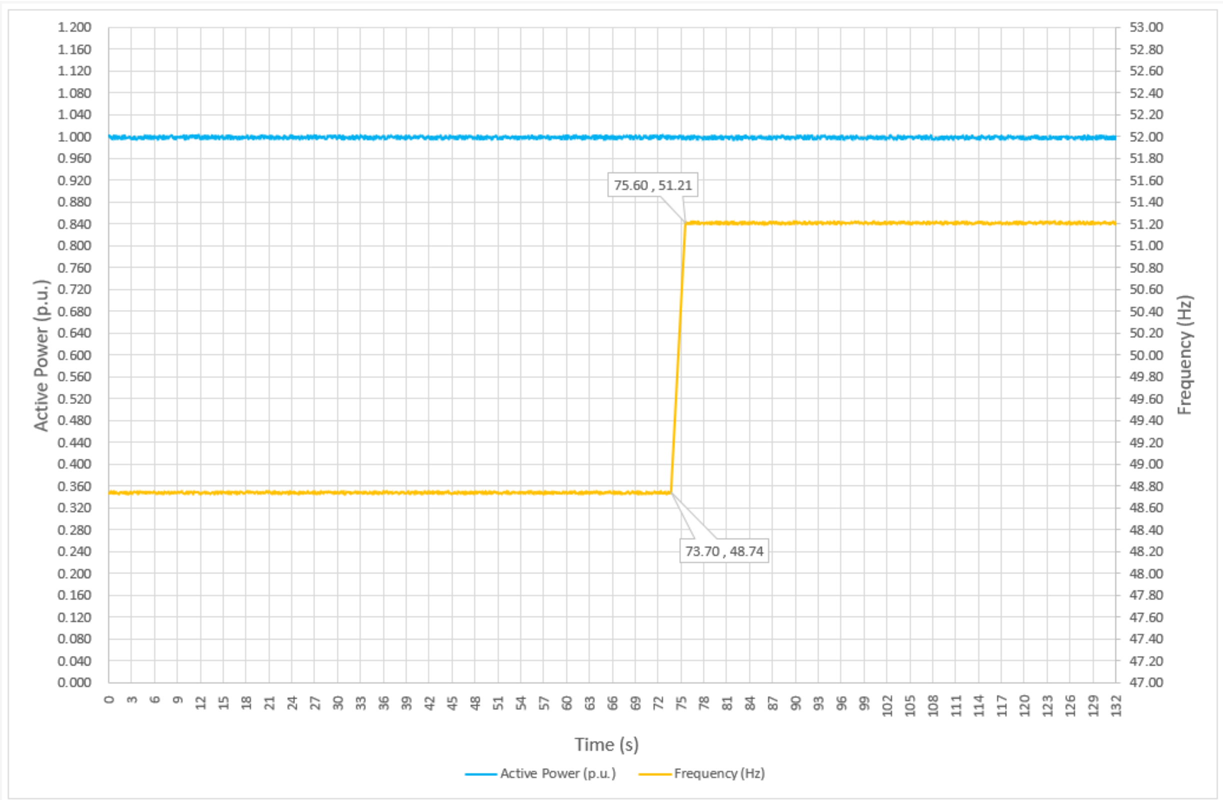
Time of change measured: 800 ms

Test 2 (-1.5 Hz/s) - Negative frequency drift



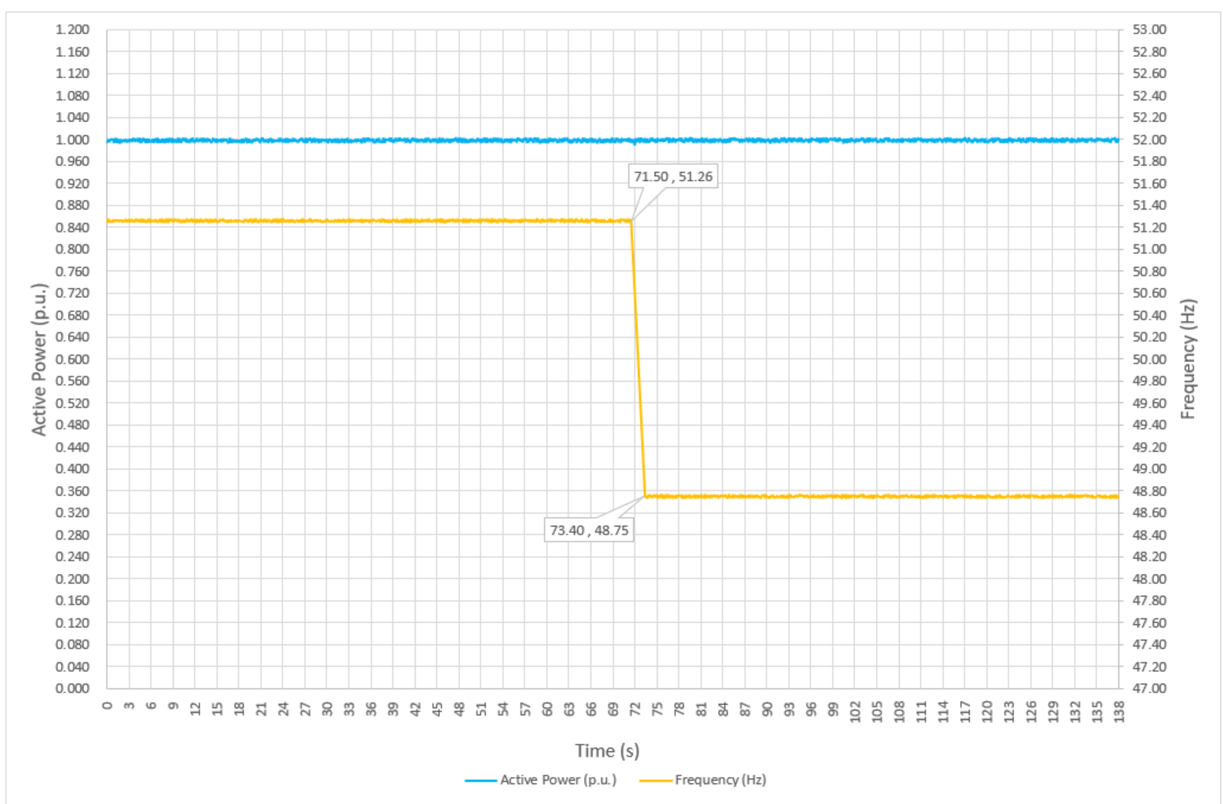
Time of change measured: 800 ms

Test 3 (+1.25 Hz/s) - Positive frequency drift



Time of change measured: 1900 ms

Test 3 (-1.25 Hz/s) - Negative frequency drift



Time of change measured: 1900 ms

4.5 REACTIVE POWER SUPPLY

4.5.1 Reactive power supply at ΣS_{Emax}

This test has been measured according to chapter 5.4.8.2 of VDE V 0124-100:2020-06 to verify requirements from chapter 5.7.2.2 of the VDE AR-N 4105:2018-11 standard. The aim of the test is to verify the following cosφ(U) characteristic and verify the maximum reactive power capacity of the EUT:

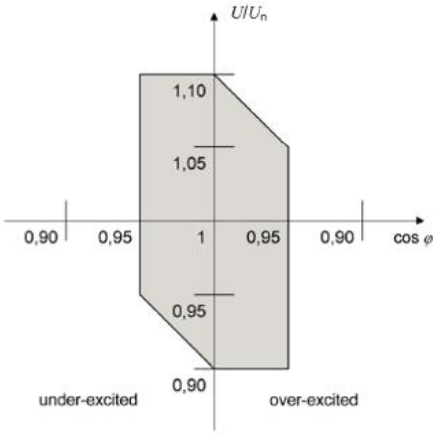


Figure 2 – Requirements for power generation units regarding the reactive power supply at the generator terminals ($\sum S_{Emax} \leq 4{,}6$ kVA)

For this test, 60s average measurements of the following operation points shall be taken at a voltage of 0.900 p.u., 1.000 p.u. and 1.100 p.u., with a 0.020 U p.u. accuracy:

FOR INVERTERS WITH $\Sigma S_{Emax} \leq 4.6$ KVA

- Cos ϕ = 0.950 (Underexcited and overexcited) and cos ϕ = 0.980 (Underexcited and overexcited), at an active power value between 40% P_{Emax} and 60% P_{Emax} and at S_{Emax}.

  Cos ϕ shall be configurable in steps of at least 0.01, measured average shall be ± 0.02 of cos ϕ setpoint.

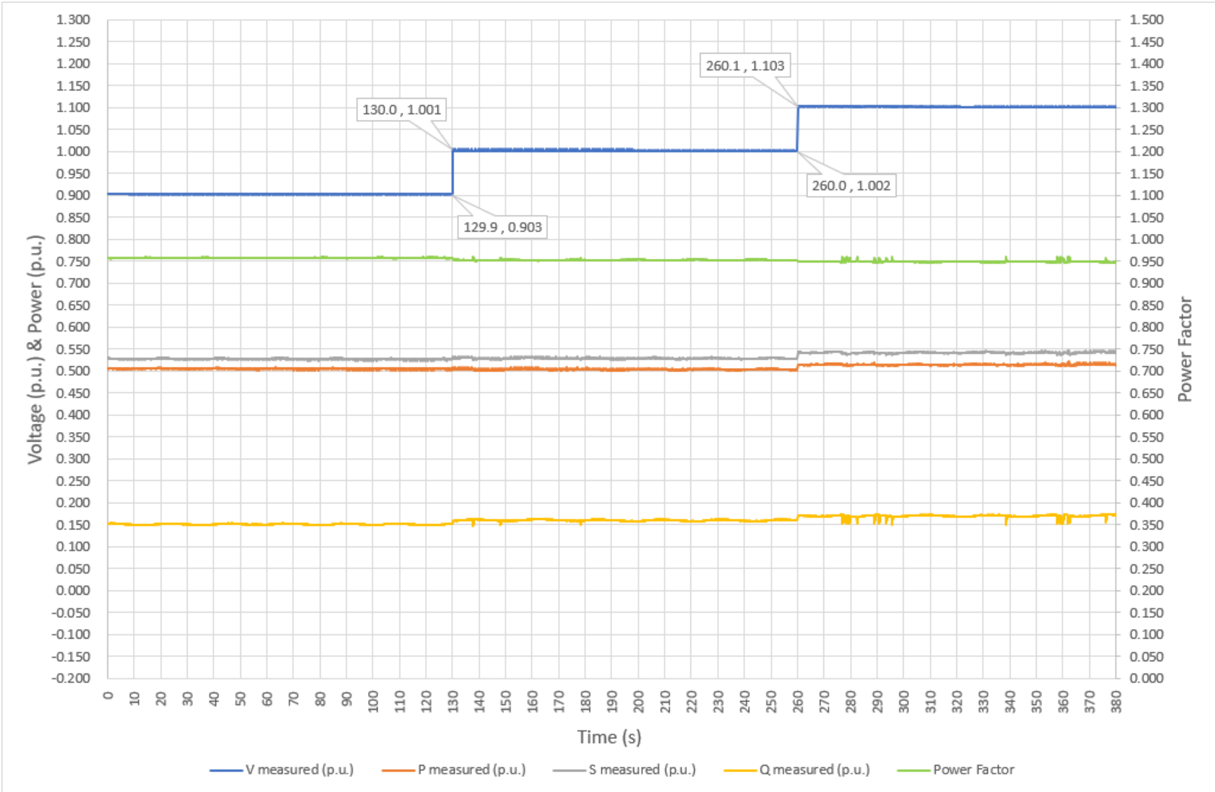
Measured average Q values tolerances are ±4.0% of P_{Emax} of the Q setpoint for each cos ϕ.

4.5.1.1 Active Powe 40%P_{Emax} ≤P setpoint ≤60P_{Emax}

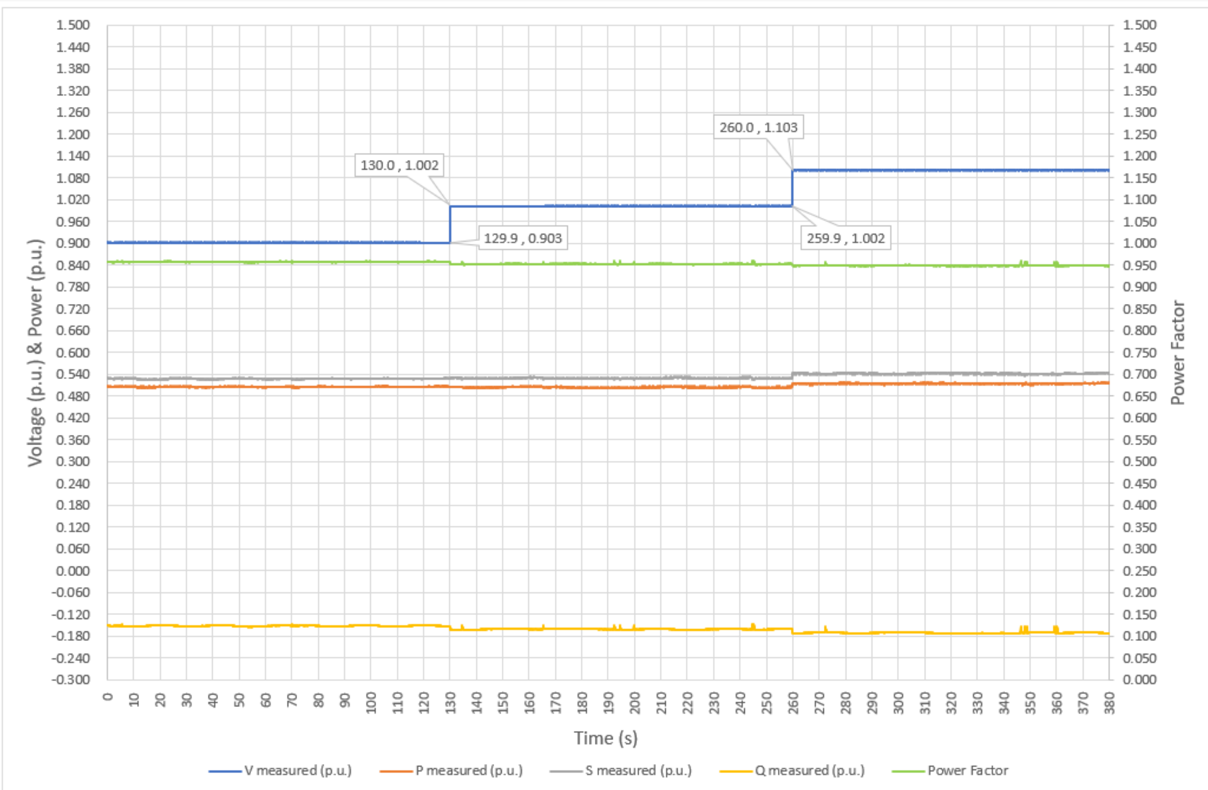
Test results are offered in the following tables and graphs:

40%P_{Emax} ≤P setpoint ≤60%P_{Emax}								
Test 1 (cos phi setpoint = 0.950 inductive)								
Step	**U setpoint (p.u.)**	**U measured ±0.02 (p.u.)**	**P measured (%P_{Emax})**	**Q measured (%P_{Emax})**	**Q setpoint (%P_{Emax})**	**Q deviation (±4.0% P_{Emax})**	**PF measured (±0.02)**	**Time measured (s)**
1	0.900	0.903	50.6	+15.1	+16.4	-1.3	0.958	129.9
2	1.000	1.002	50.4	+16.0	+16.4	-0.4	0.953	130.0
3	1.100	1.102	51.5	+17.0	+16.4	+0.6	0.950	119.9
Test 2 (cos phi setpoint = 0.950 capacitive)								
Step	**U setpoint (p.u.)**	**U measured ±0.02 (p.u.)**	**P measured (%P_{Emax})**	**Q measured (%P_{Emax})**	**Q setpoint (%P_{Emax})**	**Q deviation (±4.0% P_{Emax})**	**PF measured (±0.02)**	**Time measured (s)**
1	0.900	0.902	50.6	-15.1	-16.4	+1.3	0.958	129.9
2	1.000	1.002	50.4	-16.1	-16.4	+0.3	0.953	129.9
3	1.100	1.103	51.5	-17.0	-16.4	-0.6	0.949	120.0
Test 3 (cos phi setpoint = 0.980 inductive)								
Step	**U setpoint (p.u.)**	**U measured ±0.02 (p.u.)**	**P measured (%P_{Emax})**	**Q measured (%P_{Emax})**	**Q setpoint (%P_{Emax})**	**Q deviation (±4.0% P_{Emax})**	**PF measured (±0.02)**	**Time measured (s)**
1	0.900	0.903	50.6	+9.2	+10.2	-1.0	0.984	129.9
2	1.000	1.002	50.9	+10.5	+10.2	+0.3	0.980	129.9
3	1.100	1.102	50.3	+11.0	+10.2	+0.8	0.976	120.0
Test 4 (cos phi setpoint = 0.980 capacitive)								
Step	**U setpoint (p.u.)**	**U measured ±0.02 (p.u.)**	**P measured (%P_{Emax})**	**Q measured (%P_{Emax})**	**Q setpoint (%P_{Emax})**	**Q deviation (±4.0% P_{Emax})**	**PF measured (±0.02)**	**Time measured (s)**
1	0.900	0.903	50.6	-9.2	-10.2	+1.0	0.984	129.9
2	1.000	1.002	50.9	-10.7	-10.2	-0.5	0.979	129.9
3	1.100	1.102	50.0	-10.8	-10.2	-0.6	0.977	120.0

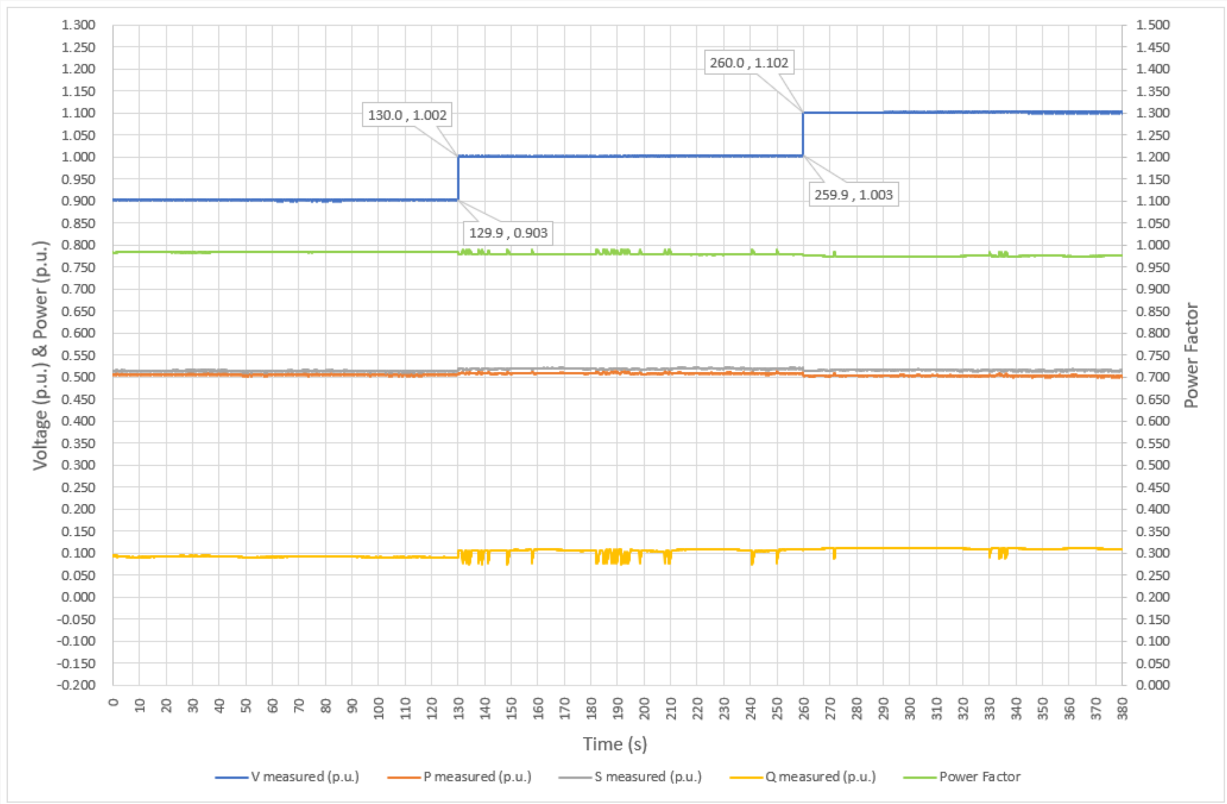
40%P_{Emax} ≤P setpoint ≤60%P_{Emax}
Test 1 (cos phi setpoint = 0.950 inductive) - Chart



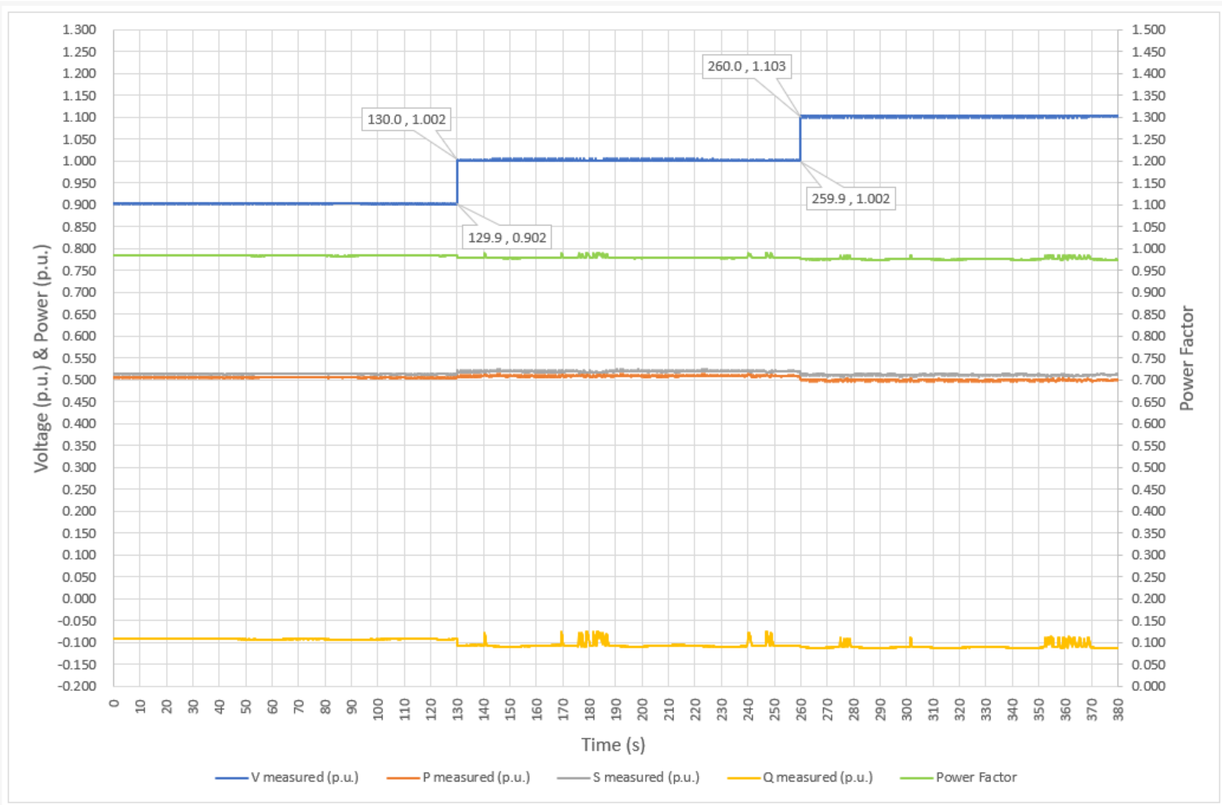
40%P_{Emax} ≤P setpoint ≤60%P_{Emax}
Test 2 (cos phi setpoint = 0.950 capacitive) - Chart



40%P_{Emax} ≤P setpoint ≤60%P_{Emax}
Test 3 (cos phi setpoint = 0.980 inductive) - Chart



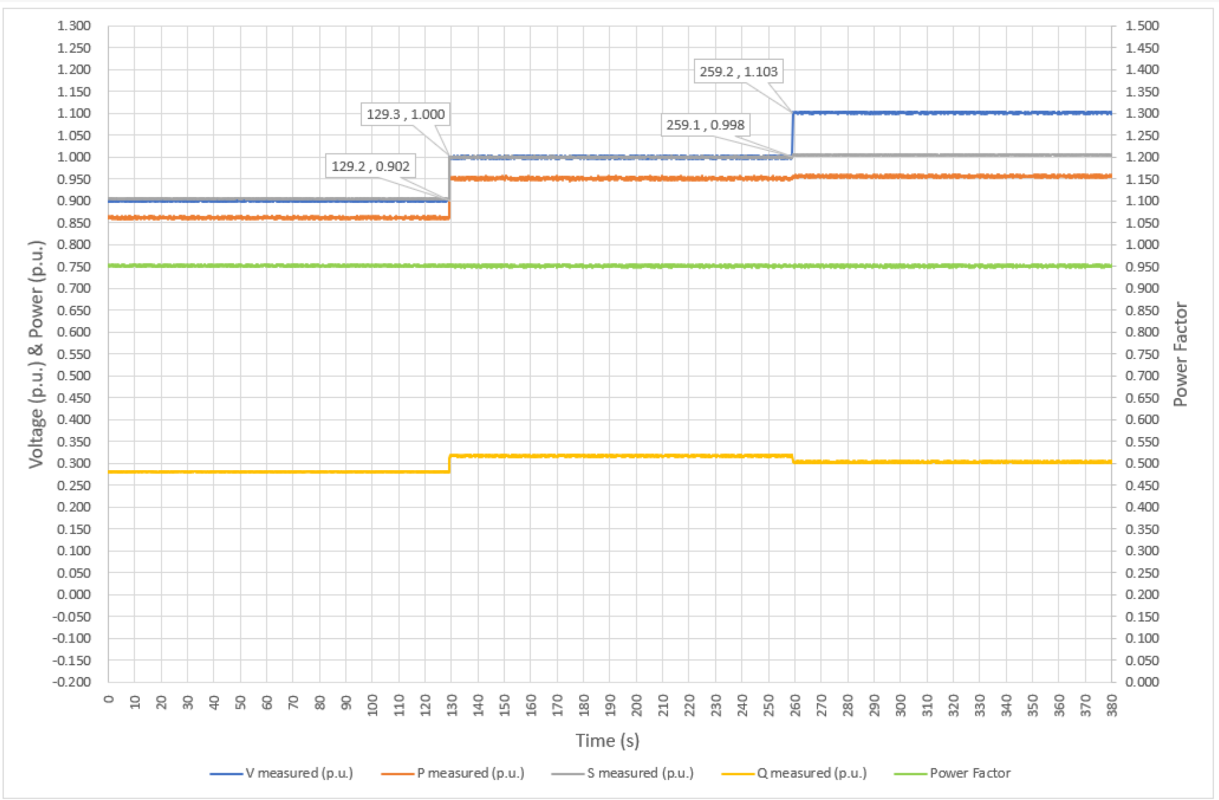
40%P_{Emax} ≤P setpoint ≤60%P_{Emax}
Test 4 (cos phi setpoint = 0.980 capacitive) - Chart



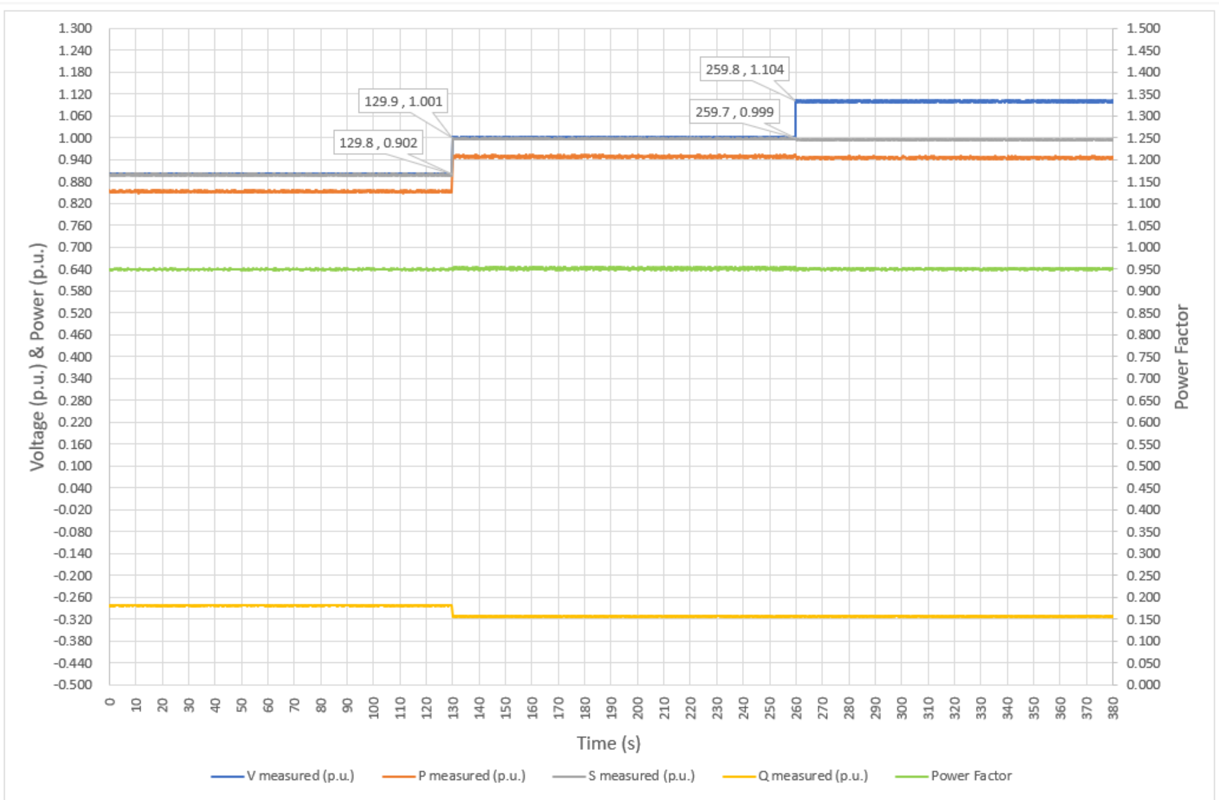
4.5.1.2 S set point = S_{Emax}

S set point = S_{Emax}								
Test 1 (cos phi setpoint = 0.950 inductive)								
Step	**U setpoint (p.u.)**	**U measured ±0.02 (p.u.)**	**P measured (%P_{Emax})**	**Q measured (%P_{Emax})**	**Q setpoint (%P_{Emax})**	**Q deviation (±4.0% P_{Emax})**	**PF measured (±0.02)**	**Time measured (s)**
1	0.900	0.901	86.2	+28.1	+28.1	0.0	0.952	129.2
2	1.000	1.000	95.2	+31.7	+31.2	+0.5	0.952	129.8
3	1.100	1.102	95.7	+30.3	+31.2	-0.9	0.952	120.8
Test 2 (cos phi setpoint = 0.950 capacitive)								
Step	**U setpoint (p.u.)**	**U measured ±0.02 (p.u.)**	**P measured (%P_{Emax})**	**Q measured (%P_{Emax})**	**Q setpoint (%P_{Emax})**	**Q deviation (±4.0% P_{Emax})**	**PF measured (±0.02)**	**Time measured (s)**
1	0.900	0.901	85.3	-28.2	-28.1	-0.1	0.950	129.8
2	1.000	1.000	94.9	-31.2	-31.2	0.0	0.951	129.8
3	1.100	1.100	94.5	-31.2	-31.2	0.0	0.950	120.2
Test 3 (cos phi setpoint = 0.980 inductive)								
Step	**U setpoint (p.u.)**	**U measured ±0.02 (p.u.)**	**P measured (%P_{Emax})**	**Q measured (%P_{Emax})**	**Q setpoint (%P_{Emax})**	**Q deviation (±4.0% P_{Emax})**	**PF measured (±0.02)**	**Time measured (s)**
1	0.900	0.900	89.1	+17.9	+17.9	0.0	0.982	129.8
2	1.000	1.000	98.6	+20.0	+19.9	+0.1	0.982	129.8
3	1.100	1.100	98.3	+19.9	+19.9	0.0	0.979	120.2
Test 4 (cos phi setpoint = 0.980 capacitive)								
Step	**U setpoint (p.u.)**	**U measured ±0.02 (p.u.)**	**P measured (%P_{Emax})**	**Q measured (%P_{Emax})**	**Q setpoint (%P_{Emax})**	**Q deviation (±4.0% P_{Emax})**	**PF measured (±0.02)**	**Time measured (s)**
1	0.900	0.901	85.3	-28.2	-17.9	-0.1	0.950	129.8
2	1.000	1.000	94.9	-31.2	-19.9	0.0	0.951	129.8
3	1.100	1.100	94.5	-31.2	-19.9	0.0	0.950	120.2

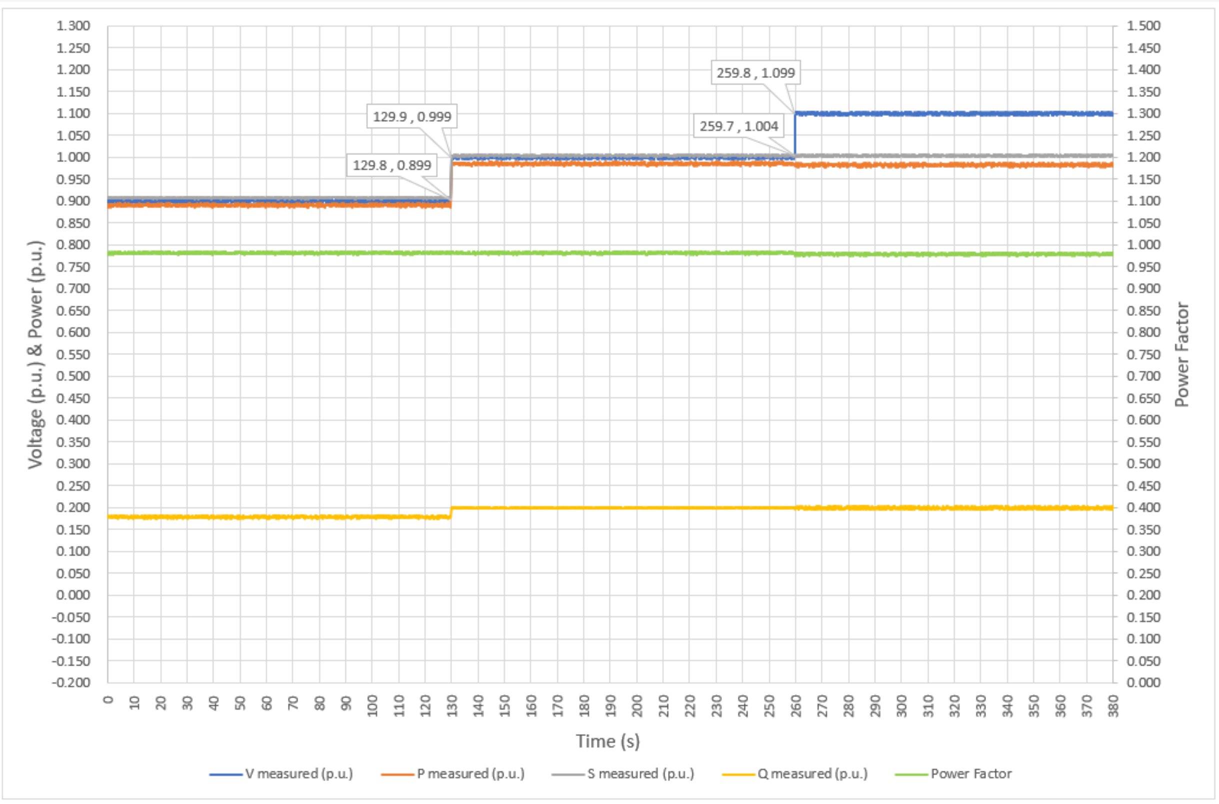
S set point = S_{Emax}
Test 3 (cos phi setpoint = 0.950 inductive) - Chart



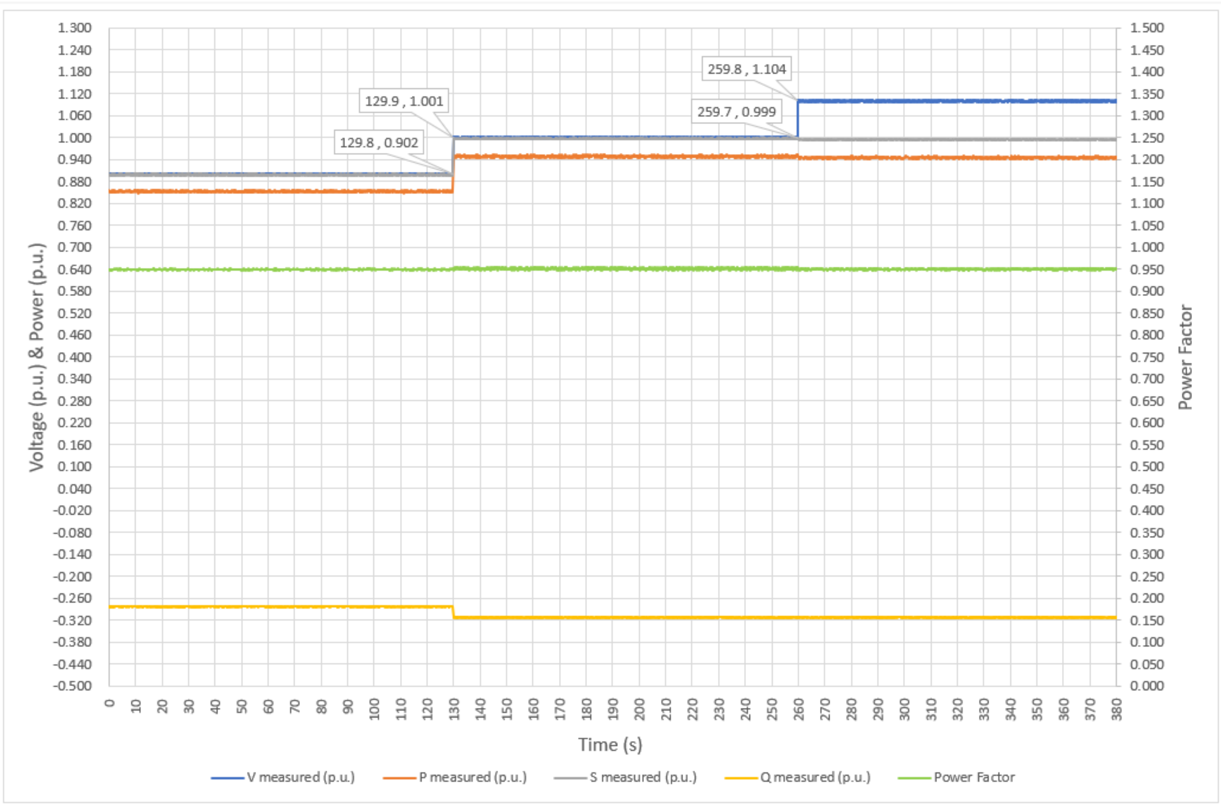
S set point = S_{Emax}
Test 4 (cos phi setpoint = 0.950 capacitive) - Chart



S set point = S_{Emax}
Test 3 (cos phi setpoint = 0.980 inductive) - Chart



S set point = S_{Emax}
Test 4 (cos phi setpoint = 0.980 capacitive) - Chart



4.5.2 Reactive power supply smaller than P_{Emax}

This test has been done to verify requirements from chapter 5.7.2.3 of the VDE AR-N 4105:2018-11 standard. The aim of the test is to verify the following P/Q characteristic:

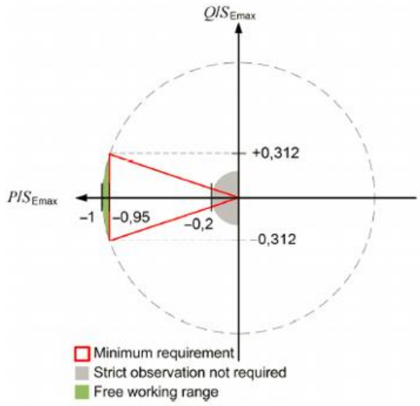


Figure 5 – *P/Q* diagram for type 2 $\sum S_{Emax} \le 4{,}6$ kVA and type 1, stirling generator, fuel cell $\sum S_{Emax} > 4{,}6$ kVA at the generator terminals in the passive sign convention system

Within the range of $0 \le P_{mom}/P_{Emax} < 0.100$ / 0.200 (or the agreed minimum technical power) the power generation unit shall not exceed the reactive power value at the generator terminals of 10 % of the active power value P_{Emax} (reactive power supply and consumption respectively).

Within the free working range, a reduction of the active power to the benefit of the reactive power is permitted.

The following tests have been done:

- Test 1: Power factor of 0.900 over-excited measuring steps of 5%P_n
- Test 2: Power factor of 0.900 under-excited measuring steps of 5%P_n
- Test 3: Power factor of 1.000 measuring steps of 5%P_n
- Test 4: Power factor of 0.900 over-excited with 20%P_n, 50%P_n and 90%P_n setpoints
- Test 5: Power factor of 0.900 under-excited with 20%P_n, 50%P_n and 90%P_n setpoints

Tests 1, 2 and 3 have been performed to confirm that the equipment complies with the minimum capabilities. Tests 4 and 5 have been performed to check the dynamics of the reactive power provision.

- Only red triangle area is Required, with tolerance: ±4% of P_{Emax}
- When operated at <20% P_{Emax} (figure 5), or <10% P_{Emax} (figure 6), reactive power <10% P_{Emax}

Note:

1. The unit can meet the requirements according to Figure 5, then the tests is completed with PF=0.9 instead of 0.95.
2. Tests 4 and 5 are not applicable according to the section 5.4.8.3 of the standard VDE V 0124-100:2020-06, due to for guided EZE dynamics: A test of the PT1 behaviour of the transition dynamics specified in VDE-AR-N 4105: 2018-11 is not necessarily due to the required limitations of the active power gradient.

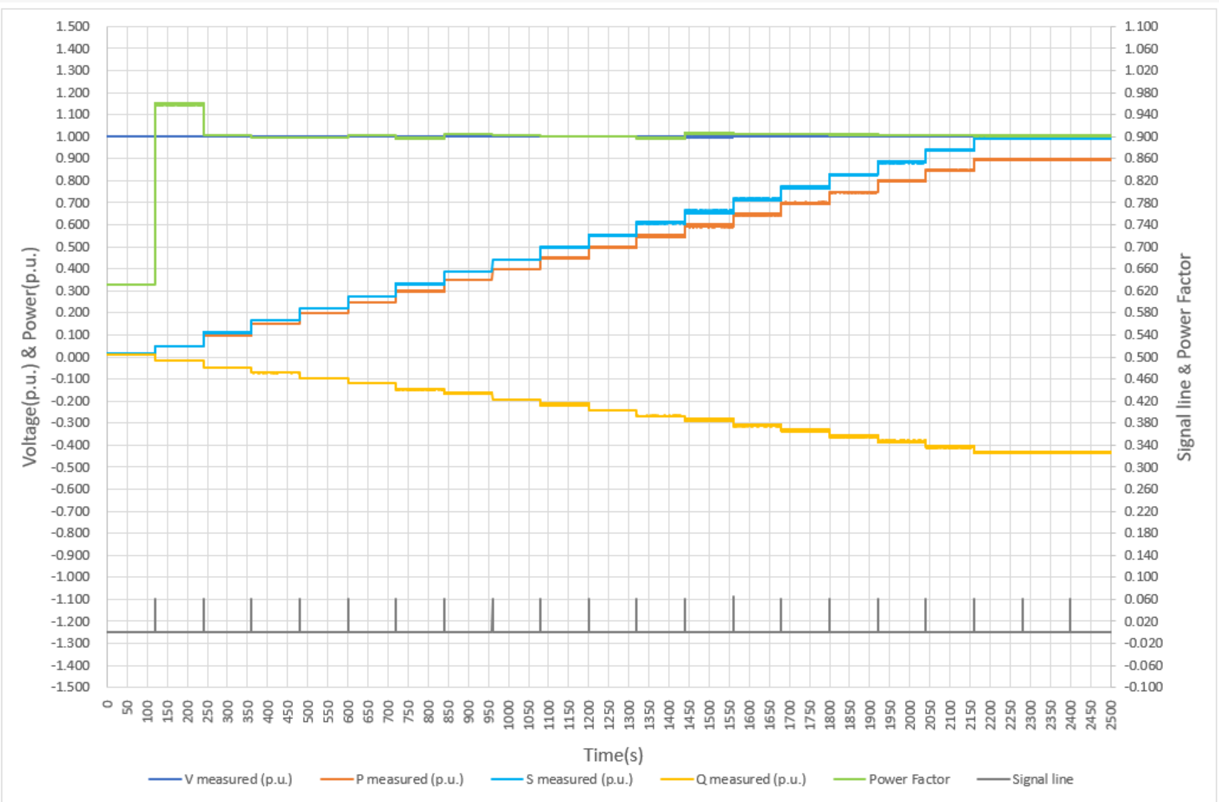
4.5.2.1 Test 1: Power factor of 0.900 over-excited measuring steps of 5%Pn

Test results are offered in the following tables and graphs:

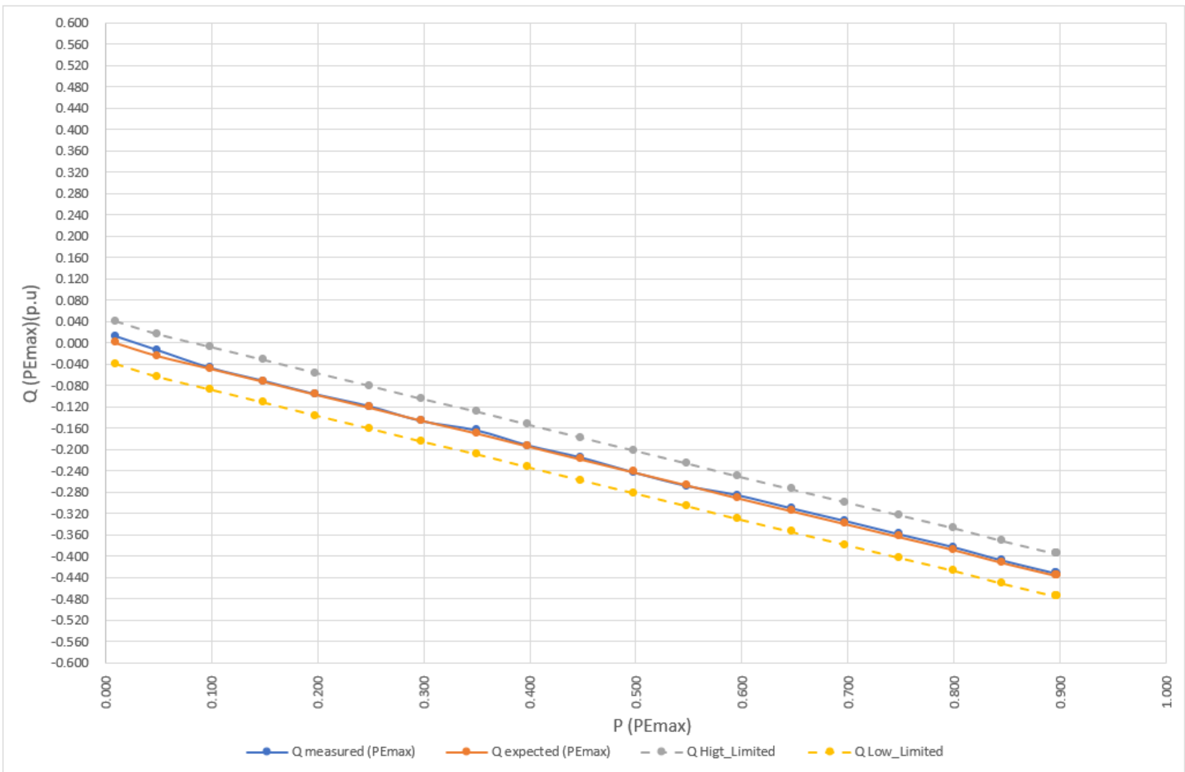
Test 1 Triangular Curve (PF = 0.9 / Capacitive)							
P Setting (% P_{Emax})	U Measured (p.u.)	P Measured (%P_{Emax})	S Measured (%P_{Emax})	Q Measured (%P_{Emax})	Q Desired (%P_{Emax})	Q Deviation (±4.0 %P_{Emax})	Δ cos φ Measured
0.0(1)	1.000	0.9	1.5	1.2	0.0	1.2	--
5.0(1)	1.000	4.9	5.1	-1.4	-2.4	1.0	--
10.0	1.000	9.9	11.0	-4.8	-4.8	0.0	0.902
15.0	1.000	14.9	16.6	-7.2	-7.3	0.1	0.899
20.0	1.000	19.8	22.1	-9.7	-9.7	0.0	0.898
25.0	1.000	24.9	27.6	-11.9	-12.1	0.2	0.902
30.0	1.001	29.8	33.2	-14.7	-14.5	-0.2	0.897
35.0	1.001	35.0	38.8	-16.5	-17.0	0.5	0.904
40.0	1.001	39.9	44.2	-19.3	-19.4	0.1	0.902
45.0	1.001	44.8	49.8	-21.5	-21.8	0.3	0.900
50.0	1.001	49.8	55.3	-24.3	-24.2	-0.1	0.900
55.0	1.001	54.8	61.1	-26.8	-26.6	-0.2	0.897
60.0	1.001	59.6	65.8	-28.6	-29.1	0.5	0.906
65.0	1.001	64.7	71.5	-31.0	-31.5	0.5	0.905
70.0	1.001	69.8	77.1	-33.4	-33.9	0.5	0.905
75.0	1.002	74.8	82.8	-35.9	-36.3	0.4	0.904
80.0	1.001	80.0	88.5	-38.3	-38.7	0.4	0.903
85.0	1.001	84.6	93.8	-40.8	-41.2	0.4	0.902
90.0	1.002	89.7	99.4	-43.3	-43.6	0.3	0.902
95.0	1.001	89.7(2)	99.5	-43.3	-43.6	0.3	0.902
100.0	1.002	89.6(2)	99.4	-43.3	-43.6	0.3	0.902

(1) When the active power is less than 10% P_{Emax}, the reactive power limitation is <10% P_{Emax}.
(2) The maximum active power is not reached due to the current limitation.

Test 1 Triangular Curve (PF = 0.9 / Capacitive)



Test 1 PQ Curve



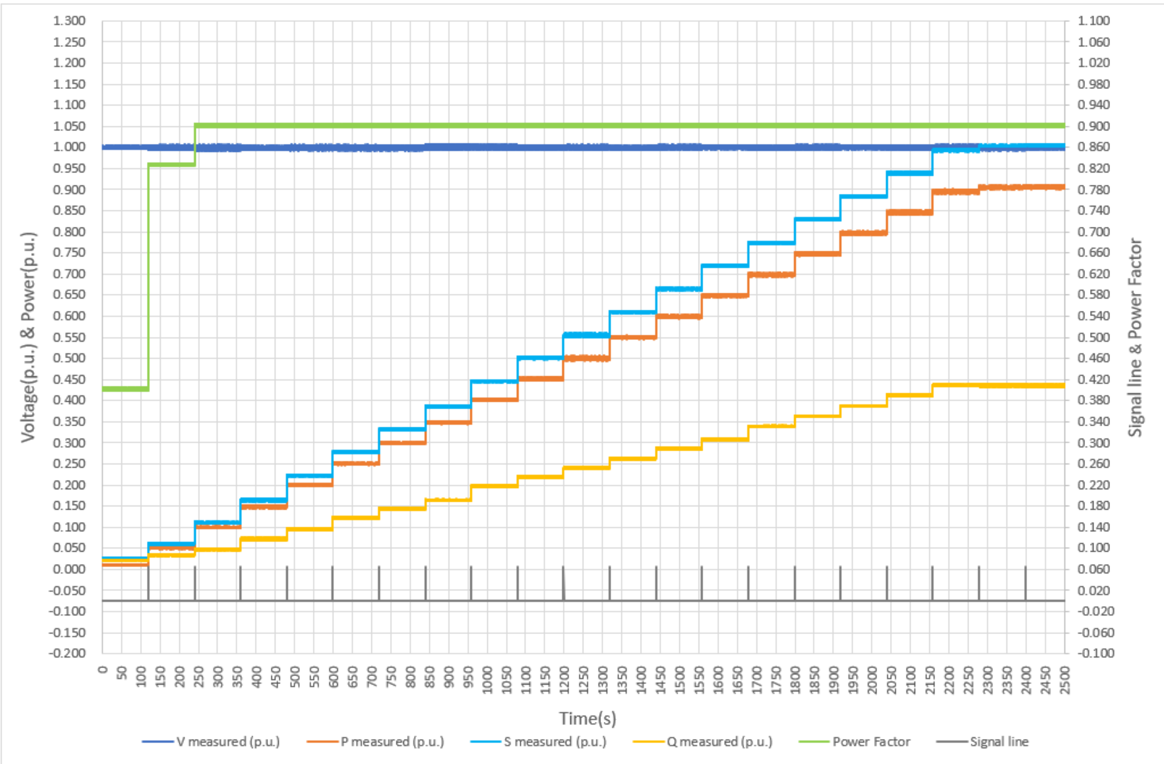
4.5.2.2 Test 2: Power factor of 0.900 under-excited measuring steps of 5%Pn

Test results are offered in the following tables and graphs:

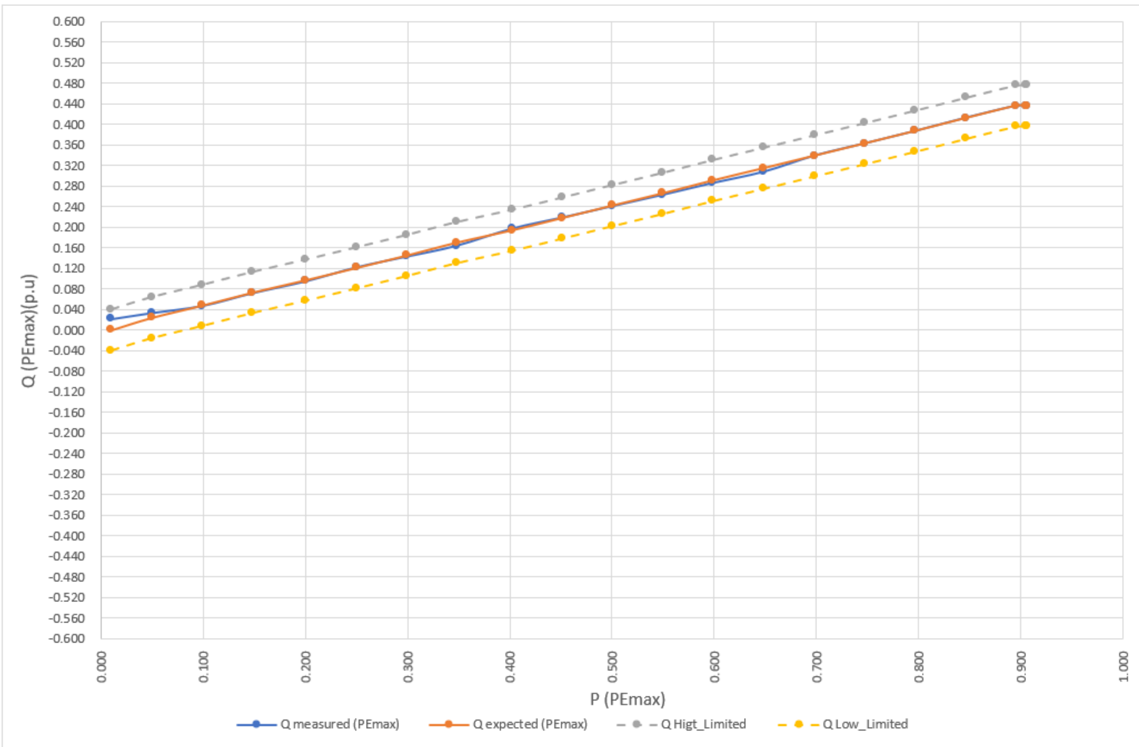
Test 2 Triangular Curve (PF = 0.9 / Inductive)							
P Setting (% P_{Emax})	U Measured (p.u.)	P Measured (% P_{Emax})	S Measured (% P_{Emax})	Q Measured (% P_{Emax})	Q Desired (% P_{Emax})	Q Deviation (±4.0 % P_{Emax})	Δ cos φ Measured
0.0[(1)]	1.000	1.0	2.6	2.2	0.0	2.2	--
5.0[(1)]	1.000	5.0	6.0	3.3	2.4	0.9	--
10.0	0.999	9.9	11.0	4.7	4.8	-0.1	0.902
15.0	0.999	14.8	16.5	7.2	7.3	-0.1	0.902
20.0	1.000	20.0	22.2	9.5	9.7	-0.2	0.902
25.0	0.999	25.0	27.8	12.2	12.1	0.1	0.901
30.0	0.999	29.9	33.2	14.3	14.5	-0.2	0.902
35.0	1.001	34.8	38.6	16.4	17.0	-0.6	0.902
40.0	1.001	40.2	44.6	19.7	19.4	0.3	0.902
45.0	1.000	45.2	50.1	21.9	21.8	0.1	0.902
50.0	1.000	50.0	55.5	24.1	24.2	-0.1	0.902
55.0	0.999	55.0	61.0	26.3	26.6	-0.3	0.902
60.0	1.001	59.9	66.4	28.6	29.1	-0.5	0.901
65.0	1.000	64.9	72.0	30.8	31.5	-0.7	0.901
70.0	1.000	69.8	77.4	33.9	33.9	0.0	0.902
75.0	1.000	74.8	83.0	36.3	36.3	0.0	0.901
80.0	1.000	79.7	88.4	38.7	38.7	0.0	0.901
85.0	1.000	84.6	93.9	41.3	41.2	0.1	0.901
90.0	1.001	89.6	99.3	43.6	43.6	0.0	0.902
95.0	0.999	90.6[(2)]	100.4	43.6	43.6	0.0	0.902
100.0	1.000	90.6[(2)]	100.5	43.6	43.6	0.0	0.901

(1) When the active power is less than 10% P_{Emax}, the reactive power limitation is <10% P_{Emax}.
(2) The maximum active power is not reached due to the current limitation.

Test 2 Triangular Curve (PF = 0.9 / Inductive)



Test 2 PQ Curve

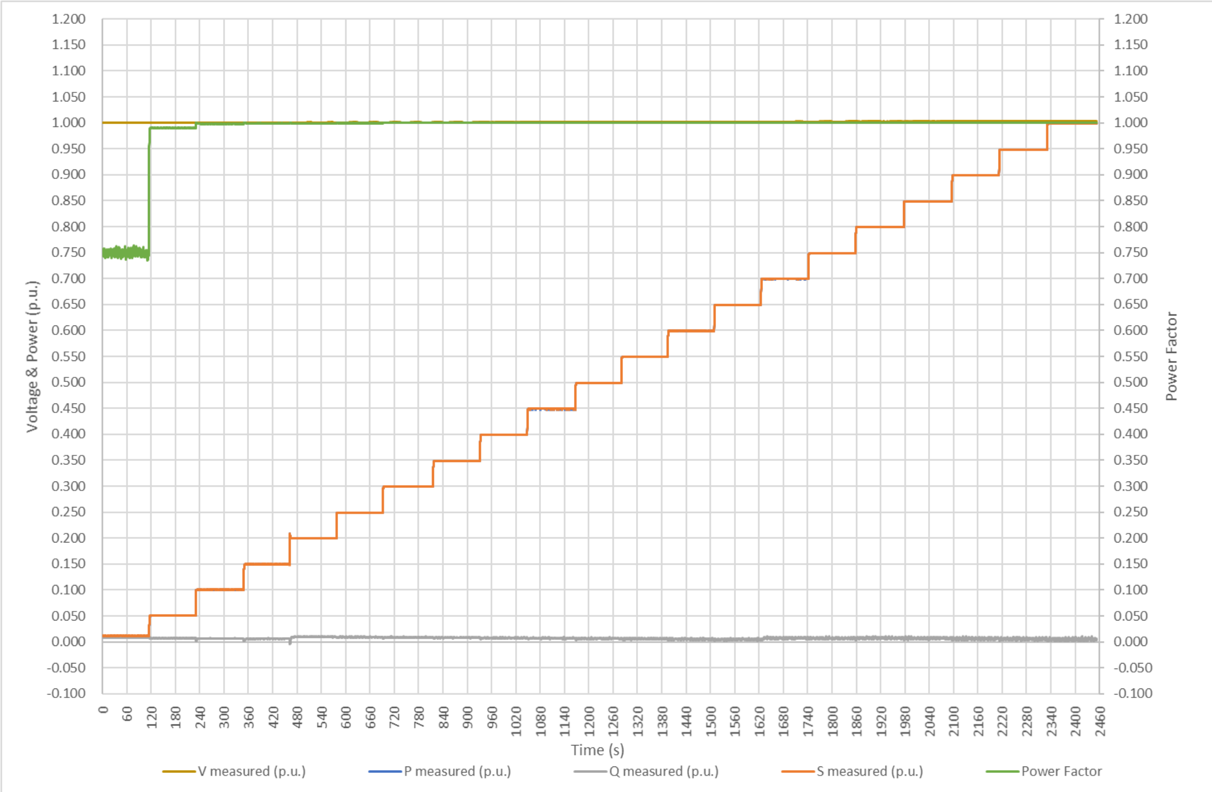


4.5.2.3 Test 3: Power factor of 1.000 measuring steps of 5%Pn

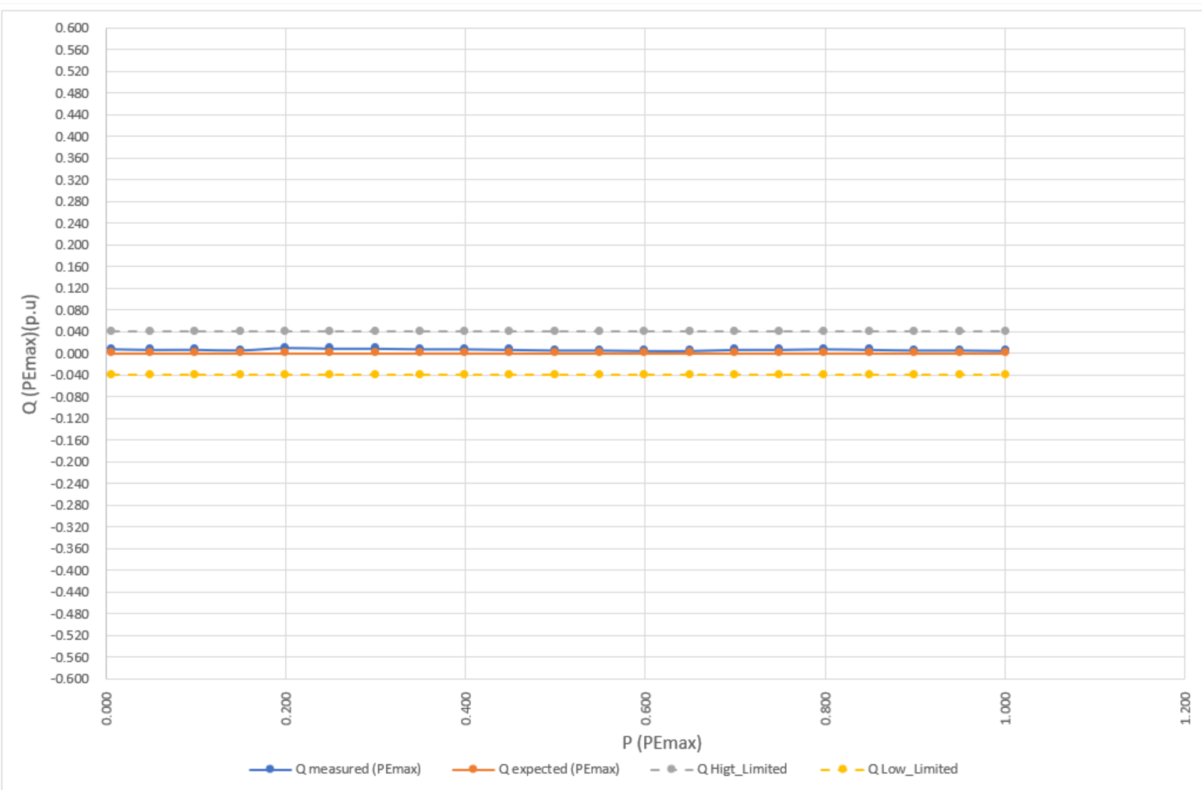
Test 2 Triangular Curve (PF = 1.000)							
P Setting (% P_{Emax})	U Measured (p.u.)	P Measured (%P_{Emax})	S Measured (%P_{Emax})	Q Measured (%P_{Emax})	Q Desired (%P_{Emax})	Q Deviation (±4 .0%P_{Emax})	Δ cos φ Measured
0.0(1)	1.001	0.7	0.9	0.8	0.0	0.8	--
5.0(1)	1.000	5.0	5.0	0.7	0.0	0.7	--
10.0	1.000	10.0	10.0	0.7	0.0	0.7	1.000
15.0	1.000	15.0	15.0	0.6	0.0	0.6	1.000
20.0	1.000	20.0	20.0	1	0.0	1.0	1.000
25.0	1.000	25.0	25.0	0.9	0.0	0.9	1.000
30.0	0.999	30.0	30.0	0.9	0.0	0.9	1.000
35.0	1.000	35.0	35.0	0.8	0.0	0.8	1.000
40.0	1.000	40.0	40.0	0.8	0.0	0.8	1.000
45.0	0.999	45.0	45.0	0.7	0.0	0.7	1.000
50.0	0.999	50.0	50.0	0.6	0.0	0.6	1.000
55.0	0.999	55.0	55.0	0.6	0.0	0.6	1.000
60.0	0.999	60.0	60.0	0.5	0.0	0.5	1.000
65.0	1.000	65.0	65.0	0.5	0.0	0.5	1.000
70.0	1.000	70.0	70.0	0.7	0.0	0.7	1.000
75.0	1.000	75.0	75.0	0.7	0.0	0.7	1.000
80.0	0.999	80.0	80.0	0.8	0.0	0.8	1.000
85.0	0.999	85.0	85.0	0.7	0.0	0.7	1.000
90.0	0.999	90.0	90.0	0.6	0.0	0.6	1.000
95.0	0.999	95.1	95.1	0.6	0.0	0.6	1.000
100.0	0.999	100.2	100.3	0.5	0.0	0.5	1.000

(1) When the active power is less than 10% P_{Emax}, the reactive power limitation is <10% P_{Emax}.

Setting cos φ = 1.000 (in steps of 5 % P_{Emax})



Test 3 PQ Curve

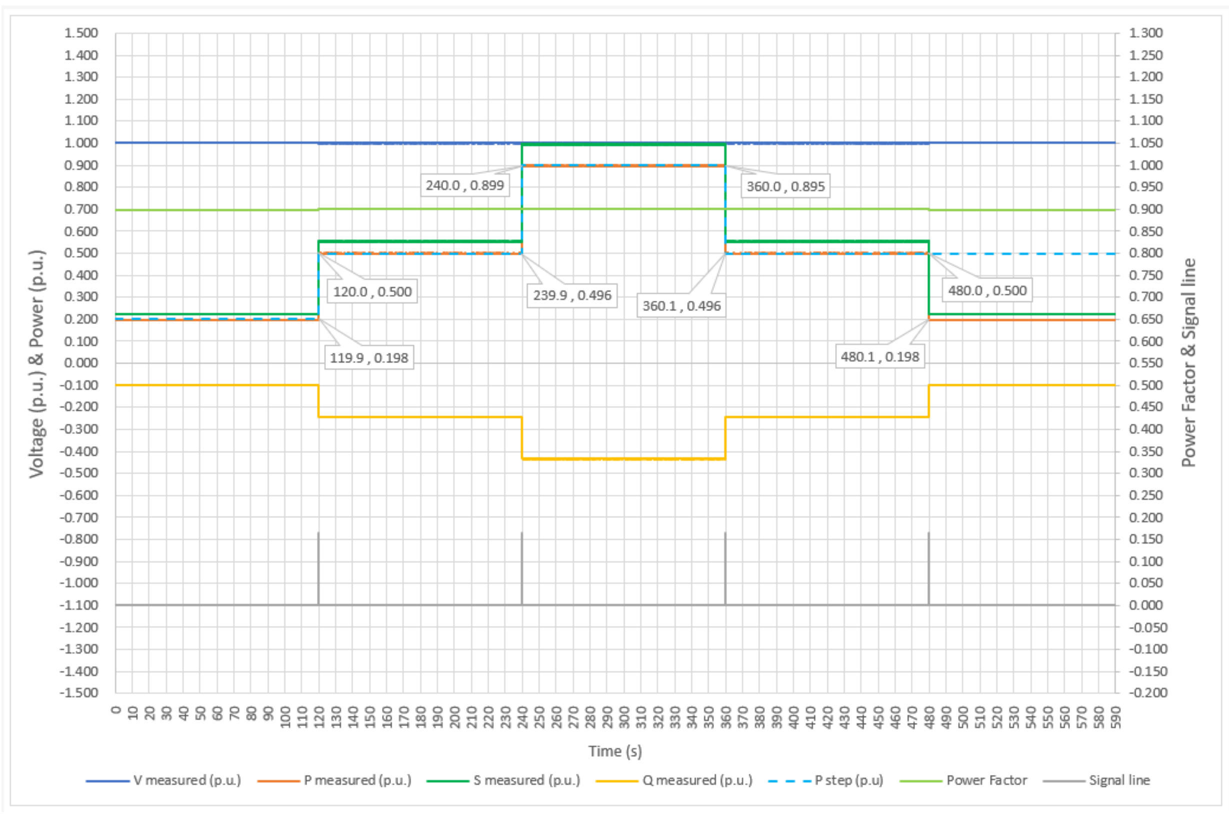


4.5.2.4 Test 4: Power factor of 0.900 over-excited with 20%Pn, 50%Pn and 90%Pn setpoints

Test results are offered in the following tables and graphs:

Test 4 Triangular Curve (PF = 0.9 / Capacitive)						
P step (%P_{Emax})	P measured (%P_{Emax})	Q measured (%P_{Emax})	Q desired (%P_{Emax})	Q deviation (±4.0%P_{Emax})	Δ cos φ Measured	Transient period (s)
20.0	0.198	-0.097	-0.097	0.000	0.898	--
50.0	0.498	-0.243	-0.242	-0.001	0.900	0.100
90.0	0.897	-0.433	-0.436	0.003	0.902	0.100
50.0	0.498	-0.243	-0.242	-0.001	0.900	0.100
20.0	0.198	-0.097	-0.097	0.000	0.898	0.100

Test 4 – Powers and PF over time

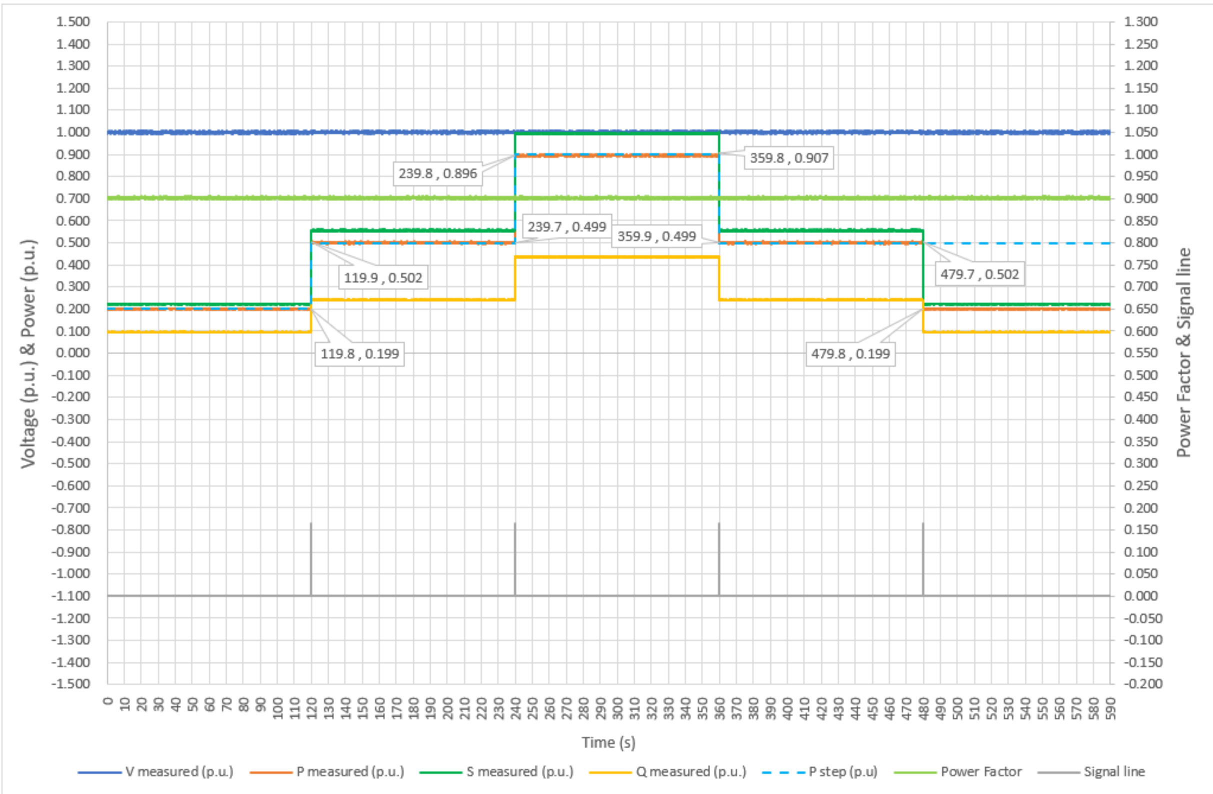


4.5.2.5 Test 5: Power factor of 0.900 under-excited with 20%Pn, 50%Pn and 90%Pn setpoints

Test results are offered in the following tables and graphs:

Test 5 Triangular Curve (PF = 0.9 / Inductive)						
P step (% P_{Emax})	P measured (% P_{Emax})	Q measured (% P_{Emax})	Q desired (% P_{Emax})	Q deviation (± 4.0% P_{Emax})	Δ cos φ Measured	Transient period (s)
20.0	0.200	0.095	0.097	-0.002	0.902	--
50.0	0.501	0.241	0.242	-0.001	0.901	0.100
90.0	0.896	0.436	0.436	0.000	0.902	0.100
50.0	0.500	0.241	0.242	-0.001	0.901	0.100
20.0	0.200	0.095	0.097	-0.002	0.902	0.100

Test 5 – Powers and PF over time



4.6 Reactive power control

4.6.1 Reactive power voltage characteristic Q(U)

This test is not applicable according to the section 5.7.2.4 of the standard VDE AR-N 4105:2018-11, due to the Q(U) rule applies only to three-phase power generation units connected to the three-phase current system

4.6.2 Displacement factor/active power characteristic curve cosφ(P)

This test has been done to verify requirements presented in chapter 5.7.2.4 b) of the VDE AR-N 4105:2018-11. For this test, test procedure from chapter 5.4.8.3 of the VDE V 0124-100:2020-06 has been used.

The aim of the test is to verify the capacity of the EUT of controlling power factor using active power through the following characteristic:

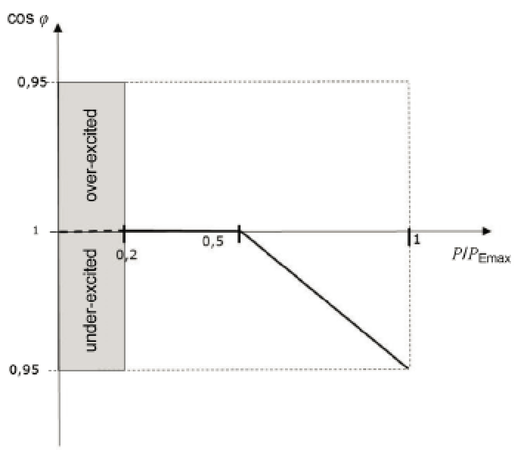


Figure 8 – Characteristic curve for type 2 $\sum S_{Emax} \leq 4{,}6\,kVA$ **and type 1, stirling generator, fuel cell** $\sum S_{Emax} > 4{,}6\,kVA$

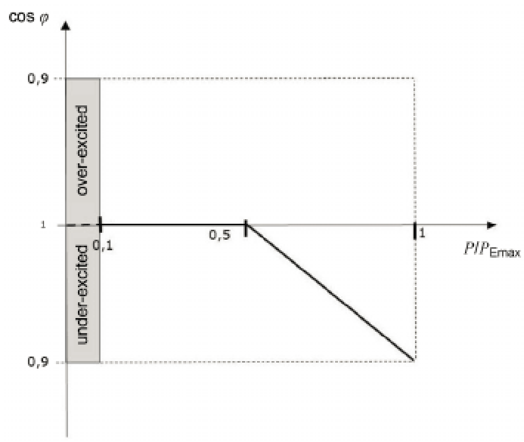


Figure 9 – Standard characteristic curve for type 2 (inverters only) $\sum S_{Emax} > 4{,}6\,kVA$

The test procedure for this characteristic and for guided EUT consists in performing two power steps, one from P ≤ 20% PrE to P = 100% PrE, and then another one from P = 100% PrE to P ≤ 20% PrE, waiting for the stationary values to settle for both steps.

The reactive power control for this characteristic curve method must be assessed with regard to stationary accuracy only. Maximum tolerance for Q is ±0.040 P p.u.

Dynamic accuracy for guided EUT is omitted due to the limitations of the prescribed active power gradients for active power setpoints changes (see section 4.8.1 of this Test Report).
The active power gradient of the steps has to be measured and in compliance with the requirements of chapter 5.7.4.1 of the VDE AR-N 4105:2018-11 standard.

The power gradients shall occur when the P steps are commanded by a third party, such as the grid operator, and in cases of network security management.

In this case, the unit is Type 2 systems and meet the requirements according to Figure 8.

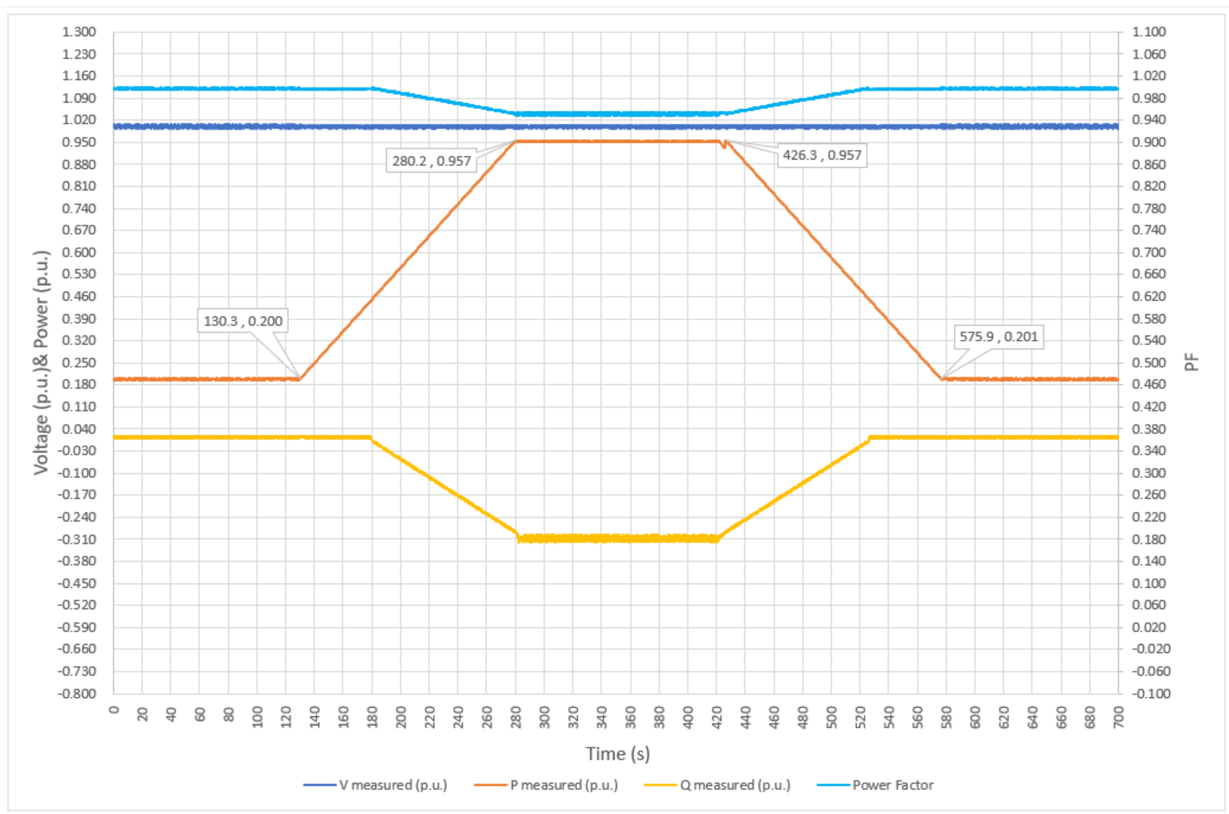
Test results are offered in the following tables and graphs:

Active Power Setting (% P_{Emax})	Active Power Measured (p.u.)	Reactive Power Measured (p.u.)	Reactive Power Desired (p.u.)	Reactive Power Deviation (p.u.) (<=±0.040 P p.u)	cos φ Measured	P gradient measured (%PAmax/s)
P ≤ 0.20	0.198	0.014	0.000	0.014	0.998	--
From 0.2 to 1.00	0.952 (1)	-0.308	-0.312 (2)	0.004	0.951	+0.5%
From 1.00 to 0.20	0.198	0.014	0.000	0.014	0.997	-0.5%

(1) Because it is limited by apparent power, the active power does not reach to 100%P_{Emax} when cos φ = 0.95.

(2) The desired reactive power is based on active power equalling to 95%P_{Emax}.

Result Chart



4.6.3 Fixed displacement factor cosφ(P)

This test is used to verify requirements presented in chapter 5.7.2.4 c) of the VDE AR-N 4105:2018-11.

The results obtained for this test can be checked in section 4.5.2 of this Test Report.

4.7 DYNAMIC NETWORK STABILITY

This test is not required according to the section 5.7.3 of the standard VDE AR-N 4105:2018-11 due to synchronous and asynchronous generators coupled directly or via inverters with Pn ≤ 50 kW are exempt from dynamic network stability.

4.8 ACTIVE POWER OUTPUT

4.8.1 Active power gradient

This test has been done in order to comply with requirements from chapter 5.7.4.1 of the VDE AR-N 4105:2018-11 standard testing procedure from chapter 5.4.3.4 of the VDE V 0124-100:2020-06 applying the correct limits has been used.

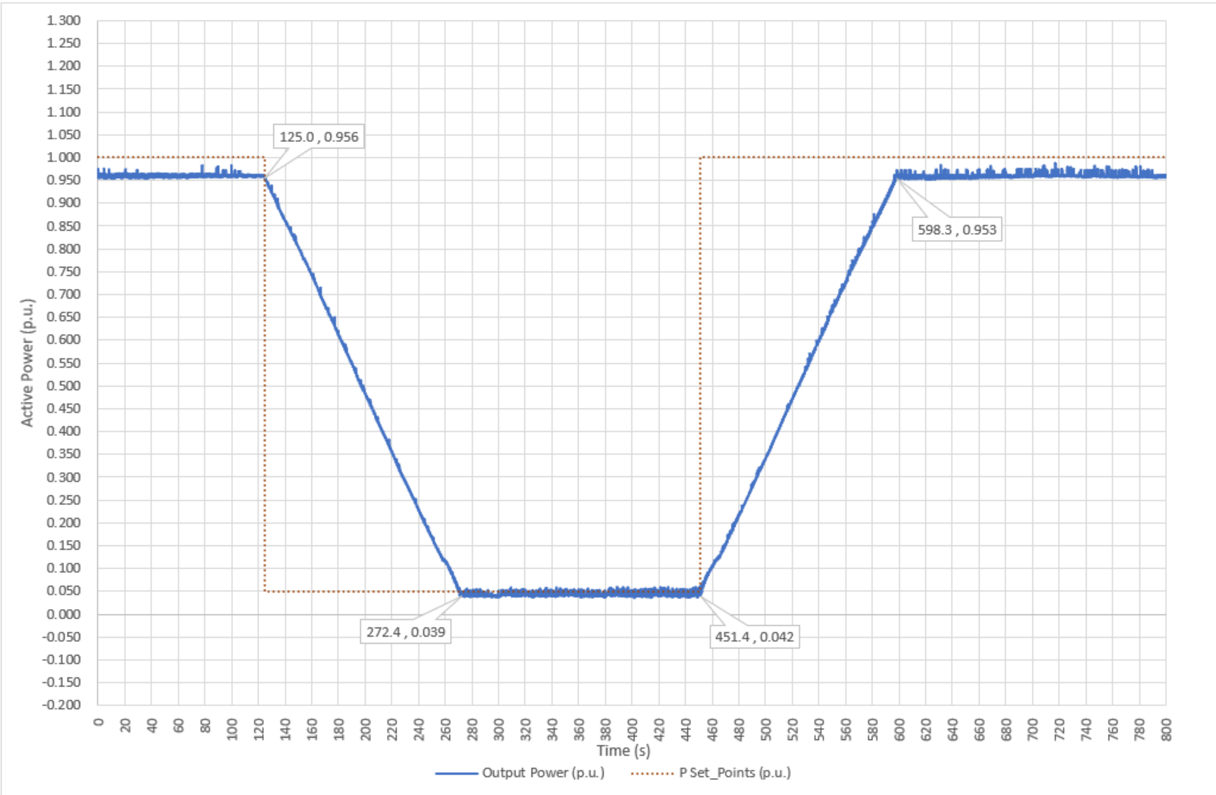
This chapter requires testing an active power step from 100% P_{Amax} to 5% P_{Amax} and another one from 5% P_{Amax} to 100% P_{Amax} for storage units with a power gradient between 0.33%P_{Amax}/s and 0.66%P_{Amax}/s.

Test results are presented in the table and graphs below:

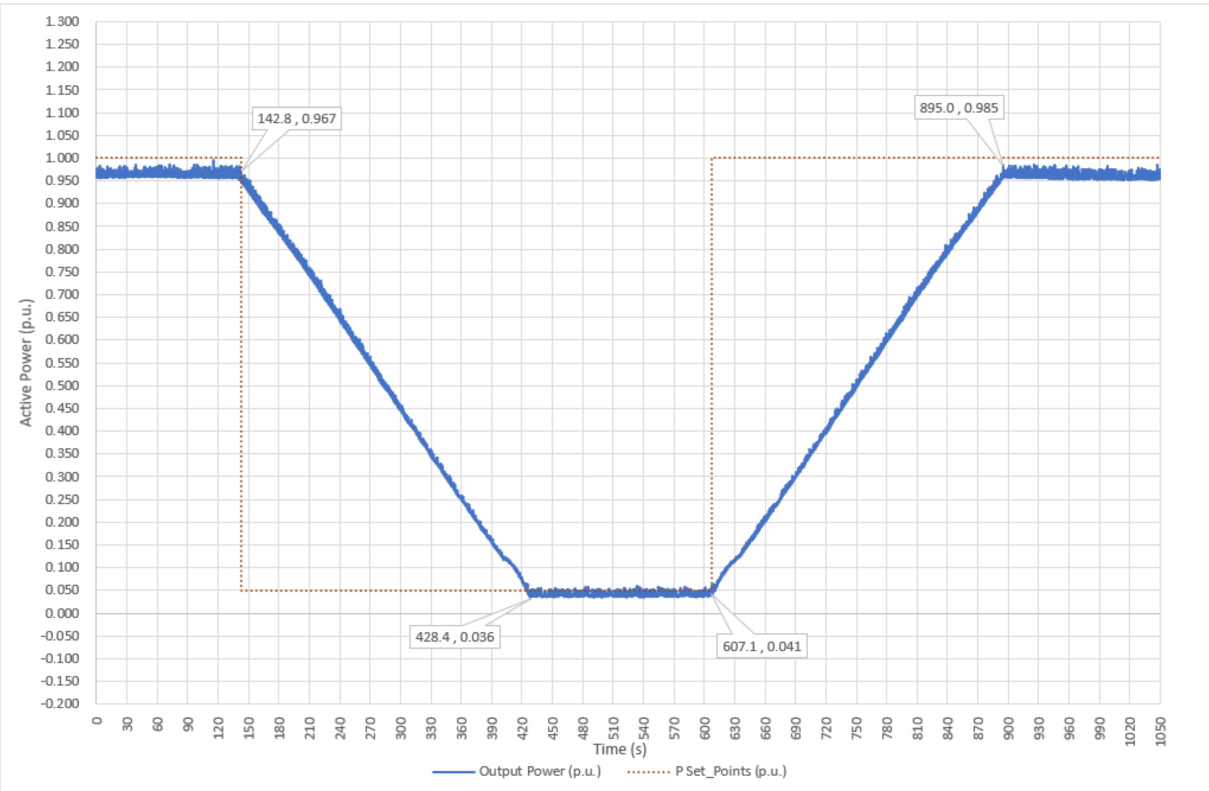
Test at maximum power gradient		
Active Power step (Setpoint)	**Gradient setting (%P_{Amax}/s)**	**Active power gradient expected (%P_{Amax}/s)**
100.0% to 5.0% P_{Amax}	-0.66	-0.66 < P grad < -0.33
5.0% to 100.0% P_{Amax}	+0.66	+0.33 < P grad < +0.66

Test at minimum power gradient		
Active Power step (Setpoint)	**Gradient setting (%P_{Amax}/s)**	**Active power gradient expected (%P_{Amax}/s)**
100.0% to 5.0% P_{Amax}	-0.33	-0.66 < P grad < -0.33
5.0% to 100.0% P_{Amax}	+0.33	+ 0.33 < P grad < +0.66

Output power change (100% to 5% to 100% of P_{Amax}) – 0.66%P_{Amax}/s



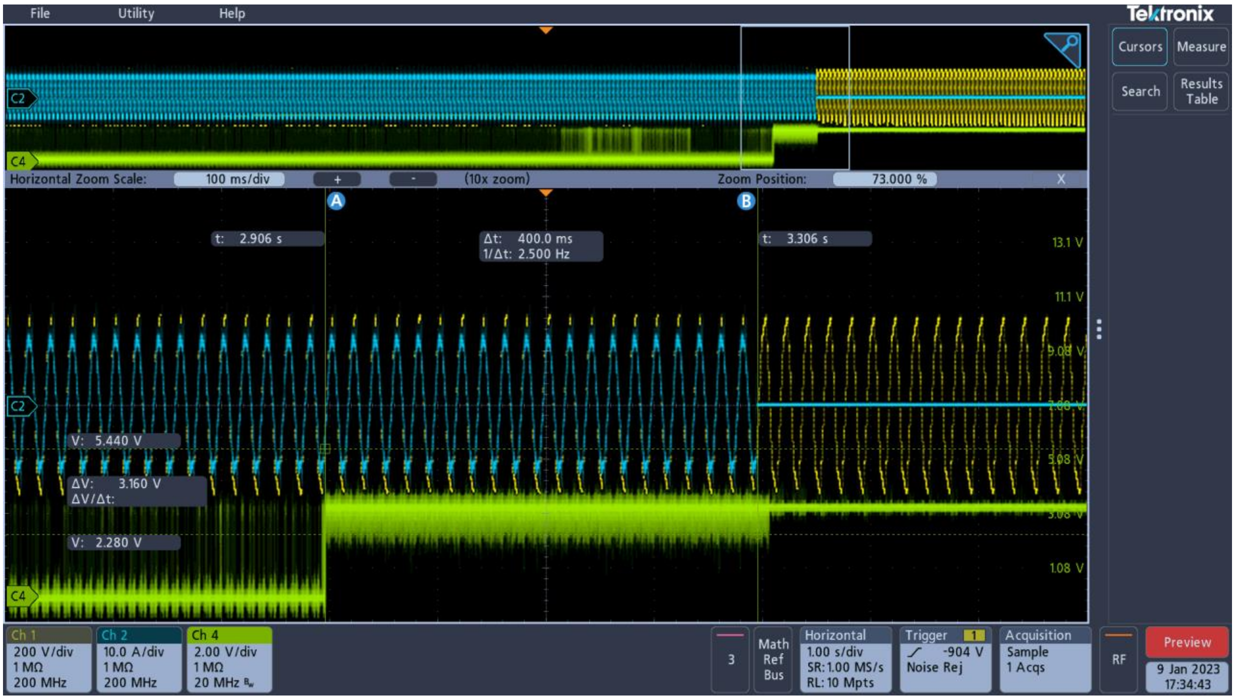
Output power change (100% to 5% to 100% of P_{Amax}) – 0.33%P_{Amax}/s



4.8.2 Ceasing of active power by external signal on input port

This test has been done in order to comply with requirements from chapter 5.7.4.1 of the VDE AR-N 4105:2018-11 standard.
Generating units shall be equipped with a logic interface (“RS485 (communication)”) in order to cease active power output within 5 seconds following an instruction from the grid operator being received at the input port, irrespective of the power gradients from point 4.8.1 of this Test Report. Additionally, the interface may be used for network security management.

Test results are graphically shown as below.

Disconnection time
 Ch1: AC Voltage Ch2: Output Current Ch4: Signal of logic interface.
Tested ceasing active power time: 0.4s (limited: <5s)

4.8.3 Active power steps

This test has been done in order to comply with requirements from chapter 5.7.4.2.2 of the VDE AR-N 4105:2018-11 standard. In order to evaluate this requirement, testing procedure from chapter 5.4.3.3 of the VDE V 0124-100:2020-06 standard has been taken.

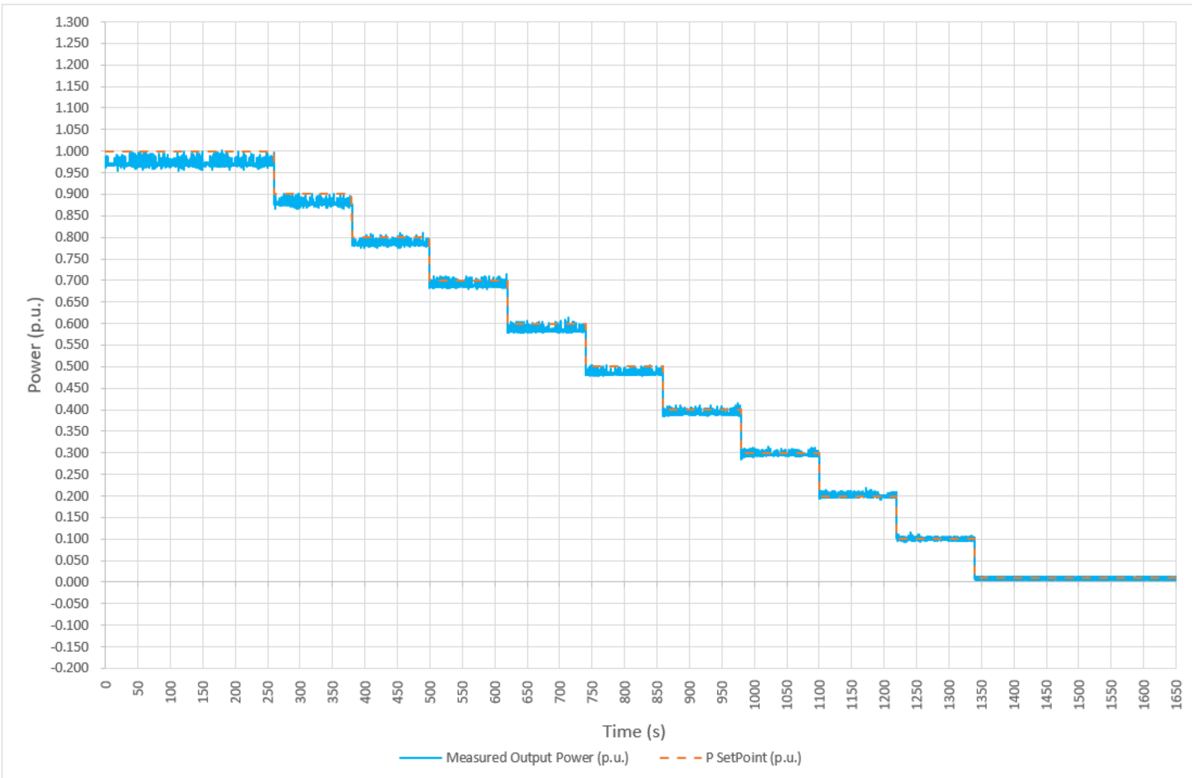
Active power will be reduced from 100%PAmax to the minimum active power possible in steps of 10% P_{Amax} to check that the EUT does not disconnect during those steps.

For each step, wait 1 minute after the change of setpoint to allow the EUT to adjust to the new setpoint. After that, the active power shall be measured as a 1-minute average.

Test results are presented in the following table and graph:

Active Power step ($\%P_{rE}$)	Setpoint value		Actual value		Deviation (Limit ±5% P_{rE})	
	(kW)	($\%P_{rE}$)	(kW)	($\%P_{rE}$)	(kW)	($\%P_{rE}$)
100.0	2.000	100.0	1.941	97.1	-0.059	-2.9
90.0	1.800	90.0	1.758	87.9	-0.042	-2.1
80.0	1.600	80.0	1.571	78.5	-0.029	-1.5
70.0	1.400	70.0	1.380	69.0	-0.020	-1.0
60.0	1.200	60.0	1.170	58.5	-0.030	-1.5
50.0	1.000	50.0	0.970	48.5	-0.030	-1.5
40.0	0.800	40.0	0.784	39.2	-0.016	-0.8
30.0	0.600	30.0	0.592	29.6	-0.008	-0.4
20.0	0.400	20.0	0.400	20.0	0.000	0.0
10.0	0.200	10.0	0.201	10.1	+0.001	+0.1
0.0	0.000	0.0	0.018	0.9	+0.018	+0.9

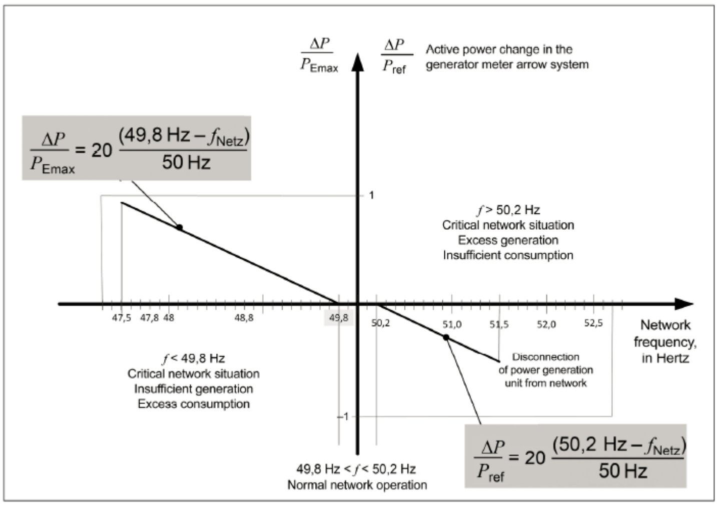
Active power steps



4.8.4 Active power adjustment at a function of grid frequency

The aim of the test is to demonstrate the response of the EUT due to a deviation in grid frequency from rated value in terms of speed (rise/settling time) and the active power gradient.

This test has been performed according to the point 5.7.4.2.3 of the VDE AR-N 4105:2018-11 standard, changing the parameters in the PGU control system.



Key

P_{Emax} highest active power of a power generation unit (10 min mean value)

P_{ref} equals P_{Emax} for type 1 power generation units or P_{mom} for type 2 power generation units at the moment when 50,2 Hz is exceeded.

ΔP power change

f network frequency

Figure 14 – Active power adjustment for type 1 and type 2 power generation units at over-frequency and under-frequency with a static value of 5 % and frequency limit values of 49,8 Hz and 50,2 Hz for starting the adjustment

Frequency measurement accuracy for this test shall be ≤± 10mHz

Tests for both over and underfrequency deviations have been done. For both tests, additional requirements shall be taken into consideration presented in the standard.

The initial delay (Tv) of the steps shall be ≤ 2s.

During a frequency step, certain conditions that shall be verified:

- After Tv + 0.1*($T_{an\_90\%}$-Tv), a minimum of 9% of the required power gradient for that step has been reached.
- After $T_{an\_90\%}$, a minimum of 90% of the required power gradient for that step has been reached.
- Settling time shall not exceed 20s with a tolerance band of 10% of the required setpoint.

(*) $T_{an\_90\%}$ refers to rise time and Tv refers to initial delay.

Static accuracy for active power is ≤±10% P_{Emax}.

4.8.4.1 Over-frequency

Test procedure from chapter 5.4.4 (for inverters) / 5.4.5 (for storage) of the VDE V 0124-100:2020-06 standard establishes two tests for certificating the power droop and the disconnection and reconnection conditions at different parameters:

- **For Inverters**

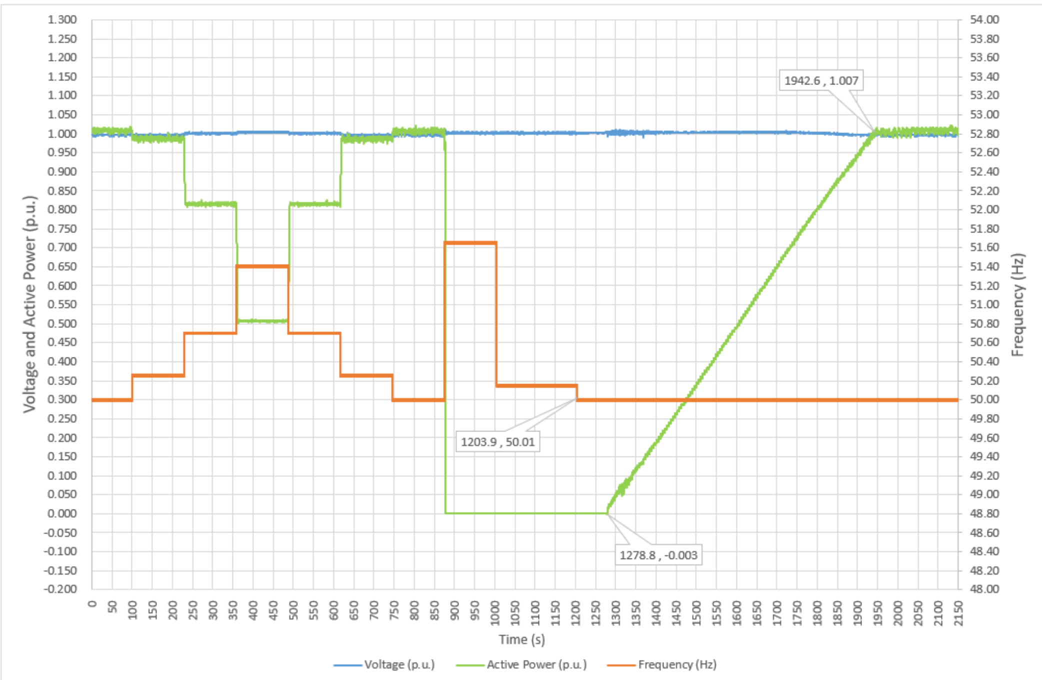
Regarding active power adjustment at over-frequency, the VDE AR-N 4105:2018-11 standard stablishes that in the frequency range from 50.2/50.5 Hz to 51.5 Hz, active power shall be reduced with a power drop of 2-12%, and that the generation unit shall disconnect if 51.5 Hz is surpassed.
Default values for threshold frequency and droop are 50.2 Hz and 5%, respectively.

- Test 1: P = 100% P_{Emax}, frequency threshold for power droop = 50.2 Hz, droop = 5%, test with disconnection and reconnection
- Test 2: P = 60% P_{Emax}, threshold for power droop = 50.5 Hz, droop = 12%, test without disconnection

Note: The PV input port of inverter was supplied by a PV simulator source with I-V characteristic during the testing.

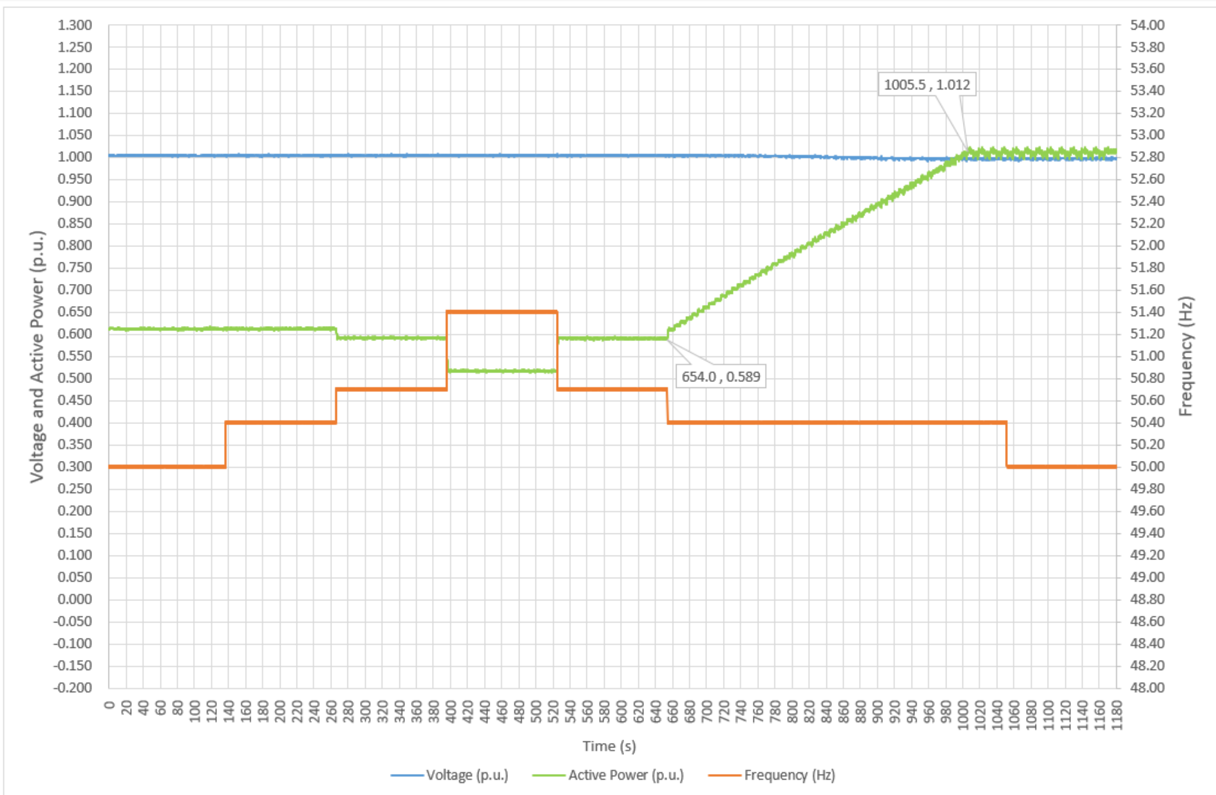
4.8.4.1.1 Test-1: PV Unit characteristic – Start power (P_M) = 100%P_{Emax}

Settings		F_{start} (Hz)	50.2	$s = \frac{\Delta f}{f_n} \Big/ \frac{\Delta P}{P_{ref}}$	5%
		$F_{disconnect}$ (Hz)	51.5		
Steps				P_M = 100% P_{Emax}	
Step	**Frequency setting (Hz)**	**Active Power expected (%P_{Emax})**	**Frequency measured (Hz)**	**Active power measured (%P_{Emax})**	**Variation measured (%P_{Emax}) (±10%P_{Emax})**
a)	50.00	100.0	50.00	100.8	+0.8
b)	50.25	98.0	50.25	98.6	+0.6
c)	50.70	80.0	50.70	81.6	+1.6
d)	51.40	52.0	51.40	50.7	-1.3
e)	50.70	80.0	50.70	81.5	+1.5
f)	50.25	98.0	50.25	98.6	+0.6
g)	50.00	100.0	50.00	100.7	+0.7
h)	51.65	0.0	51.65	0.0	0.0
--	Disconnect confirm (Yes or No)		Yes		
i)	50.15	0.0	50.15	0.0	0.0
--	Reconnected confirm (Yes or No)		No		
j)	50.00	100.0	50.00	100.8	+0.8
--	Reconnection Time (≥60.0s)		74.9		
	Power gradient limited during step j (<= 10%P_{Emax}/min)				
	Power gradient measured (%P_{Emax} /min)		9.1		
Active power feed-in at over frequency (P_M = 100% P_{Emax})					



4.8.4.1.2 Test-2: PV Unit characteristic – Start power (P_M) = 60%P_{Emax}

Settings		F_{start} (Hz)	50.5	$s = \frac{\Delta f}{f_n} \Big/ \frac{\Delta P}{P_{ref}}$	12%
		$F_{disconnect}$ (Hz)	51.5		
Steps				P_M = 60% P_{Emax}	
Step	Frequency setting (Hz)	Active Power expected (%P_{Emax})	Frequency measured (Hz)	Active power measured (%P_{Emax})	Variation measured (%P_{Emax}) (±10%P_{Emax})
a)	50.00	60.0	50.00	61.2	+1.2
b)	50.40	60.0	50.40	61.3	+1.3
c)	50.70	58.0	50.70	59.2	+1.2
d)	51.40	51.0	51.40	51.7	+0.7
e)	50.70	58.0	50.70	59.1	+1.1
f)	50.40	60.0 to 100.0 stable at 100.0	50.40	100.9	+0.9
--	Power gradient limited during step f (<= 10%P_{Emax}/min)				
	Power gradient measured (%P_{Emax} /min)		7.2		
g)	50.00	100.0	50.01	101.1	+1.1
Active power feed-in at over frequency (P_M = 60% P_{Emax})					



4.8.4.2 Under-frequency

Test procedure from chapter 5.4.6 (for inverters) / 5.4.7 (for storage) of the VDE V 0124-100:2020-06 standard establishes two tests for verification the power droop and the disconnection and reconnection conditions at different parameters:

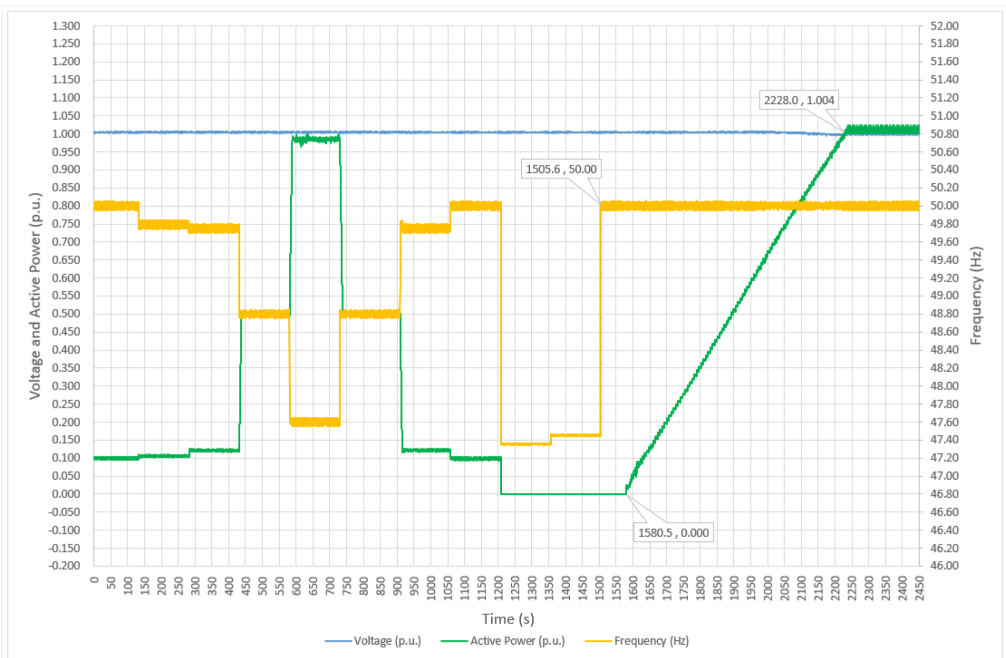
- **For Inverters**

Regarding active power adjustment at underfrequency, the VDE AR-N 4105:2018-11 standard states that under 49.8 Hz, active power shall be increased with a power gradient of 40%Pref / Hz. If frequency is reduced under 47.5 Hz, the generation unit shall disconnect.

– Test 1: P = 10% P_{Emax}, test with disconnection and reconnection
– Test 2: P = 60% P_{Emax}, test without disconnection

4.8.4.2.1.1 Test-1: PV Unit characteristic – Start power (P_M) = 10%P_{Emax}

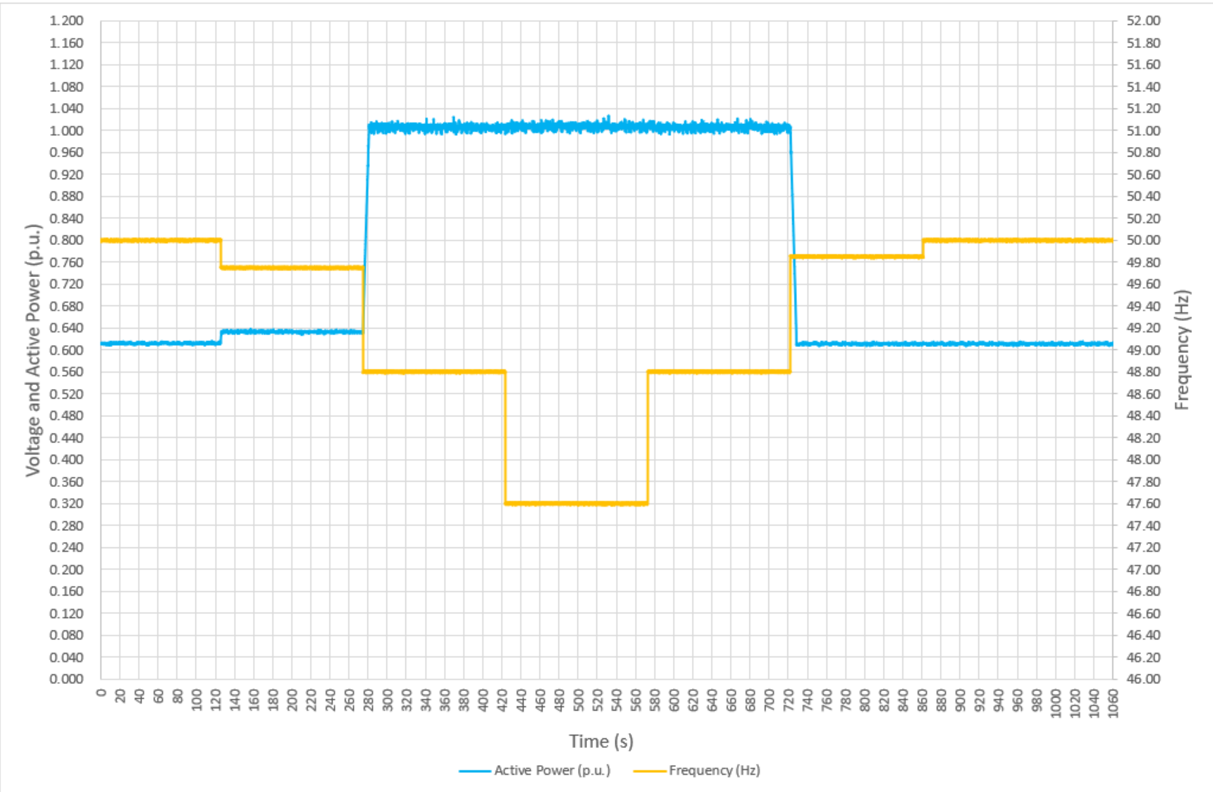
Settings		F_{start} (Hz)	49.8	$s = \frac{\Delta f}{f_n} \Big/ \frac{\Delta P}{P_{ref}}$	5%
		$F_{disconnect}$ (Hz)	47.5		
Steps				P_M = 10% P_{Emax}	
Step	**Frequency setting (Hz)**	**Active Power expected (%P_{Emax})**	**Frequency measured (Hz)**	**Active power measured (%P_{Emax})**	**Variation measured (%P_{Emax}) (±10%P_{Emax})**
a)	50.00	10.0	50.00	10.0	0.0
b)	49.79	10.4	49.79	10.6	+0.2
c)	49.75	12.0	49.75	12.2	+0.2
d)	48.80	50.0	48.80	50.3	+0.3
e)	47.60	98.0	47.60	98.5	+0.5
f)	48.80	50.0	48.82	50.3	+0.3
g)	49.75	12.0	49.75	12.2	+0.2
h)	50.00	10.0	50.00	9.9	-0.1
i)	47.35	0.0	47.35	0.0	0.0
--	Disconnect confirm (Yes or No)		Yes		
j)	47.45	0.0	47.45	0.0	0.0
--	Reconnected confirm (Yes or No)		No		
k)	50.00	100.0	50.00	100.9	+0.9
--	Reconnection Time (s)		73.9		
	Power gradient limited during step j (<= 10%P_{Emax}/min)				
	Power gradient measured (%P_{Emax} /min)		9.3		
Active power feed-in at underfrequency (P_M = 10% P_{Emax})					



4.8.4.2.1.2 Test-2: PV Unit characteristic – Start power (P_M) = 60%P_{Emax}

Settings		F_{start} (Hz)	49.8	$s = \frac{\Delta f}{f_n} / \frac{\Delta P}{P_{ref}}$	5%
		$F_{disconnect}$ (Hz)	47.5		
Steps				P_M = 60% P_{Emax}	
Step	Frequency setting (Hz)	Active Power expected (%P_{Emax})	Frequency measured (Hz)	Active power measured (%P_{Emax})	Variation measured (%P_{Emax}) (±10%P_{Emax})
a)	50.00	60.0	50.00	61.2	+1.2
b)	49.75	62.0	49.75	63.3	+1.3
c)	48.80	100.0	48.81	100.6	+0.6
d)	47.60	100.0	47.60	100.7	+0.7
e)	48.80	100.0	48.80	100.6	+0.6
f)	49.85	60.0	49.85	61.1	+1.1
g)	50.00	60.0	50.00	61.1	+1.1

Active power feed-in at underfrequency (P_M = 60% P_{Emax})



4.8.5 Voltage-dependent active power reduction

This test is not required according to the section 5.7.4.4 of the standard VDE AR-N 4105:2018-11 due to reduce the active power feed-in as a function of the voltage of (a) power generation unit(s) is optional.

4.9 SHORT-CIRCUIT CONTRIBUTION

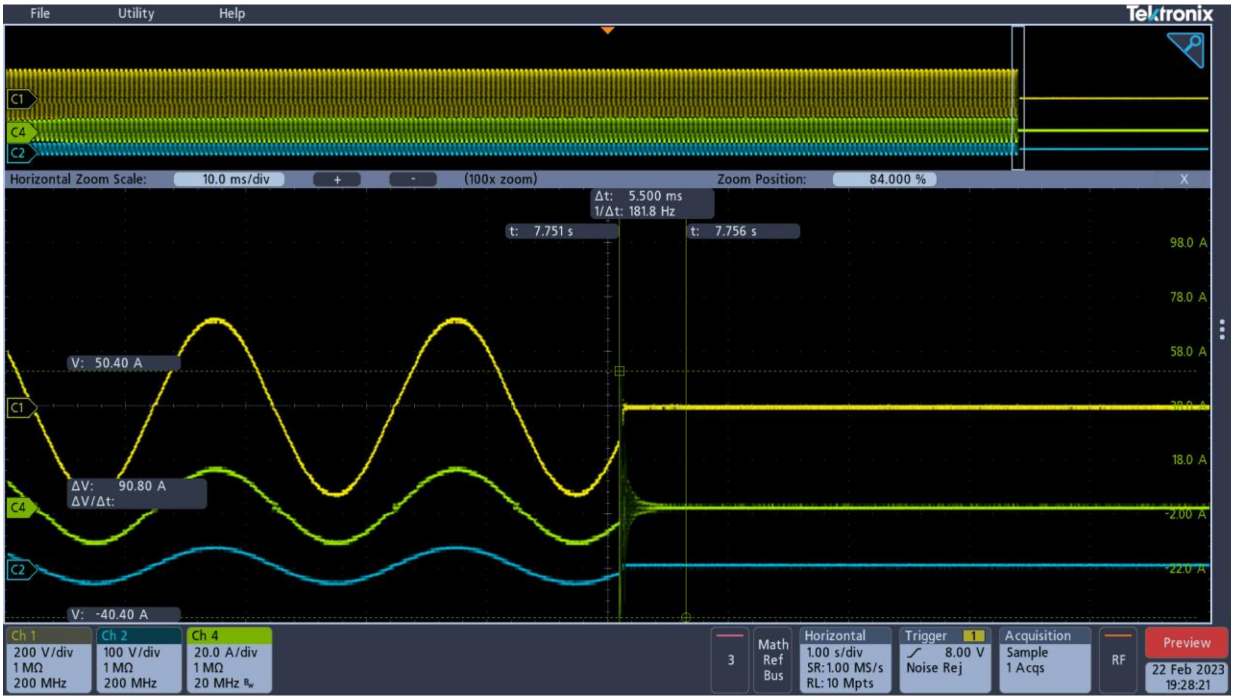
According to the paragraph 5.7.5 of the VDE-AR-N 4105:2018-11, due to the operation of a power generation system, the short-circuit current of the low-voltage network is increased by the short-circuit current of the power generation system. Therefore, the short-circuit current of the power generation system to be expected at the network connection point shall be indicated in accordance with 4.2. For the determination of the initial short-circuit AC current contribution IkA of a power generation system, the following roughly estimated values can be assumed:

– for synchronous generators: 8 times the rated current;
– for asynchronous generators: 6 times the rated current;
– for generators and storage units with inverters: the rated current.

If the power generation system causes a short-circuit current increase in the network operator’s network in excess of the rated value, then connection owner and network operator shall agree upon appropriate measures limiting the short-circuit current from the power generation system accordingly.

Short circuit current	
Short Circuit Applied	**Isc Max (A)**
Phases (L to N)	50.4 A

Short circuit test Phases (L1 to N)



4.10 PROTECTION SETTING

As indicated in VDE-AR-N 4105:2018-11, section 6 (*Construction of the power generation system/network and system protection (NS protection)*), the requirements for the network and system protection differ depending on the maximum apparent power ($S\text{Amax}\sum S_{Amax}$) of the generating and storage units connected to the same network connection point.

- For installations with $S\text{Amax}\sum S_{Amax}$ ≤ 30kVA, the NS protection can either be
  - a central NS protection at the central meter panel or decentralized in a sub-distribution; or
  - integrated NS protection

  The equipment covered by this Test Report are all below this limit and both of these options can be chosen.

- For installations with $S\text{Amax}\sum S_{Amax}$ > 30kVA, the NS protection must be accomplished by a central NS protection device at the central meter panel.

In the case, taking into account the equipment covered by this Test Report, this situation will happen when several units are connected to the same network connection point.

Note: the NS protection shall meet that a single fault shall not lead to a loss of the protective function (single fault tolerance). The output is switched off redundant by the high-power switching bridge and two relay in series. This assures that the opening of the output circuit will also operate in case of one error. AC Relay Model HF167F, 320 Vac / 90 A.

All the tests in this section have been performed without an additional relay connected, to check the internal protection of the equipment.

This test has been done according to requirements presented in chapter 6.5 of the VDE AR-N 4105:2018-11 standard.

Testing procedure from chapter 5.5.7 of the VDE V 0124-100:2020-06 has been used for determining the trip value and the trip time as follows:

For U>>, U< and U<< tests:

- For testing the accuracy of threshold: Starting from a voltage level 2.0% U_n below or above the trip value of the protection function to be tested, the voltage is increased or decreased in steps of 0.5% U_n or less for at least the trip time stated in the protection function to be tested + 200ms (taking into account the maximum 100ms delay for the NS + interface switch), and the voltage at which the EUT trips is to be recorded

- For testing the accuracy of the trip time: Starting from a voltage value 2.0% U_n below or above the expected trip value, the voltage shall be increased in a single step to a value 2.0% U_n above or below that value. The time taken from the start of the step until the EUT trips is recorded as the trip time.

For the U> tests (tests number 3.1, 3.2 and 3.3) the procedure is the following:

- For test 3.1: Starting from U_n, a single step to 112.0% U_n is performed. The expected behaviour is tripping of the EUT between 450.0s and 550.0s from the start of the step. Each step shall be maintained for at least 600.2s

- For test 3.2: Starting from 100.0% U_n, a single step to 108.0% U_n is performed. The expected behaviour of the EUT is no-tripping. Each step shall be maintained for at least 600.2s

- For test 3.3: Starting from 106.0% U_n, a single step to 114.0% U_n is performed. The expected behaviour is tripping of the EUT between 225.0s and 375.0s from the start of the step. Each step shall be maintained for at least 600.2s

For over/underfrequency tests:

- For testing the accuracy of threshold: Starting from a voltage level 0.10 Hz below or above the trip value of the protection function to be tested, the voltage is increased or decreased in steps of 0.05% f_n or less for at least the trip time stated in the protection function to be tested + 200ms (taking into account the maximum 100ms delay for the NS + interface switch), and the voltage at which the EUT trips is to be recorded

- For testing the accuracy of the trip time: Starting from a voltage value 0.10 Hz below or above the expected trip value, the voltage shall be increased in a single step to a value 0.10 Hz above or below that value. The time taken from the start of the step until the EUT trips is recorded as the trip time.

The permissible tolerance for the trip value tests is ±1.0% Un for voltage tests and ±0.1% fn for the frequency tests.

The trip time tests results shall be within the requirements of Table 2 from chapter 6.5.2 of VDE-AR-N 4105: 2018-11.

Protective function	Setting values for protection relays[a]					
	Stirling generators, fuel cells Synchronous and asynchronous generators with $P_n \le 50$ kW coupled directly or via inverters		Directly coupled synchronous and asynchronous generators with $P_n > 50$ kW		Inverter(s)	
Rise-in-voltage protection U>>	1,15 U_n	≤ 100 ms	1,25 U_n	≤ 100 ms	1,25 U_n	≤ 100 ms
Rise-in-voltage protection U>	1,10 U_n[b]	≤ 100 ms	1,10 U_n[b]	≤ 100 ms	1,10 U_n[b]	≤ 100 ms
Voltage drop protection U<	0,8 U_n[c]	≤ 100 ms	0,8 U_n	1,0 s[d]	0,8 U_n	3,0 s
Voltage drop protection U<	Not applicable		0,45 U_n	300 ms[d]	0,45 U_n	300 ms
Frequency decrease protection f<	47,5 Hz	≤ 100 ms	47,5 Hz	≤ 100 ms	47,5 Hz	≤ 100 ms
Frequency increase protection f>	51,5 Hz	≤ 100 ms	51,5 Hz	≤ 100 ms	51,5 Hz	≤ 100 ms

[a] The duration set-point "< 100 ms" for the protection relay setting value is based on the assumption that the maximum response time for NS protection + interface switch is also 100 ms. This results in a maximum "total disconnection time" of 200 ms. If the response time of the components is < 100 ms (e. g. 50 ms), then this allows for a longer period during which to perform the measurements and the evaluation of the protective function (e. g. up to 150 ms). This would then result in a protection relay setting value higher than "< 100 ms", i. e. "< 150 ms". However, in that case, only the 100 ms shall be visualised as the setting value at the NS protection. Nevertheless, the disconnection time of 200 ms shall in no case be exceeded.

[b] It shall be ensured, that the voltage 1,10 U_n is not exceeded at the network connection point. If compliance with this requirement is ensured by a central NS protection, then it is permissible to set the rise-in-voltage protection at the decentralised power generation unit/system to a value of up to 1,15 U_n. In that case, the system installer should consider any potential effects on the customer installation. Combination of central NS protection (U>: 1,1 U_n) and integrated NS protection (U>: 1,1 U_n to 1,15 U_n) is recommended, if the voltage drop in the house installation cannot be neglected. This is typically the case with longer connection lines.

[c] For the protection of the power generation unit, disconnection may also be realised by means of an additional self-protection setting value (e. g. 0,83 U_n) before the setting value of 0,8 U_n is reached.

[d] Where the medium-voltage network of the network operator upstream of the power generation system is operated with automatic reclosing (AWE, de: automatische Wiedereinschaltung), the following protective settings are recommended: U<<-Relay: 0,45 U_{NS}, undelayed (i. e. shortest possible time delay) and U<-Relay: 0,8 U_{NS}, 300 ms. The requirement is specified by the network operator.

Results are presented in the following tables:

Test No.	Protective function	Ramp or leap	Use on	Start value (p.u.)	End value (p.u.)	Step height ΔU (p.u.)	Step duration Δt	Expected trip value (p.u.)	Measured trip value (p.u.)	Disconnection
1.2	U>>	Ramp	L to N	<1.230	>1.270	<0.005	>400 ms	1.250	1.255	☒ Yes ☐ No
4.2	U<	Ramp	L to N	>0.820	<0.780	<0.005	>3.2 s	0.800	0.804	☒ Yes ☐ No
6.2	V<<	Ramp	L to N	>0.470	<0.430	<0.005	>500 ms	0.450	0.456	☒ Yes ☐ No

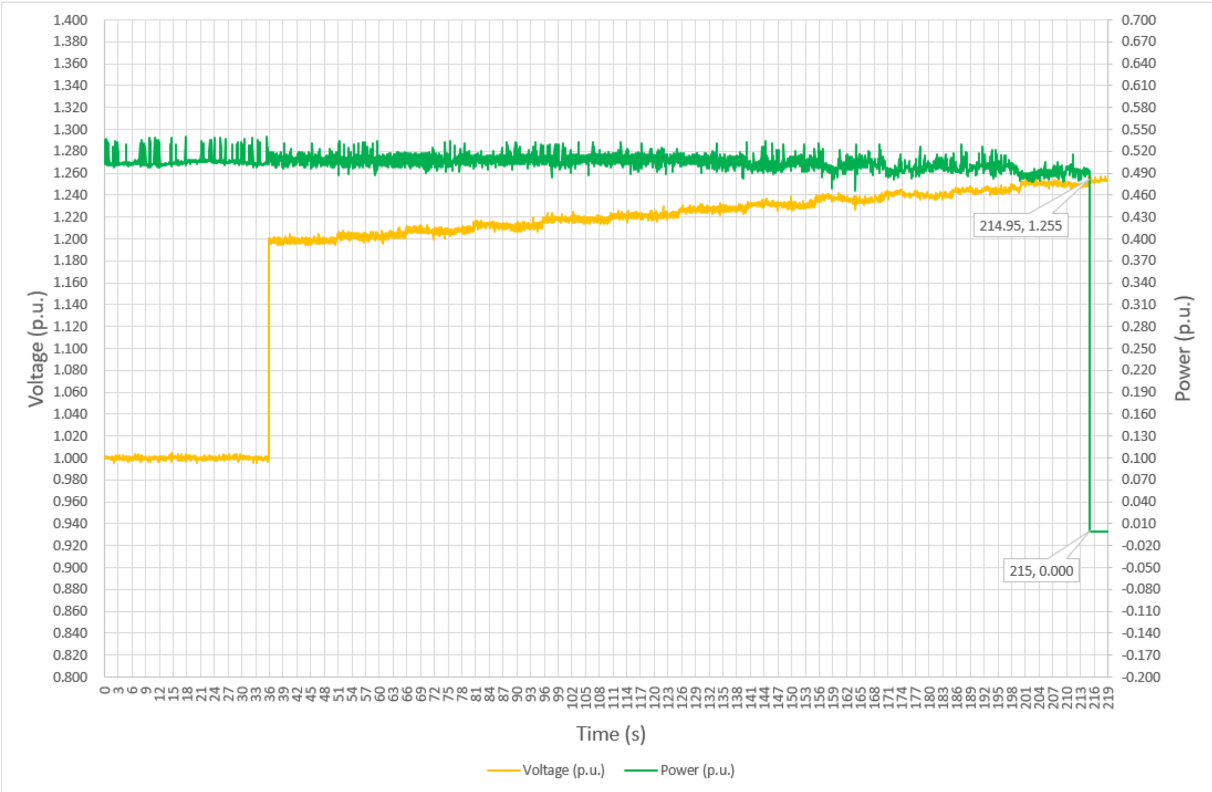
Test No.	Protective function	Ramp or leap	Use on	Start value (p.u.)	End value (p.u.)	Step height ΔU (p.u.)	Step duration Δt	Expected trip time	Measured trip time	Disconnection
2.2	U>>	Leap	L to N	< 1.230	> 1.270	> 0.040	> 400 ms	≤ 100 ms	68.0 ms	☒ Yes ☐ No
3.1	U>	Leap	L to N	1.000	1.120	0.120	> 600.2 s	450~550 s	500.2 s	☒ Yes ☐ No
3.2	U>	Leap	L to N	1.000	1.080	0.080	> 600.2 s	No Trip	No Trip	☐ Yes ☒ No
3.3	U>	Leap	L to N	1.060	1.140	0.080	> 600.2 s	225~375 s	300.1 s	☒ Yes ☐ No
5.2	U<	Leap	L to N	> 0.870	< 0.780	> 0.040	> 3.2 s	3.0~3.1s	3.1 s	☒ Yes ☐ No
7.2	U<<	Leap	L to N	> 0.470	< 0.430	> 0.040	> 500 ms	> 300 ms	352.0 ms	☒ Yes ☐ No

Test No.	Protective function	Ramp or leap	Use on	Start value (p.u.)	End value (p.u.)	Step height ΔU (p.u.)	Step duration Δt	Expected trip value (p.u.)	Measured trip value (Hz)	Disconnection
8.1	f>	Ramp	L to N	< 51.40	>51.60	< 0.025	> 400 ms	51.50	51.541	☒ Yes ☐ No
10.1	f<	Ramp	L to N	> 47.60	< 47.40	< 0.025	> 500 ms	47.50	47.490	☒ Yes ☐ No

Test No.	Protective function	Ramp or leap	Use on	Start value (Hz)	End value (Hz)	Step height Δf (Hz)	Step duration Δt	Expected trip time	Measured trip time	Disconnection
9.1	f>	Leap	L to N	< 51.40	>51.60	> 0.2	> 400 ms	≤ 100 ms	90.4 ms	☒ Yes ☐ No
11.1	f<	Leap	L to N	> 47.60	< 47.40	< 0.2	> 400 ms	≤ 100 ms	81.6 ms	☒ Yes ☐ No

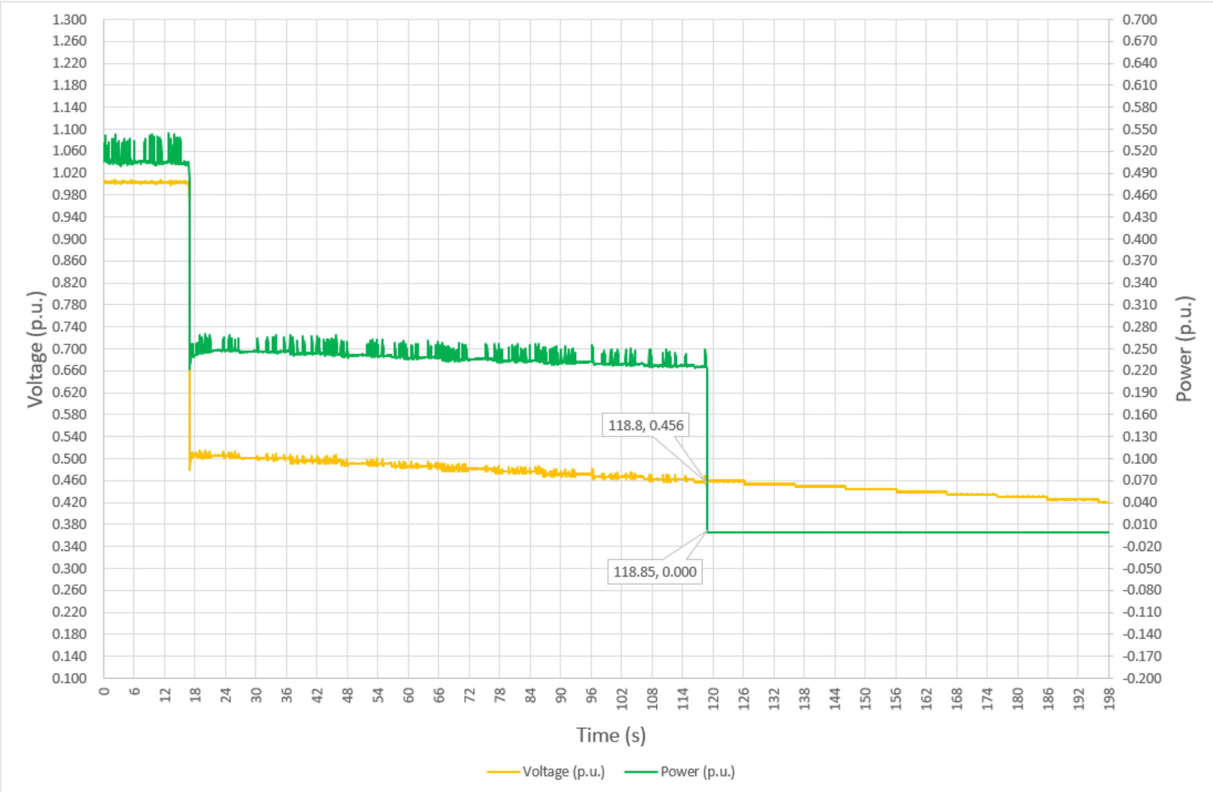
In the picture below are offered graphically the results of the test.

Test No.1.2 - Trip value 1.25Un - L to N

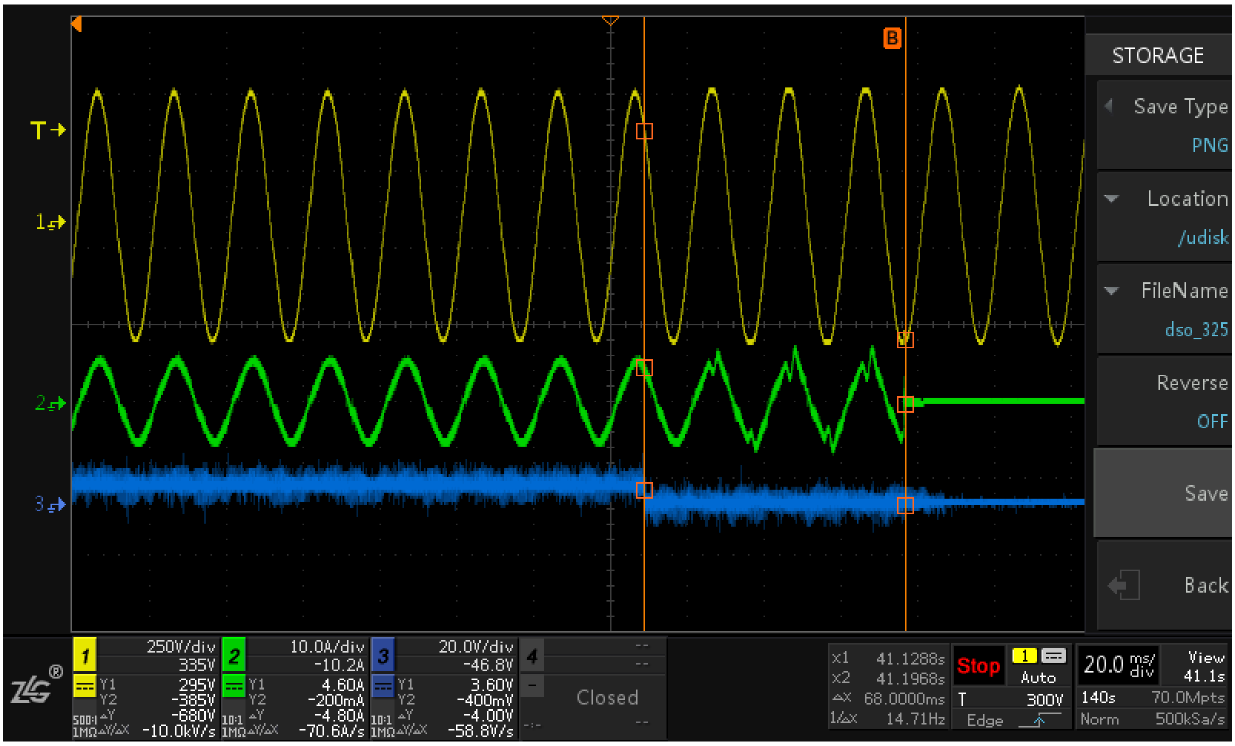


Test No.4.2 - Trip value 0.80Un - L to N

Test No.6.2 - Trip value 0.45Un - L to N

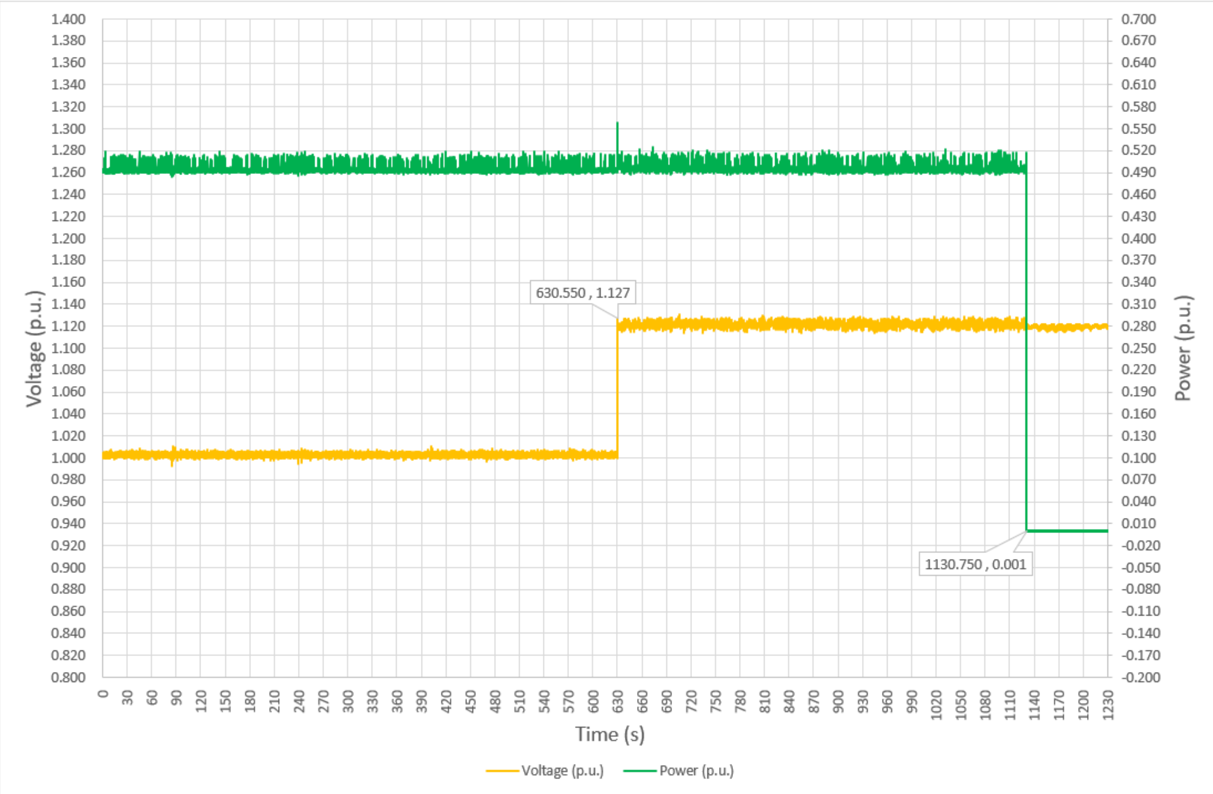


Test No.2.2 - Trip time 1.25Un - L to N

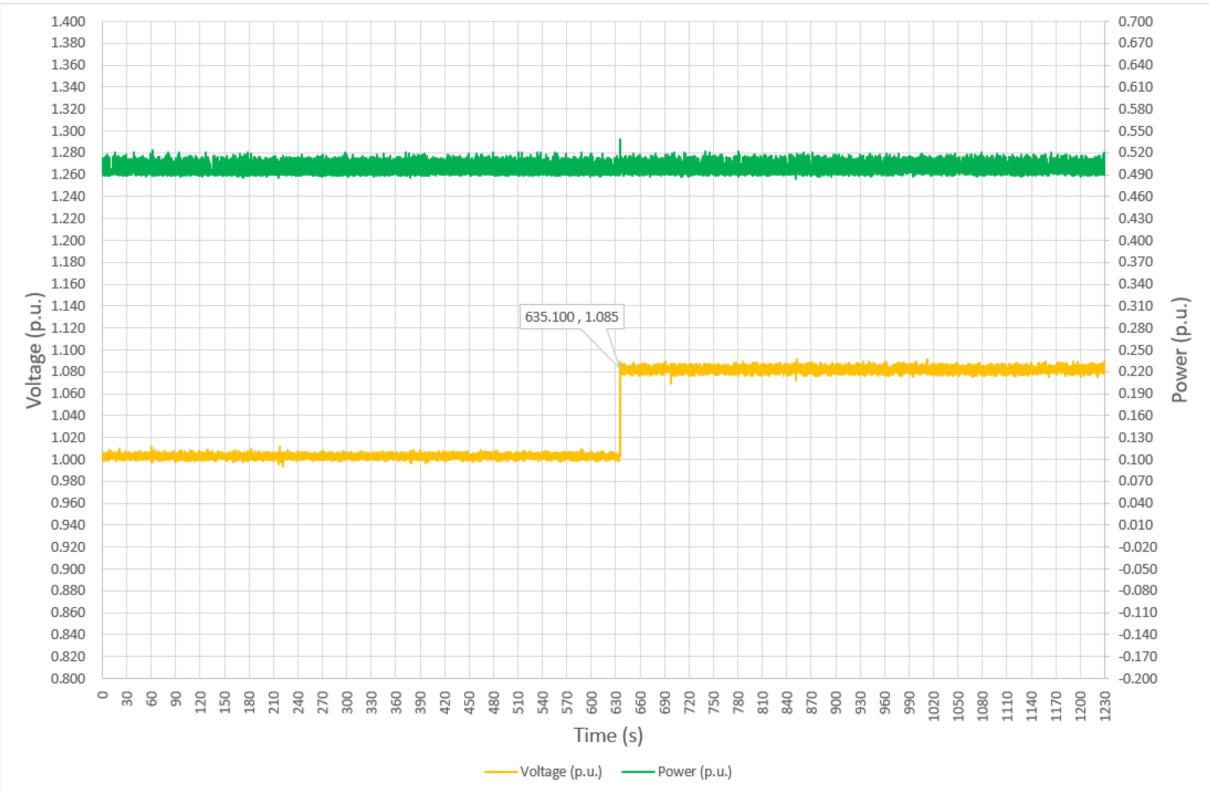


CH1: AC Voltage	CH2: AC current	CH3: Trigger signal

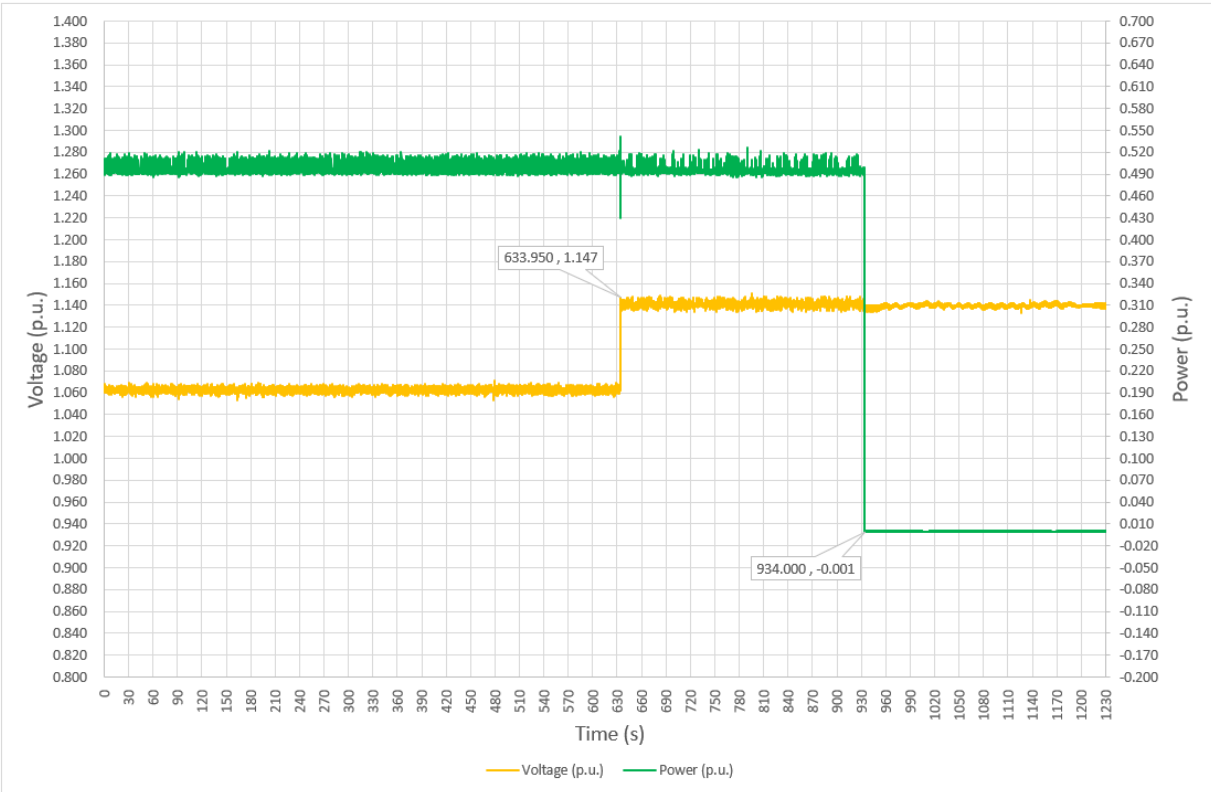
Test No.3.1 - Trip time - L to N



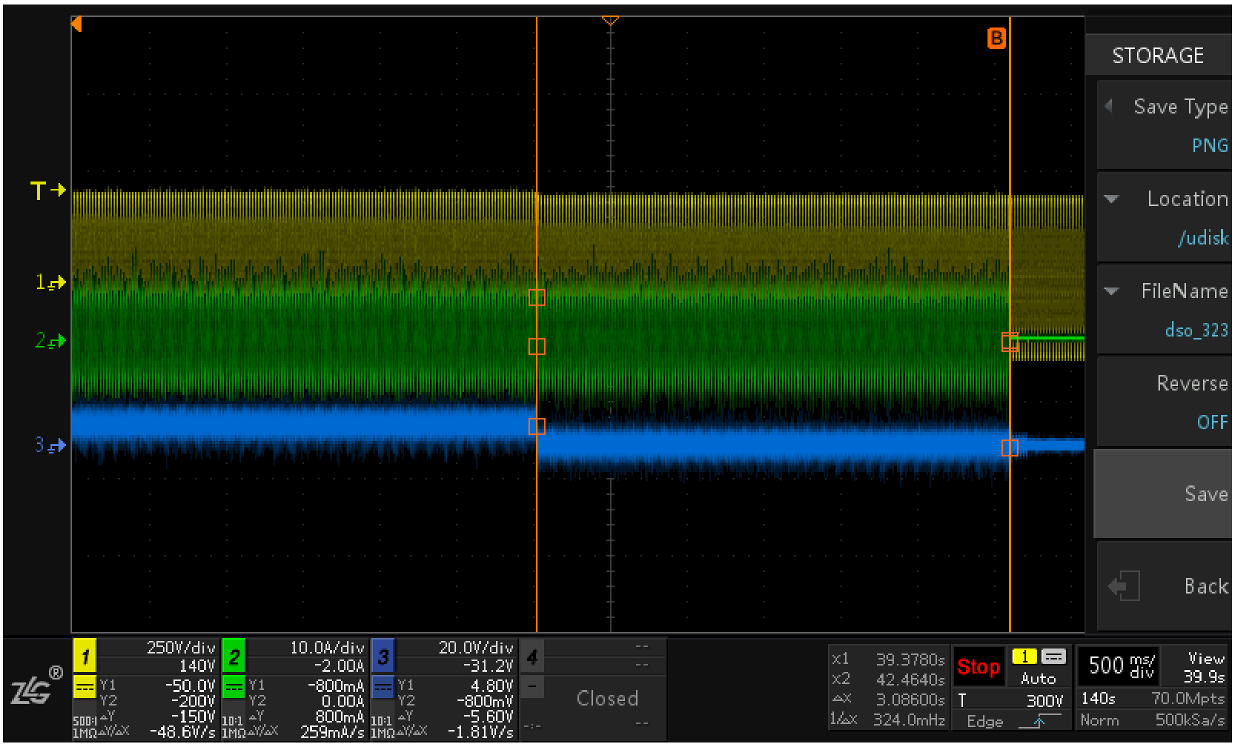
Test No.3.2 - Trip time - L to N



Test No.3.3 - Trip time - L to N

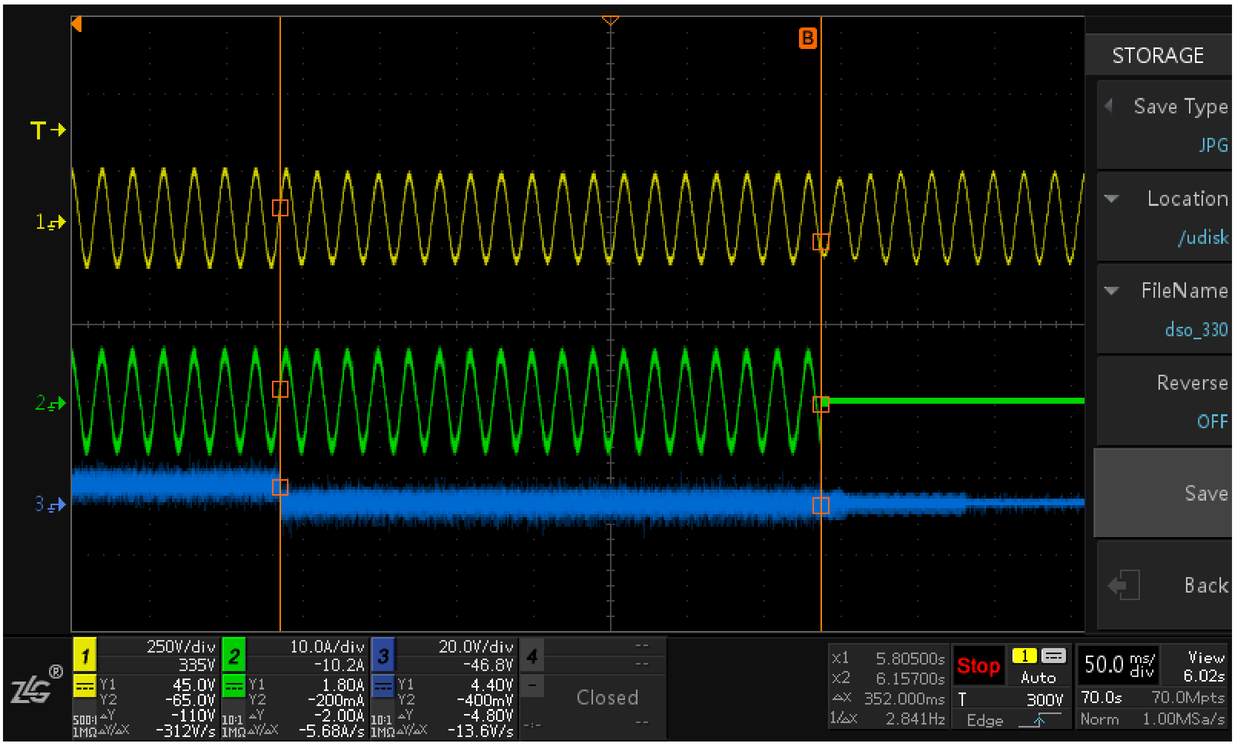


Test No.5.2 - Trip time 0.80Un - L to N



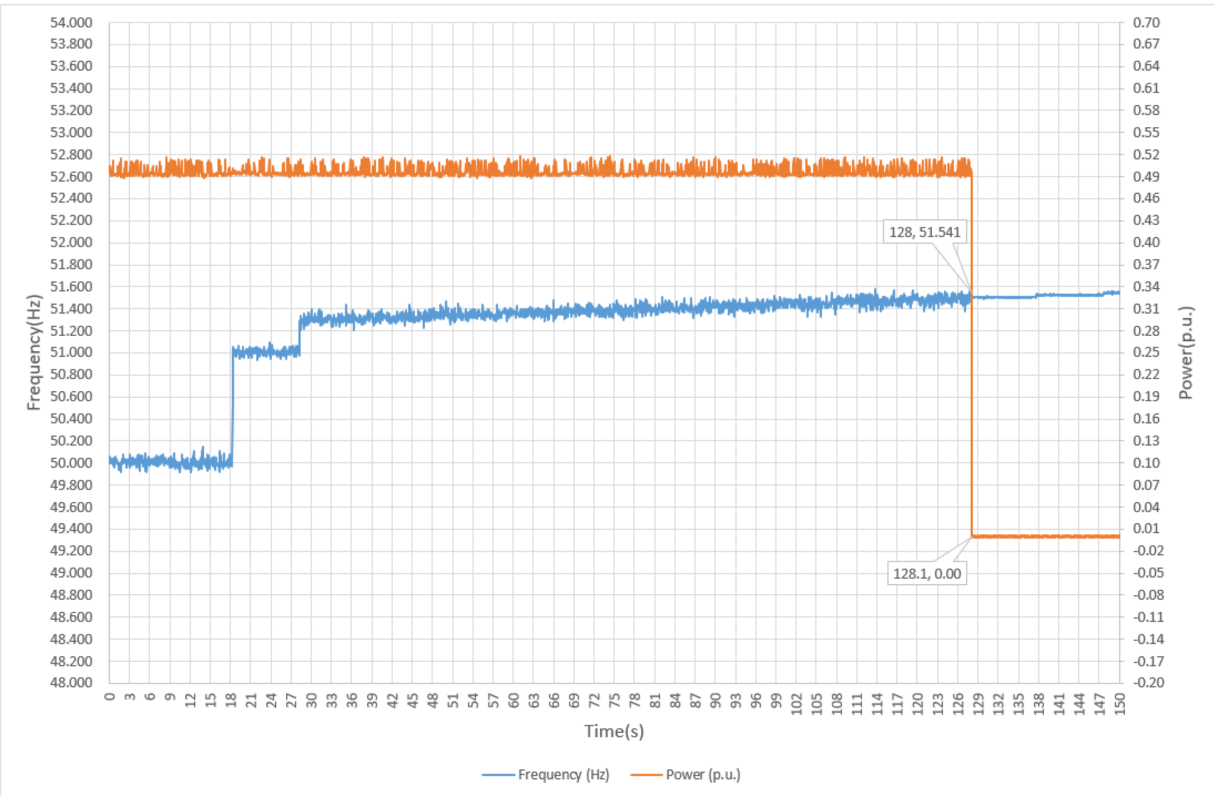
CH1: AC Voltage	CH2: AC current	CH3: Trigger signal

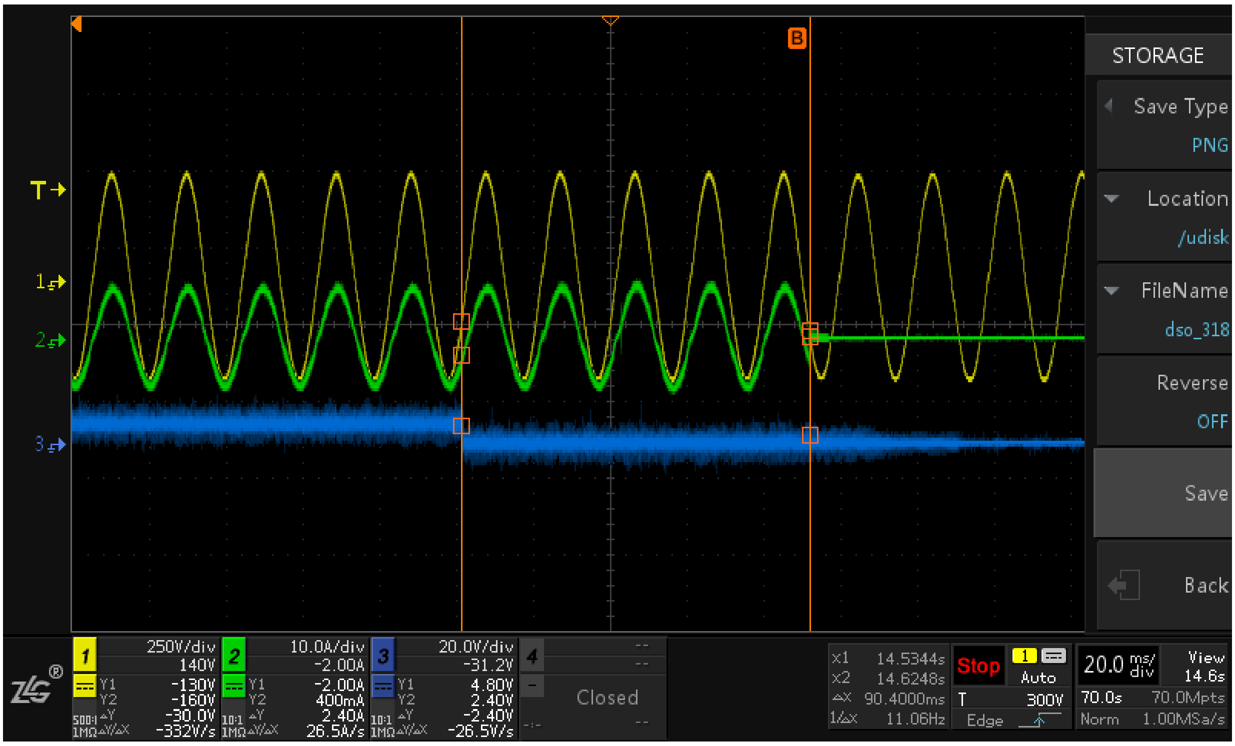
Test No.7.2 - Trip time 0.45Un - L to N

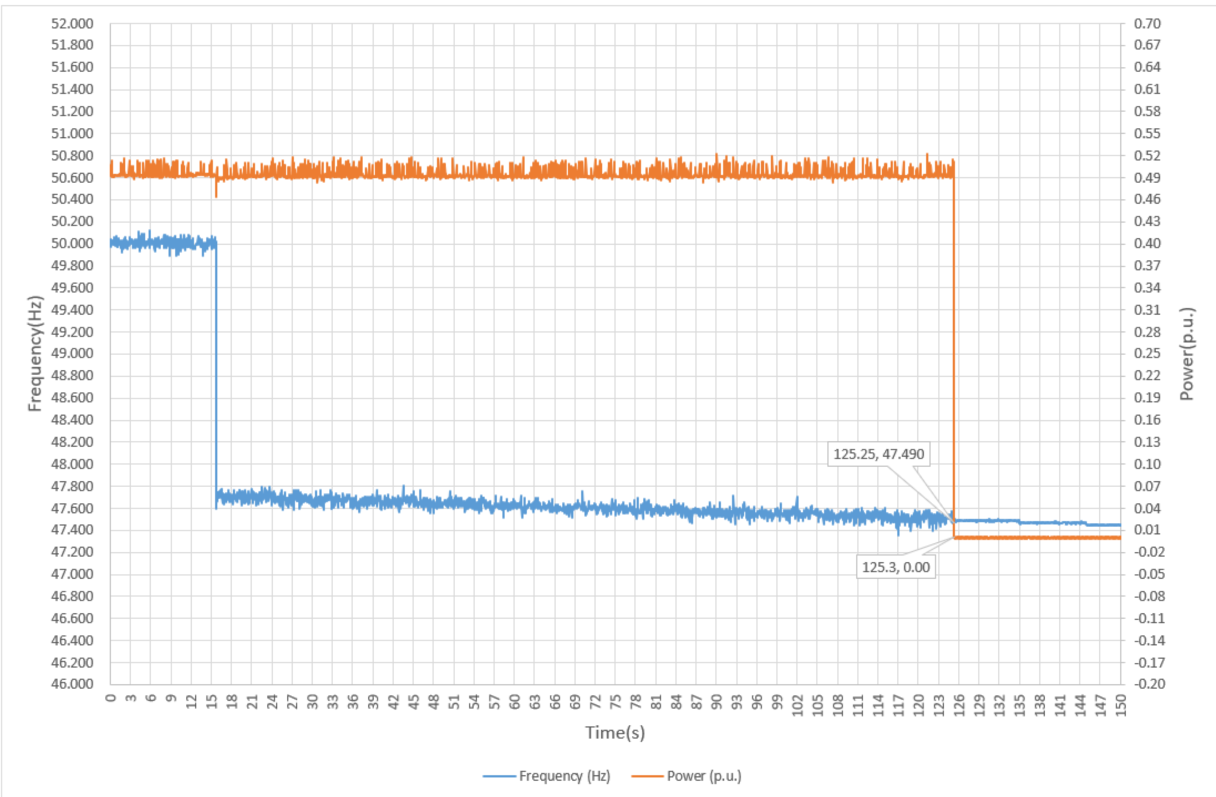


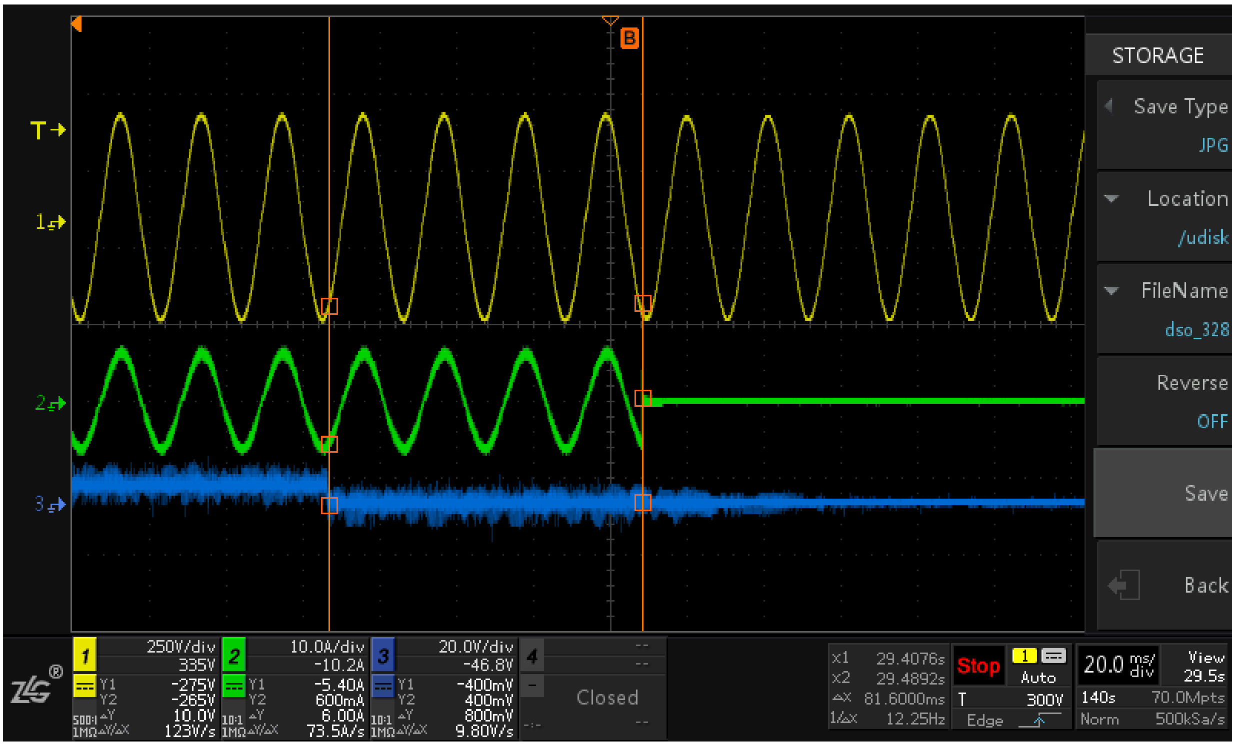
CH1: AC Voltage	CH2: AC current	CH3: Trigger signal

Test No.8.1 - Trip value 51.5Hz - L to N



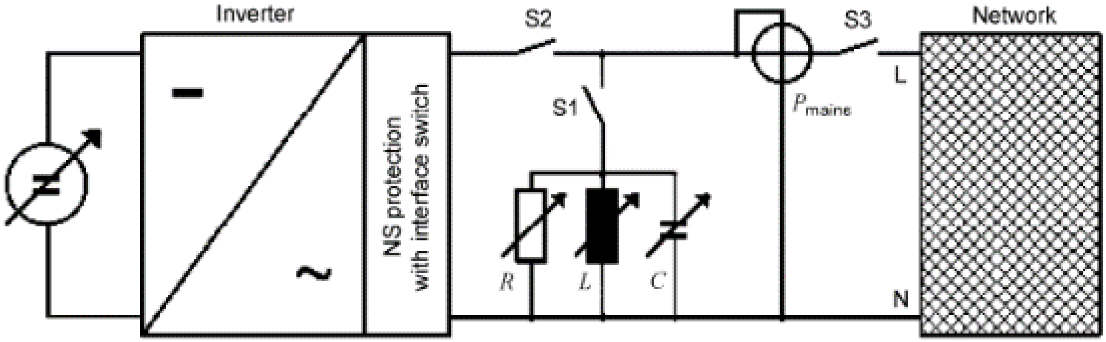
Test No.9.1 - Trip time 51.5Hz - L to N		
		
CH1: AC Voltage	CH2: AC current	CH3: Trigger signal

Test No.10.1 - Trip value 47.5Hz - L to N


Test No.11.1 - Trip time 47.5Hz - L to N		
		
CH1: AC Voltage	CH2: AC current	CH3: Trigger signal

4.11 ISLANDING DETECTION

According to the paragraph 6.5.3 of the VDE-AR-N 4105:2018-11 and the paragraph 5.5.10 of the VDE V 0124-100:2020-06 (refer to DIN EN 62116), detection of an island network and disconnection of the power generation system by means of the interface switch shall be completed within 5 s.



All the tests and checks have been performed in accordance with the reference Standard as specified previously. The used quality factor of resonant load was Qf=1.
There are required three different tests:

- Test A is at full power
- Test B is at 50%Pn to 66%Pn
- Test C is at 20%Pn to 33%Pn

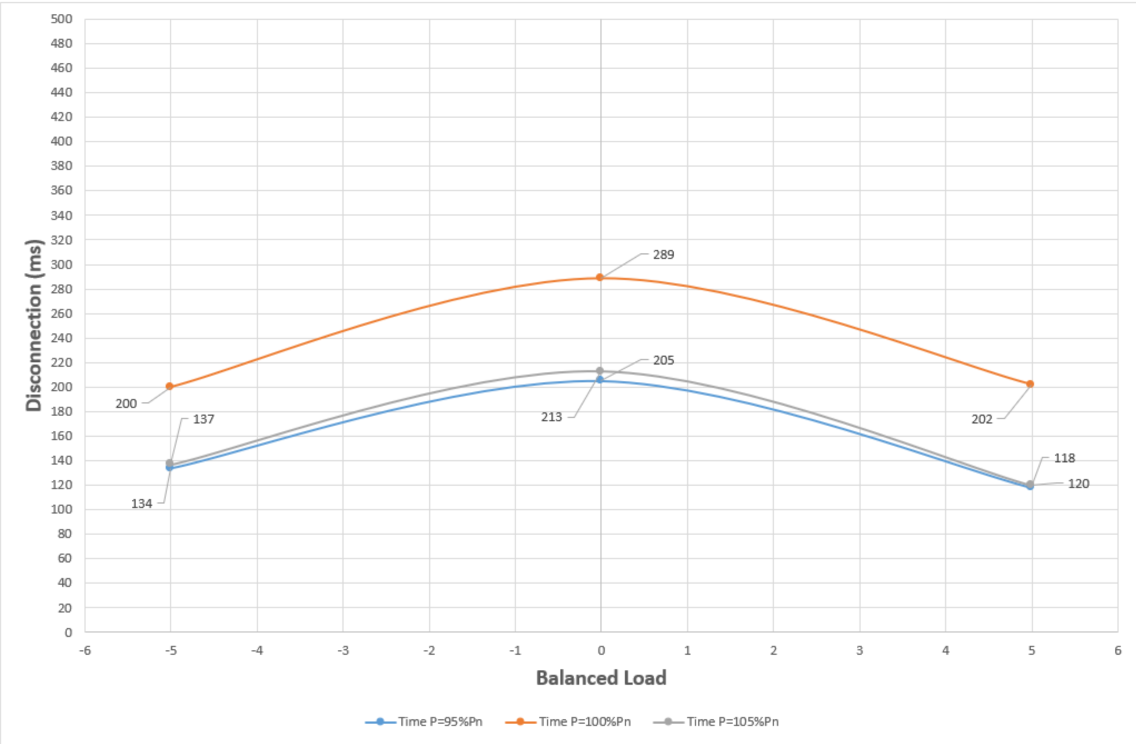
Test results are shown as below table:

Table: tested condition and run-on time										
No.	P_{EUT} (% of EUT rating)	Reactive load (% of normal)	P_{AC}	Q_{AC}	Run-on time (ms)	P_{EUT} (kW)	Q_{EUT} (kVar) (Cap.)	Q_{EUT} (kVar) (Ind.)	Actual Q_f	Which load is selected to be adjusted (R or C)
Test Condition A										
1	100	100	-5	5	118	1.928	2.115	2.033	1.076	R/C
2	100	100	-5	0	205	1.928	2.010	2.033	1.049	R
3	100	100	-5	-5	134	1.913	1.898	2.033	1.027	R/C
4	100	100	0	5	202	2.017	2.115	2.025	1.026	C
5	100	100	0	0	289	1.955	1.988	2.003	1.000	--
6	100	100	0	-5	200	2.003	1.905	2.025	0.981	C
7	100	100	5	5	120	2.175	2.115	2.033	0.953	R/C
8	100	100	5	0	213	2.153	2.010	2.033	0.939	R
9	100	100	5	-5	137	2.145	1.905	2.025	0.916	R/C
Test Condition B										
10	66	66	0	-5	119	1.320	1.283	1.345	0.994	C
11	66	66	0	-4	149	1.320	1.298	1.335	0.997	C
12	66	66	0	-3	116	1.328	1.313	1.343	1.000	C
13	66	66	0	-2	139	1.328	1.320	1.343	1.003	C
14	66	66	0	-1	120	1.320	1.327	1.343	1.011	C
15	66	66	0	0	124	1.320	1.320	1.320	1.000	--
16	66	66	0	1	123	1.355	1.343	1.343	1.006	C
17	66	66	0	2	122	1.328	1.358	1.343	1.017	C
18	66	66	0	3	133	1.328	1.365	1.343	1.020	C
19	66	66	0	4	128	1.328	1.373	1.343	1.023	C
20	66	66	0	5	84	1.328	1.380	1.343	1.025	C
Test Condition C										
21	33	33	0	-5	123	0.674	0.614	0.674	0.954	C
22	33	33	0	-4	151	0.674	0.614	0.674	0.954	C
23	33	33	0	-3	170	0.674	0.622	0.674	0.960	C
24	33	33	0	-2	166	0.674	0.630	0.674	0.966	C
25	33	33	0	-1	129	0.674	0.630	0.674	0.996	C
26	33	33	0	0	68	0.671	0.670	0.671	1.000	--
27	33	33	0	1	170	0.674	0.680	0.674	1.004	C
28	33	33	0	2	153	0.671	0.677	0.671	1.004	C
29	33	33	0	3	64	0.672	0.685	0.671	1.009	C
30	33	33	0	4	81	0.675	0.694	0.674	1.014	C
31	33	33	0	5	71	0.674	0.701	0.674	1.019	C

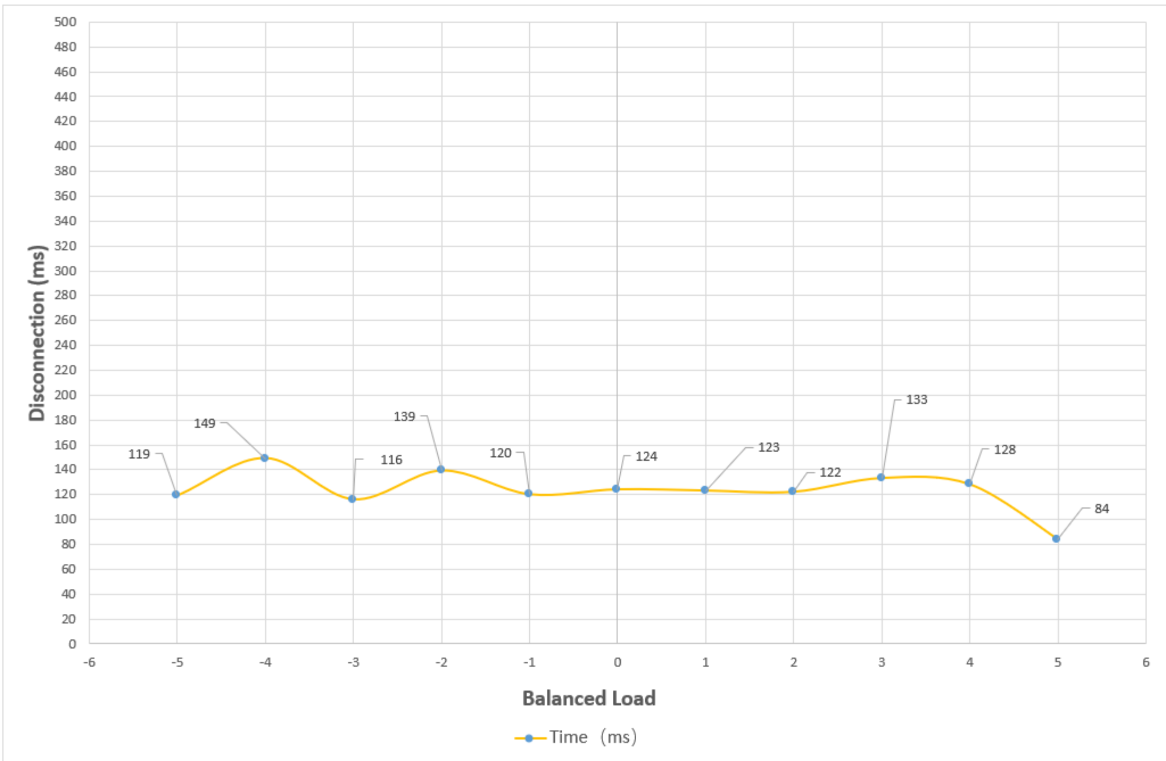
Remark:
For test condition A:
If any of the recorded run-on times are longer than the one recorded for the rated balance condition, then the non-shaded parameter combinations also require testing.
For test condition B and C:
If run-on times are still increasing at the 95 % or 105 % points, additional 1 % increments is taken until run-on times begin decreasing.

Test results are graphically shown as below.

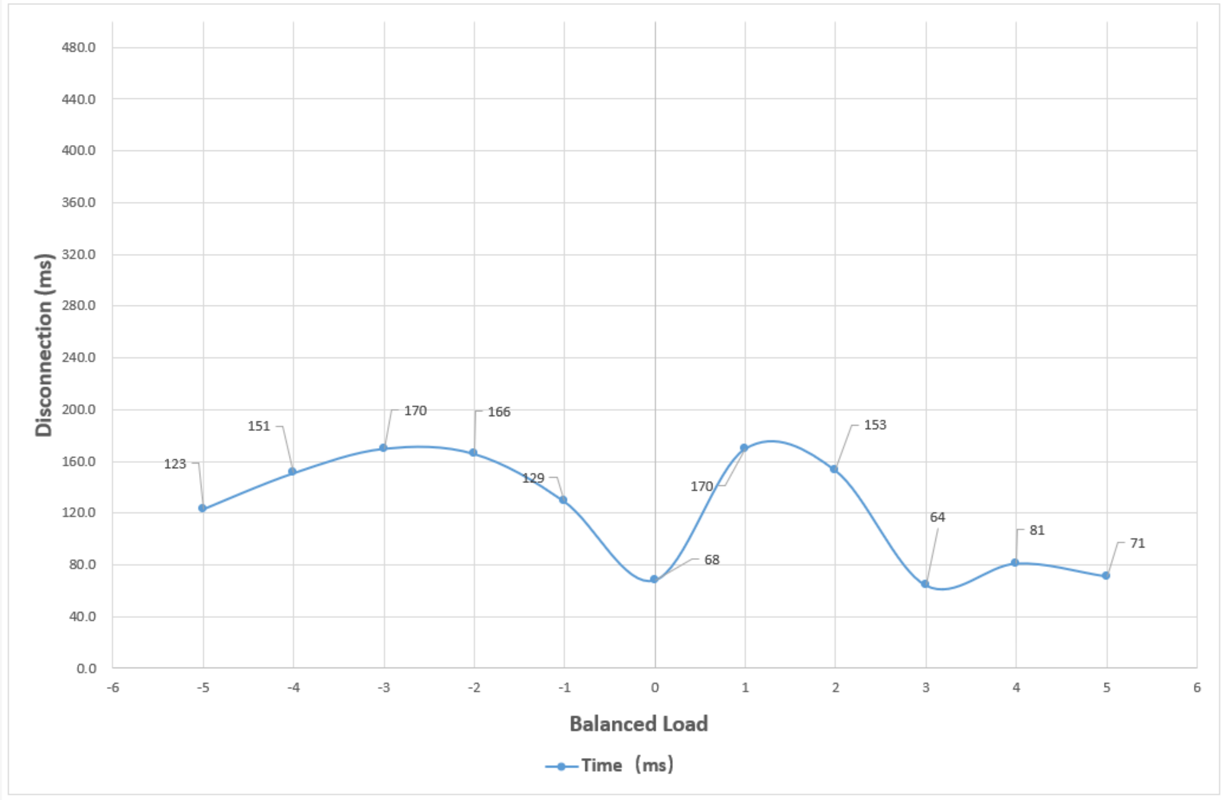
Test Condition A



Test Condition B



Test Condition C



4.12 CONNECTION CONDITIONS AND SYNCHRONIZATION

The power generation system shall be connected to the network only if both voltage and frequency are within the tolerance range according to the 8.3.1 of VDE-AR-N 4105:2018-11 and the sections 5.6 of VDE V 0124-100:2020-06

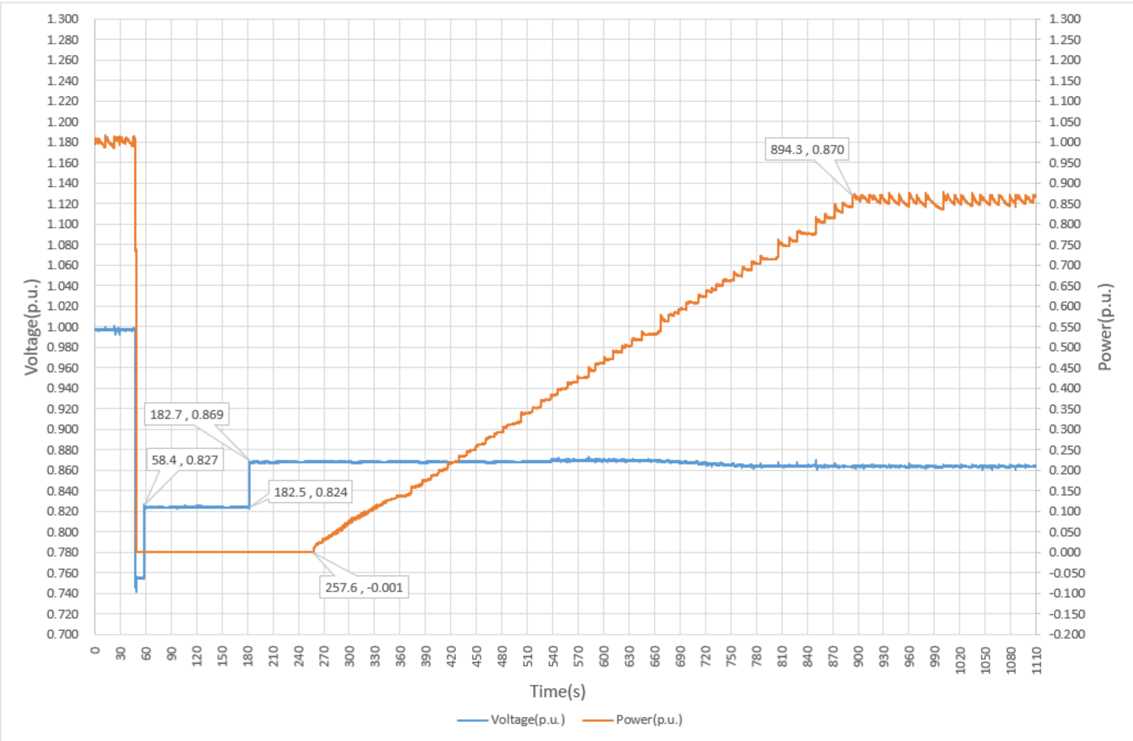
In the pictures below are offered the tests performed. The inverter has to be reconnected after a delay time of 60 seconds once voltage and frequency are within the range specified. It is also shown that the active power doesn't exceed the gradient of 10 % of the active power per minute.

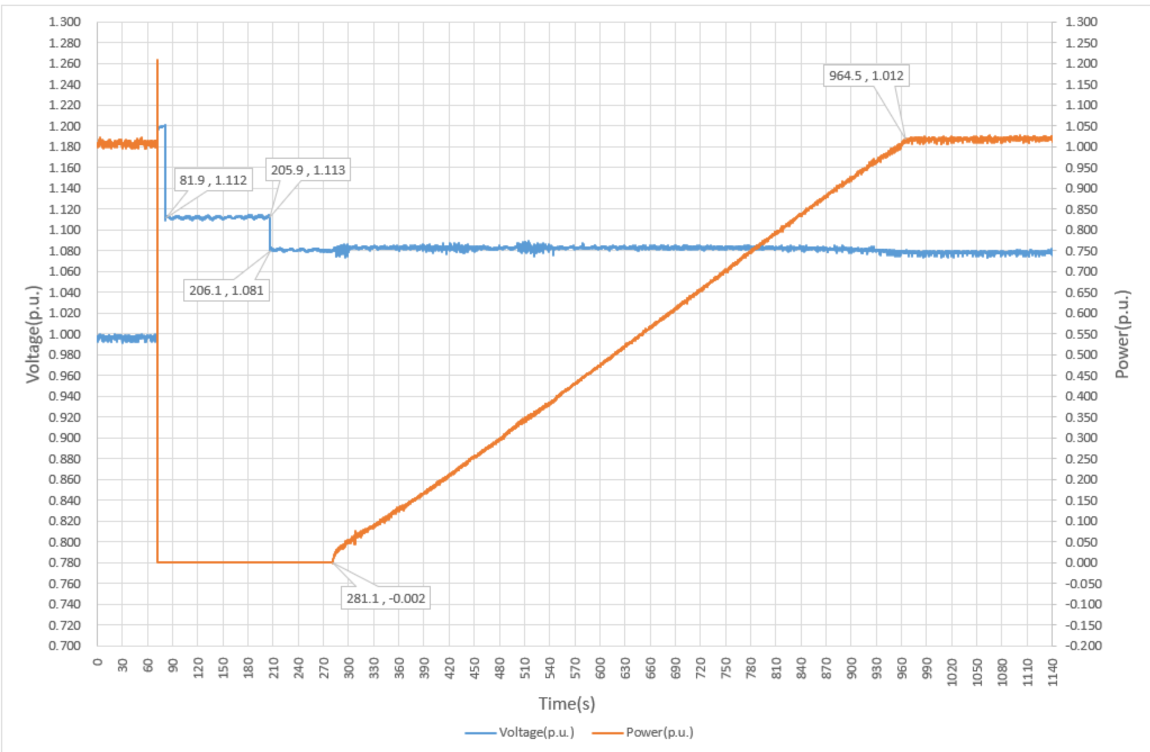
Each step shall be maintained for at least 120s or until the power has recovered completely.

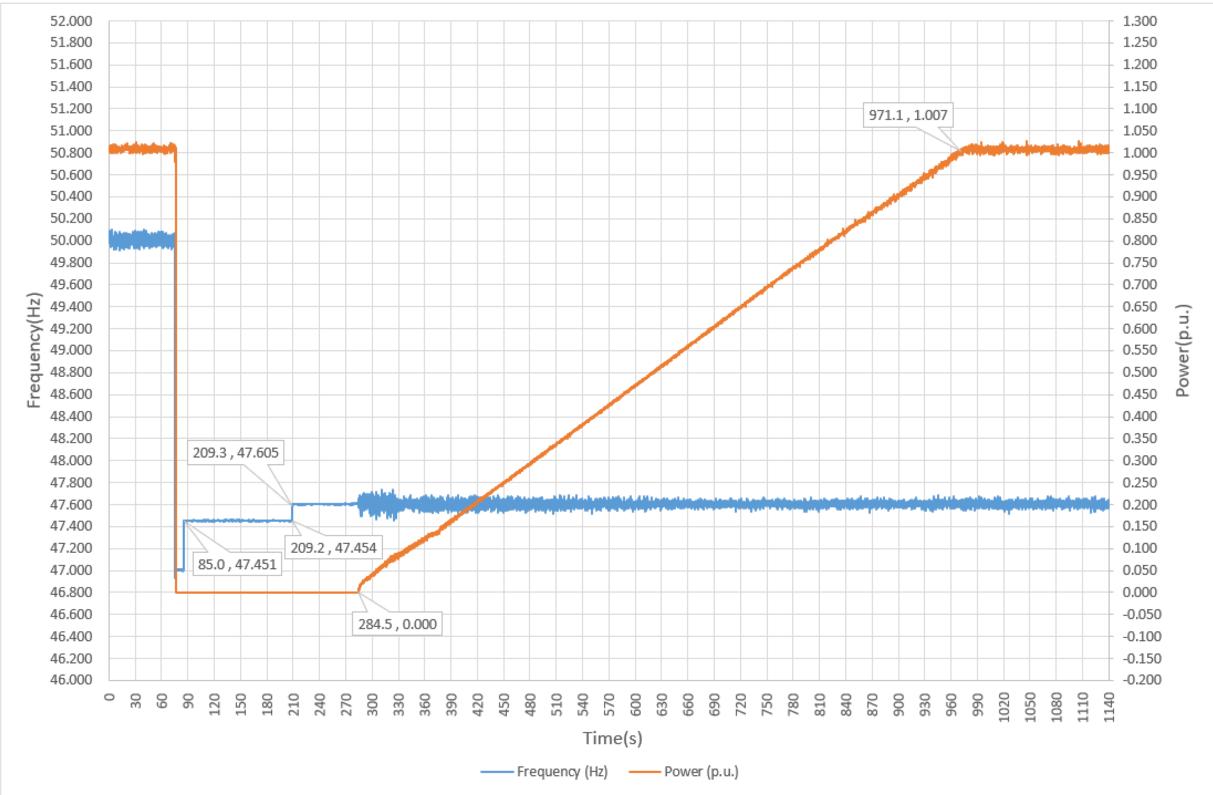
The results are offered in the table and graphs below:

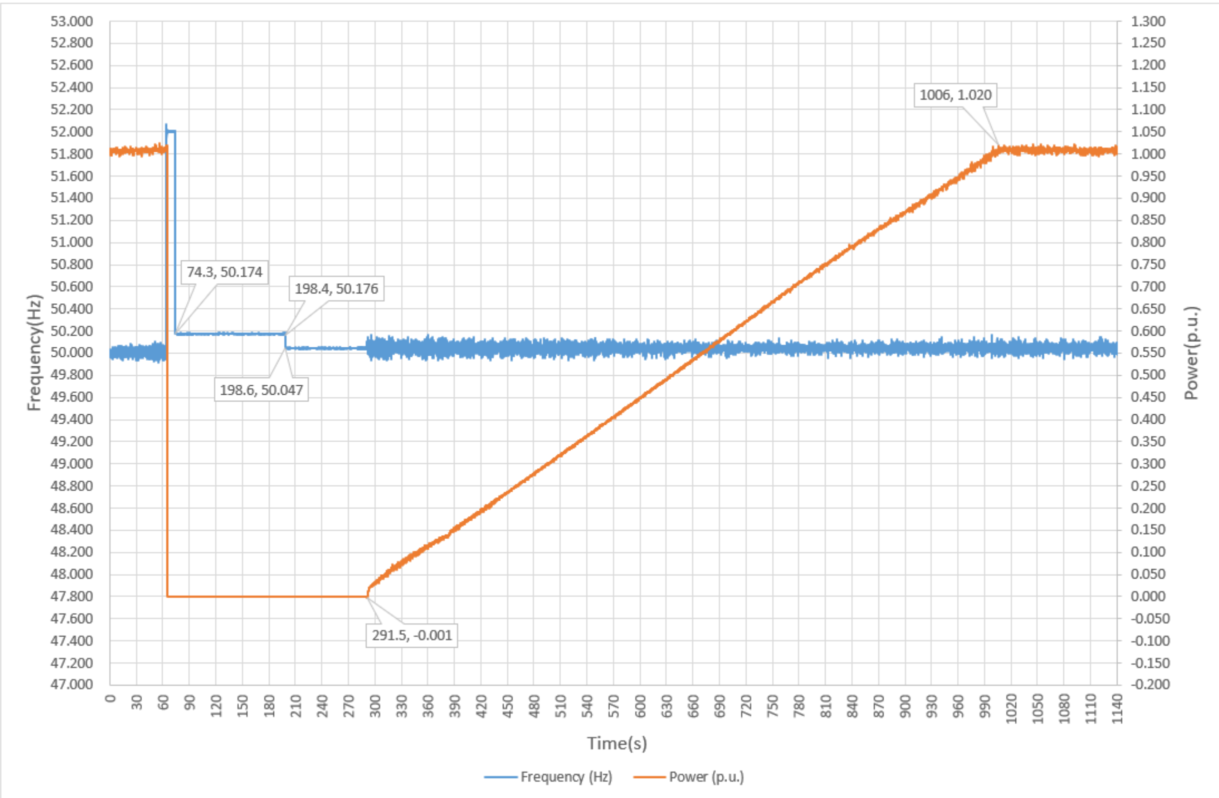
Test item	Measured Value	Reconnection (Yes or No?)	Reconnection Time (s) (>60 s)	Measured gradient (%P_{Amax}/min)
U_{ist} < <84% U_n	82.3% U_n	☒ NO ☐ YES	--	--
U_{ist} ≥ 86% U_n	86.2% U_n	☐ NO ☒ YES	74.9	8.29
U_{ist} > >111% U_n	111.3% U_n	☒ NO ☐ YES	--	--
U_{ist} ≤ 109% U_n	108.2% U_n	☐ NO ☒ YES	75.0	9.06
f_{ist} < <47.45 Hz	47.45 Hz	☒ NO ☐ YES	--	--
fist ≥ 47.55 Hz	47.60 Hz	☐ NO ☒ YES	75.2	8.80
f_{ist} > >50.15 Hz	50.16 Hz	☒ NO ☐ YES	--	--
f_{ist} ≤ 50.05 Hz	50.04 Hz	☐ NO ☒ YES	92.9	8.40

In the picture below are offered waveforms and graphically the results of the test.

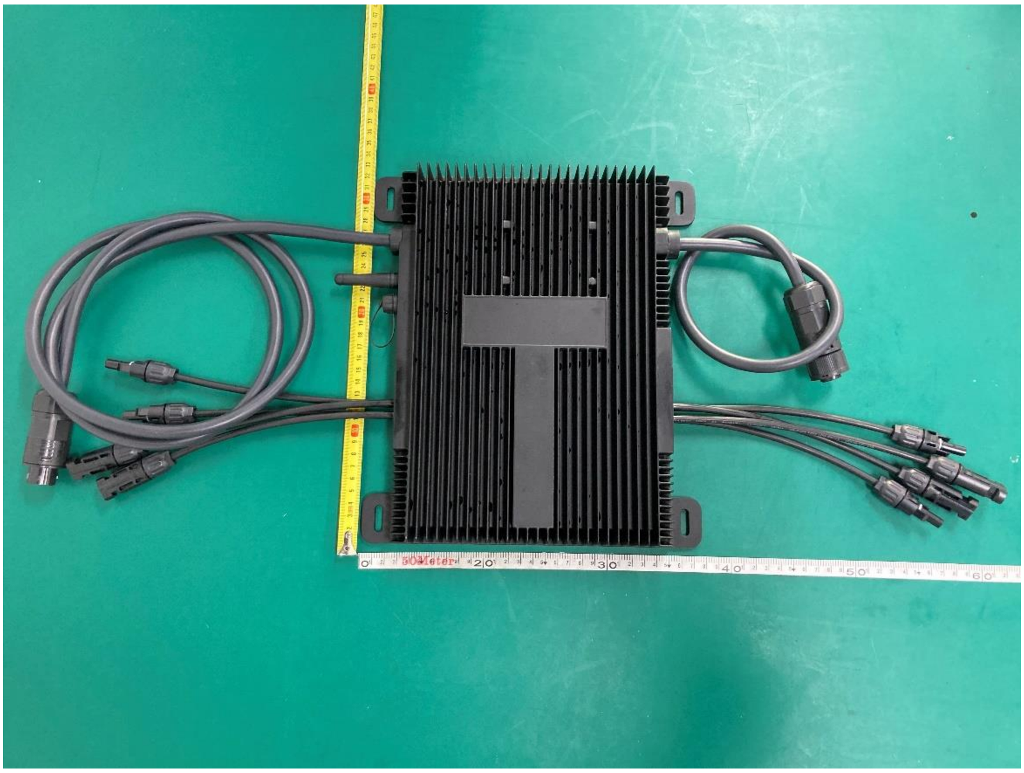
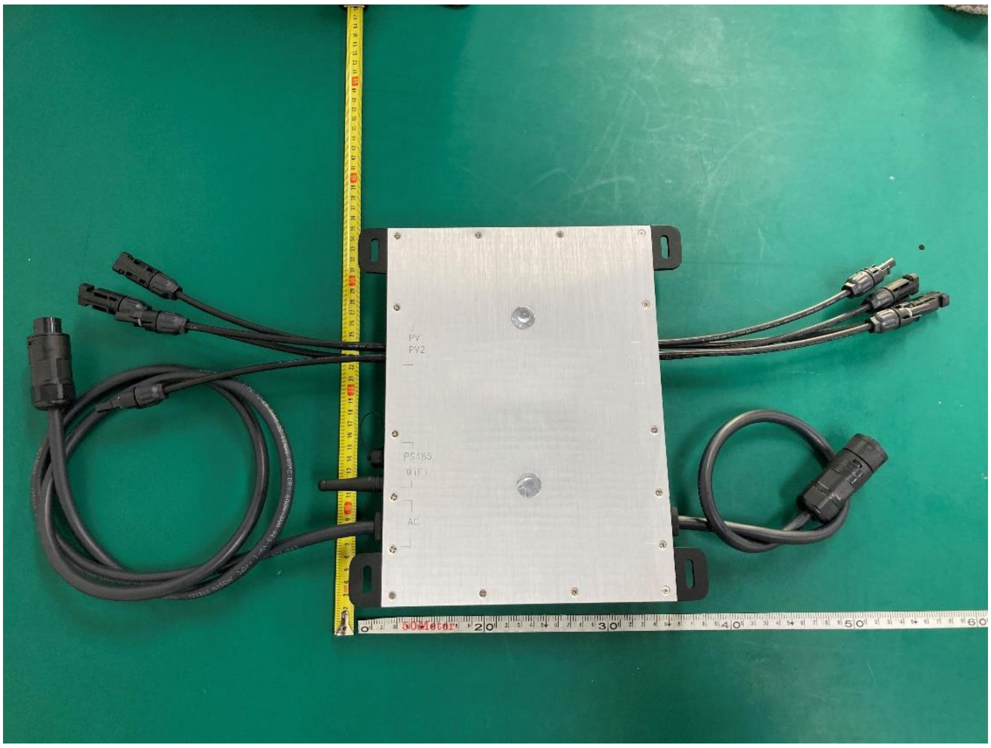
Undervoltage Reconnection	
	
Reconnection delay time limit: >60 s	Reconnection time measured: 74.9 s

Overvoltage Reconnection	
	
Reconnection delay time limit: >60 s	Reconnection time measured: 75 s

Underfrequency Reconnection	
	
Reconnection delay time limit: >60 s	Reconnection time measured: 74.8 s

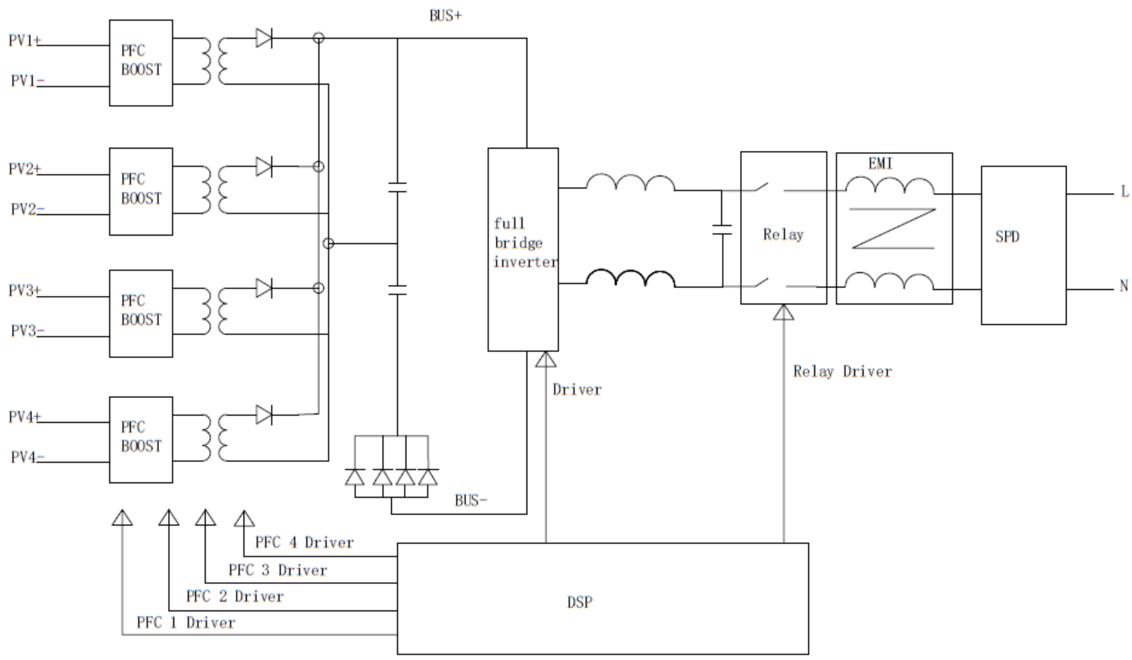
Overfrequency Reconnection	
	
Reconnection delay time limit: >60 s	Reconnection time measured: 92.9 s

5 PICTURES

Front view

Back view


EUT Software Version
Software Version TJ01V1.002
EUT Serial Number
TJ0123A15A0358

6 ELECTRICAL SCHEMES

Equipment under testing


---END OF REPORT---