DNV·GL

TYPE CERTIFICATE

Certificate No.:	Issued:	Valid until:
TC-GCC-TR8-06046-0	2020-06-05	2025-06-04

Issued for:

Huawei SUN2000-33KTL-A, SUN2000-36KTL

Specified in Annex 2

Issued to:

Huawei Technologies Co., Ltd.

Bantian, Longgang District,
Shenzhen 518129,
P.R. China

According to:

VDE-AR-N 4110:2018-11 Technical requirements for the connection and operation of customer installations to the medium voltage network

FGW TG8:2019-02 Technical Guidelines for Power Generating Units, Systems and Storage Systems as well as for their Components, Part 8

Based on the documents:

CR-GCC-TR8-06046-A065-0	Certification report: Model validation GCC, dated 2020-06-04
CR-GCC-TR8-06046-A066-0	Certification report: Fault ride-through, dated 2020-06-04
CR-GCC-TR8-06046-A067-0	Certification report: Control behaviour and other grid code requirements, dated 2020-06-05

The generating unit complies with the requirements of VDE-AR-N 4110:2018-11 and the complementary documents stated in Annex 1 provided the conditions of Annex 1 are considered at project level. The simulation model and the measurement reports of the type tests are cited in Annex 3.

Changes of the system design, software or the manufacturer's quality system are to be approved by DNV GL.

Hamburg, 2020-06-05

For DNV GL Renewables Certification

Dr. Bente Vestergaard
Director and Service Line Leader
Type and Component Certification

DAkkS
Deutsche
Akkreditierungsstelle
D-ZE-11053-01-00

By DAkkS according DIN EN IEC/ISO 17065 accredited Certification Body for products. The accreditation is valid for the fields of certification listed in the certificate.

Hamburg, 2020-06-05

For DNV GL Renewables Certification

Torge Wehrend
Senior Engineer

Conditions and assessment criteria

1 Conditions

- In case PT1-behaviour for reactive power set point changes is requested on project level, this needs to be implemented by a plant controller providing the corresponding set-points to the generating unit.

- The PGU has one interface to handle active power set points. Consequently, prioritization of control input signals from different actors (such as grid operators and direct sellers) is not possible. To have this feature implemented a plant controller is needed in order to comply with A.1.2.5.1.1 No. 3 in FGW TG8 /4/ on project level.

- The display to check the protection settings is missing, as well as the test terminals used to enable protection tests without disconnecting any wires. This is not in agreement with the requirements of the VDE-AR-N 4110 /1/. Therefore, the following shall be taken into account:

    - With regard to the missing display, the operator of the PV-plant is responsible to provide a proper solution for checking the settings of the generating unit. If requested by the grid operator, it might therefore be necessary to provide such device (e.g. tablet or smartphone) with a corresponding application, which is either to be stored on site or need to be provided on demand.

    - With regard to the missing test terminals, the consequences need to be investigated on project level. Depending on the requirements of the corresponding grid operator, an additional "intermediate" protective disconnection device on the low-voltage side of the transformer might be necessary.

- In general, it needs to be investigated on project level whether a permanent reduction of the rated active power is necessary to meet the reactive power requirement at the grid connection point. This applies especially to the inverter SUN2000-36KTL when running in PQ-Mode 1.

- The parameters of the generation unit are summarised in the parameter list provided by the manufacturer. The specified "default values" do not automatically meet the requirements according to the guidelines mentioned in Annex 1 section 2. If necessary, the settings must be adjusted and checked on a project level.

- If a reactive power provision by the functionality "Q(U) control" or by "Q with voltage limiting function" is required on project level the use of a plant control having these functions implemented is mandatory.

- The P(f) function prioritizes some external active power setpoint inputs higher than the active power calculated based on the P(f) characteristic (for more details see section 5.4.2.2 of CR-GCC-TR8-06046-A067-0). If this is not desired on project level in the way it is implemented, the use of a plant control having these functions implemented is mandatory.

- For assessments related to project certification, the simulation model shall only be used in the certified version. For clear identification, a checksum (MD5) was assigned to the model (see Annex 3, Section 2).

2 The assessment criteria and normative references for this certificate are:

/1/ VDE-AR-N 4110: Technische Regeln für den Anschluss von Kundenanlagen an das Mittelspannungsnetz und deren Betrieb (TAR Mittelspannung), VDE Verband der Elektrotechnik Elektronik Informationstechnik e.V., vom November 2018 *(VDE-AR-N 4110 Technical requirements for the connection and operation of customer installations to the medium voltage network (TCR medium voltage)*

/2/ FGW TG3: Technische Richtlinie für Erzeugungseinheiten und -anlagen, Teil 3: Bestimmung der elektrischen Eigenschaften von Erzeugungseinheiten und -anlagen, Speicher sowie für deren Komponenten am Mittel-, Hoch- und Höchstspannungsnetz, Fördergesellschaft Windenergie und andere Dezentrale Energien (FGW), Revision 25, vom 01.09.2018 *(FGW Technical Guidelines, Part 3: Determination of the Electrical Characteristics of Power Generating Units and Systems, Storage Systems as well as their Components in Medium, High and Extra-High Voltage Grids)*

/3/ FGW TG4: Technische Richtlinie für Erzeugungseinheiten und -anlagen, Teil 4: Anforderungen an Modellierung und Validierung von Simulationsmodellen der elektrischen Eigenschaften von Erzeugungseinheiten und -anlagen, Speicher sowie deren Komponenten, Fördergesellschaft Windenergie und andere Erneuerbare Energien (FGW), Revision 9, vom 01.02.2019 *(FGW Technical Guidelines, Part 4: Demands on modelling and validation of simulation models of generating units and systems as well as their components)*

/4/ FGW TG8: Technische Richtlinie für Erzeugungseinheiten, -anlagen und Speicher sowie für deren Komponenten, Teil 8: Zertifizierung der elektrischen Eigenschaften von Erzeugungseinheiten und -anlagen, Speicher sowie für deren Komponenten am Stromnetz, Fördergesellschaft Windenergie und andere Dezentrale Energien (FGW), Revision 9, vom 01.02.2019 *(FGW Technical Guidelines for Power Generating Units, Systems and Storage Systems as well as for their Components, Part 8: Certification of the Electrical Characteristics of Power Generating Units and Systems, Storage Systems as well as their Components on the Grid)*

Description and technical data of the generating unit

1 Description of the generating unit

The generating units Huawei SUN2000-33KTL-A and SUN2000-36KTL convert electrical energy generated by photovoltaic modules (DC) to three-phase alternating current (AC). Power control on the DC side is implemented by a Maximum Power Point (MPP) tracking system. The rated output voltage of the SUN2000-33KTL-A is 400 V while the SUN2000-36KTL has two output voltage ratings, 400 V and 480 V. All variants are technically equal to the SUN2000-36KTL 400 V version according to the definition in the FGW TG8 /4/. The inverter type SUN2000-36KTL running at 400 V was tested for the default rated active power of 36 kW. On the SUN2000-36KTL the maximum active power limit can also be increased up to the apparent power limit of 40 kVA.

The electrical data of the generating unit is summarised in the following section.

2 Technical data and main components

2.1 General data

Generating unit	**SUN2000-33KTL-A**	**SUN2000-36KTL**
No. of phases	3-phase	3-phase
Maximum apparent power	33 kVA	40 kVA
Rated active power*)	30 kW	36 kW (PQ-Mode 2) (40 kW @ cos φ=1, PQ-Mode 1)
Rated AC voltage (phase-to-phase)	400 V	400 V / 480 V
Rated frequency	50 Hz	50 Hz
Rated current	43.5 A	52.0 A (@ 400 V in PQ-Mode 2) 43.4 A (@ 480 V in PQ-Mode 2)

*) The specified rated active power values allow for a power factor of 0.9 at full load and rated voltage (PQ-Mode 2). For the SUN2000-36KTL it is possible to set the rated active power identical to the rated apparent power (PQ-Mode 1). Project planners should note that PQ-Mode 1 decreases the reactive power capability down to zero at full load. The maximum active power limits are therefore 30 kW for the SUN2000-33KTL-A and 40 kW for the SUN2000-36KTL. The FRT testing was carried out on the SUN2000-36KTL operating in PQ-Mode 2.

2.2 DC input

Generating unit	**SUN2000-33KTL-A**	**SUN2000-36KTL**
Min. MPP voltage	200 V	200 V
Max. MPP voltage	1000 V	1000 V
Max. DC input voltage	1100 V	1100 V
Max. DC input current	88 A	88 A

2.3 Inverter

Manufacturer	Huawei	Huawei
Type name	SUN2000-33KTL-A	SUN2000-36KTL
Generic type	Transformerless	Transformerless
Pulsing frequency of inverter	16 kHz	16 kHz
Generic type of power control	MPP-Tracking	MPP-Tracking
Software version	V200R002	V200R002

2.4 Unit transformer

The transformer is not part of the generating unit and so is not part of this assessment.

2.5 Grid protection

The grid protection is integrated into the control of the generating unit.

2.6 Disconnection device

Manufacturer	Panasonic	Panasonic
Type name	HE1aN-W-DC12V-Y6	HE1aN-W-DC12V-Y6

Type tests and validated simulation model

1 Type tests of the generating unit

The measurements were performed on a SUN2000-36KTL photovoltaic inverter of Huawei Technologies Co., Ltd. in Shanghai. The components and the software versions are described in Annex 2 of this certificate.

The measurement results are documented in the following measurement reports. Specific results can be found in the corresponding extracts as well as the certification reports CR-GCC-TR8-06046-A066-0 and CR-GCC-TR8-06046-A067-0 also providing details on the assessment.

Measurement report no.	Extract no.	Content
10157045-A-4-A	-	Fault ride-through tests
10157045-A-3-A	10157045-S-2-A	Control behaviour and power quality tests
GLGH-4280 16 13964 294-A-0002-A	-	Reactive Power provision

All tests according to FGW TG3 /2/ were assessed according to FGW TG8 /4/ and in compliance with VDE-AR-N 4110 /1/.

2 Validated simulation model of the generating unit

The validated simulation model of the generating unit for the simulation of voltage dips is contained in the following table. In order to identify the file of the simulation model clearly, a check sum (MD5) is used.

File name	Check sum (MD5)
Huawei_VDE4110_SUN2000-36KTL_Enc_V1.2.pfd	278eff5f966a0ea04e5917f95b909f7d

This simulation model was validated according to FGW TG4 /3/. Further explanations to the simulation model are contained in the certification report CR-GCC-TR8-06046-A065-0.

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HUAWEI SUN2000-33KTL-A AND SUN2000-36KTL

Certification Report: Model Validation GCC

Huawei Technologies Co., Ltd.

Report No.: CR-GCC-TR8-06046-A065-0
Date: 2020-06-04

Project name:	Huawei SUN2000-33KTL-A and SUN2000-36KTL	DNV GL - Energy
Report title:	Certification Report:	Germanischer Lloyd Industrial
	Model Validation GCC	Services GmbH,
Customer:	Huawei Technologies Co., Ltd.,	Renewables Certification
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Date of issue:	2020-06-04	DE 228282604
Project No.:	10157033	
Organisation unit:	Grid Code Compliance	
Report No.:	CR-GCC-TR8-06046-A065-0	

Applicable contract(s) governing the provision of this Report: 180686-SFA-2019-04-23

Objective: Assessment of the simulation model and model validation of the Huawei SUN2000-33KTL-A and SUN2000-36KTL.

Prepared by:	Verified and approved by:
i.A. Hannes Pietsch — Digitally signed by Pietsch, Hannes Date: 2020.06.04 13:11:15 +02'00'	i.A. Torge Wehrend — Digitally signed by Wehrend, Torge Date: 2020.06.04 13:07:45 +02'00'
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Keywords:
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Rev. No.	Date	Reason for Issue	Prepared by	Verified and approved by
0	2020-06-04	First issue	Hannes Pietsch	Torge Wehrend

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1 EXECUTIVE SUMMARY

The purpose of this certification report is to document the assessment of the simulation models, including model validation, of the PV inverter types Huawei SUN2000-33KTL-A and SUN2000-36KTL. For this, the assessment criteria of the mentioned guidelines in section 2 were applied. The final result of the assessment is stated at the end of this certification report which gives a recommendation as part of the final certification decision.

2 ASSESSMENT CRITERIA

The assessment and validation of the simulation models is based on the following:

/A/ VDE-AR-N 4110:2018-11, Technische Regeln für den Anschluss von Kundenanlagen an das Mittelspannungsnetz und deren Betrieb (TAR Mittelspannung), VDE Verband der Elektrotechnik Elektronik Informationstechnik e.V., vom November 2018
(VDE-AR-N 4110 Technical requirements for the connection and operation of customer installations to the medium-voltage network (TAR medium voltage), in the following: VDE-AR-N 4110)

/B/ Technische Richtlinie für Erzeugungseinheiten und -anlagen, Teil 3: Bestimmung der elektrischen Eigenschaften von Erzeugungseinheiten und -anlagen, Speicher sowie deren Komponenten am Mittel-, Hoch- und Höchstspannungsnetz, Fördergesellschaft Windenergie und andere Erneuerbare Energien (FGW), Revision 25, vom 01.09.2018
(FGW Technical Guidelines, Part 3: Determination of the electrical behaviour of generating units, in the following: FGW TG3)

/C/ Technische Richtlinie für Erzeugungseinheiten und -anlagen, Teil 4: Anforderungen an Modellierung und Validierung von Simulationsmodellen der elektrischen Eigenschaften von Erzeugungseinheiten und -anlagen, Speicher sowie deren Komponenten, Fördergesellschaft Windenergie und andere Erneuerbare Energien (FGW), Revision 9, vom 01.02.2019
(FGW Technical Guidelines, Part 4: Demands on modelling and validation of simulation models of generating units and systems as well as their components in the following: FGW TG4)

/D/ Technische Richtlinie für Erzeugungseinheiten und -anlagen, Teil 8: Zertifizierung der elektrischen Eigenschaften von Erzeugungseinheiten und -anlagen, Speicher sowie für deren Komponenten am Mittel-, Hoch- und Höchstspannungsnetz, Fördergesellschaft Windenergie und andere Erneuerbare Energien (FGW), Revision 9, vom 01.02.2019
(FGW Technical Guidelines, Part 8: Certification of the electrical behaviour of generating units, Systems and Storage as well as their Components on the grid in the following: FGW TG8)

3 SCOPE OF ASSESSMENT

The assessment of the simulation models of the generating units contains the following:

- The completeness of the documents used for the model description
- The plausibility of the documents received
- The assessment of the simulation models and the assessment of the plausibility of the received characteristics according to the requirements of the documents listed in section 2
- Validation of the simulation models for the dynamic grid support (Fault Ride Through, FRT) based on the specifications in the documents listed in section 2
- Validation of the simulation models for active and reactive control during normal operations based on the specifications in the documents listed in section 2

4 DESCRIPTION OF THE SIMULATION MODEL

The following tables provide a summary of the evaluation criteria and assessment results, following chapter A.1.2.9.1.1 of FGW TG 8 /D/.

Table 4-1 General criteria

No.	Evaluation criteria	Acceptance criteria	Assessment result
1	Functional scope of the models meets at least the requirements according to chapter 11.2.6.2 [of VDE 4110 /A/]	True	Compliant (see chapter 4.2)
1.1	If necessary, the named functions are mapped in multiple models.	Allocation visible from model documentation	Compliant One model for the whole functionality. (see chapter 4.2)
2	Models for the grid fault case are implemented as rms value models. In special cases the use of EMT models is permitted	True. To extent that EMT models are used in justified cases, the calculation results are checked for robustness.	Compliant RMS models used. (see chapter 4.2)
2.1	Models for the grid fault case map the positive and negative phase sequence systems and zero phase sequence system.	True. Asymmetric faults can be represented.	Compliant (see chapter 4.2)
2.3	Models for grid fault case cover at least the PGU and protection devices, as long as these are part of the PGU.	True	Compliant (see chapter 4.2)
2.4	The time increment is a maximum of 10 ms. When using an automatic step width adjustment, the maximum step size is 0.2 s.	True	Compliant, validated fixed step size: 1 ms and 2 ms (see chapter 4.2)

4.1 Schematic description of the generating unit

The generating units Huawei SUN2000-33KTL-A and SUN2000-36KTL convert electrical energy generated by photovoltaic modules (DC) to three-phase alternating current (AC). Power control on the DC side is implemented by a Maximum Power Point (MPP) tracking system. The rated output voltage of the SUN2000-33KTL-A is 400 V while the SUN2000-36KTL has two output voltage ratings, 400 V and 480 V. All variants are technically equal to the SUN2000-36KTL 400 V version according to the definition in the FGW TG8 /C/. The inverter type SUN2000-36KTL running at 400 V was tested for the default rated active power of 36 kW. On the SUN2000-36KTL the maximum active power limit can also be increased up to the apparent power limit of 40 kVA.

Detailed descriptions and schematics are given in the Overview on the necessary documentation /8/ as well as the User Manual /9/.

4.2 Implementation of the generating unit in a simulation model

Huawei Technologies Co., Ltd. provided the simulation model mentioned in section 6.1 as template. The basis for the simulation model is a static generator of the DIgSILENT PowerFactory library. The control is implemented in few DIgSILENT Simulation Language (DSL)- models. The simulation model and the structure of the control are explained in the description of the simulation model /5/.

The simulation models are designed to use an RMS-Simulation method, with an adjustable fix step size between 1 ms and 2 ms.

There are for each type of inverter one set of parameters which has to be changed for achieving the behaviour of the corresponding inverter (see /5/).

4.3 Software and functionality of the simulation model

The model of the generating units is based on the software PowerFactory by DIgSILENT. The software versions 2019 SP4 (Build 19.0.6 (9043) / Rev. 66182) were used for the assessment. The purpose of the model is to reflect the behaviour of the physical PGU at any symmetric or asymmetric grid fault according to VDE-AR-N 4110 /A/.

Additionally set point changes for active and reactive power can be performed with the model.

- The set point of the active power can be adapted by changing the parameter "P_per" or "Pref" of the DSL-Object "P_Control". The conversion of the desired set point value to "P_per" or "Pref" values according to the model documentation /5/ is to be considered.
- The set point of the reactive power can be adapted by changing the parameter "Qref" of the DSL-Object "Q_Control". The conversion of the desired set point value to the "Qref" value according to the model documentation /5/ is to be considered.

The characteristic of the active power change in dependence of the grid frequency according to VDE-AR-N 4110 /A/ is also implemented.

The initial active and reactive power set point is to be defined in the static generator representation in the "load flow" tab.

The simulation model contains a set of protection functionalities. See CR-GCC-TR8-06046-A067 and the parameter list of the physical PGU /7/ for the protection functionalities and settings of the physical PGU and Table 4-2 for the functionalities represented in the model.

All settings do not meet the requirements of the guidelines mentioned in section 2 automatically, there may be adaptions necessary on project level.

Table 4-2 Protection functions and settings integrated in the model

Protection function	Value	Time/setting	Comment
Overvoltage U>	1.12 p.u.	1800 s	
Overvoltage U>>	1.25 p.u.	66 s	
Overvoltage U>>>	1.3 p.u.	0.2 s	
Undervoltage U<	0.87 p.u.	3600 s	According to the parameter /7/ list the default value is 66 s
Undervoltage U<<	0.8 p.u.	6 s	
Overfrequency f>	1.02 p.u.	1800 s	Contrary to the manual /5/ the values must be set as p.u. values.
Overfrequency f>>	1.03 p.u.	0.1 s	see above
Underfrequency f<	0.98 p.u.	1800 s	see above
Underfrequency f<<	0.95 p.u.	0.1 s	see above

The Q(U) function is implemented in the model as well. But the implementation is not in accordance with the VDE-AR-N 4110 /A/. The $U_{Q0,ref}$ is not online adjustable. Please see CR-GCC-TR8-06046-A067 for further explanations.

The P(f) function is implemented in the model. In section 5.4.2.2 of CR-GCC-TR8-06046-A067 a detailed description of the prioritization of external set point changes over the calculated set point based on the the P(f) characteristic is given. This needs to be considered for simulation with active power set point changes during frequency events.

4.4 Model documentation

The model documentation /5/ contains a detailed description of the model, the protection and parameters to be used for the different variants. There is also a description available for how to implement the models into new projects.

Not mentioned in the model documentation /5/ is an explanation of the Parameters "P_Control\P_per", "P_Control\Pref" and "Q_Control\Qref" which needs to be changed by a parameter event. The following table gives an overview about the unit and the related parameter.

Table 4-3 Set point parameters

DSL-Element\Parameter	Related to	unit
P_Control\P_per	P/Pmax	%
P_Control\Pref	P/Pn	p.u.
Q_Control\Qref	Q/Pn	p.u.

5 ASSESSMENT OF THE SIMULATION MODEL AND MODEL VALIDATION

The following tables provide a summary of the evaluation criteria and assessment results, following chapter A.1.2.9.1.1 of FGW TG 8 /D/.

Table 5-1 General criteria

No.	Evaluation criteria	Acceptance criteria	Assessment result
2.2	Models for the grid fault case can represent the behaviour in the event of a fault in the overarching grid and the return to quasi steady-state operation from any given quasi steady-state operating point.	True	Compliant (see chapter 5.1.1 and 5.1.2)
3	Models for normal operation represent all setting times and accuracies regarding active and reactive power according to the relevant requirements.	True	Compliant (see chapter 5.2.1)
3.1	The difference in the sliding 5 s mean values for simulated and measured active and reactive power in normal operation remain under specific limits.	$\lvert P_{1,\text{mess}} - P_{1,\text{sim}} \rvert \leq \varepsilon \cdot S_{\text{rE}}$ $\lvert Q_{1,\text{mess}} - Q_{1,\text{sim}} \rvert \leq \varepsilon \cdot S_{\text{rE}}$ $\lvert P_{2,\text{mess}} - P_{2,\text{sim}} \rvert \leq \varepsilon \cdot S_{\text{rE}}$ $\lvert Q_{2,\text{mess}} - Q_{2,\text{sim}} \rvert \leq \varepsilon \cdot S_{\text{rE}}$ $\lvert P_{0,\text{mess}} - P_{0,\text{sim}} \rvert \leq \varepsilon \cdot S_{\text{rE}}$ $\lvert Q_{0,\text{mess}} - Q_{0,\text{sim}} \rvert \leq \varepsilon \cdot S_{\text{rE}}$ With $\varepsilon = 0.15$ in the dynamic transition range and $\varepsilon = 0.05$ in the stationary range.	Compliant (see chapter 5.2.1)
3.2	For PGU models, which represent the behaviour for frequency deviations and which are used to determine the accuracy of aggregated PGS models, a comparison with the measurements according to 11.2.7 [of VDE 4110 /A/ has been completed.	True. Otherwise direct comparison of the aggregated model with the measurements according to 11.2.7 [of VDE 4110 /A/].	Compliant see chapter 4.2 and 5.2.1
4	PGU models are subjected to plausibility checks for use at additional operating points.	True	Compliant see chapter 5.1.2

Table 5-2 Additional criteria

No.	Additional evidence	Acceptance criteria	Assessment result
A	Validation of the PGU models for the grid fault case based on measurements according to 11.2.5 and 11.2.10 [of VDE 4110 /A/] according to the specifications of TG 4 by a certification body accredited according to DIN EN ISO/IEC 17065 has been completed	True	Compliant see chapter 5.1.1
B	Validation of the PGU models for normal operation based on measurements according to 11.2.4 and 11.2.7 [of VDE 4110 /A/] according to the specifications of TG 4 by a certification body accredited according to DIN EN ISO/IEC 17065 has been completed	True	Compliant see chapter 5.2.1

5.1 Assessment of the model regarding grid faults

For all simulations performed in this section the model mentioned in section 6.1 was used. In this chapter only the behaviour during grid faults were assessed.

The validations and plausibility checks were carried out for all variants mentioned in the following:

- SUN2000-33KTL-A
- SUN2000-36KTL-A with 400 V
- SUN2000-36KTL-A with 480 V

Each variant is not explicitly addressed in the individual subchapters. Reference is only made to individual variants if there are special aspects of one or more variants that need to be mentioned.

If not stated otherwise the standard parameters of the model were used in this section.

5.1.1 Validation of the simulation model

The validation was performed with the simulation model for grid faults mentioned in section 6.1 for the inverter Huawei SUN2000-33KTL-A, SUN2000-36KTL (400 V and 480 V) and SUN2000-42KTL . The simulation model was validated for three-phase and two-phase voltage dips (also called Low Voltage Ride Through - LVRT) and overvoltage tests (also called High Voltage Ride Through HVRT, and in general Fault Ride Through - FRT) according to the requirements of the FGW TG4 /C/. Since the inverter is a type 2 unit, the most-favoured test defined in FGW TG4 /C/ was performed. All FRT tests were simulated and then compared to corresponding test results, measured at the Huawei SUN2000-36KTL (400 V) and documented in the measurement report /3/.

The basis for comparison, and consequently for validation, is the data of the tests listed in Table 5-3, which are taken from the measurement report /3/. All data were provided in digital form by the measurement institute.

The validation of the simulation model is based on the tests mentioned in Table 5-3 and the requirements of the FGW TG4 /C/. The voltage dips and overvoltage tests were achieved in the software environment as well as in reality with a grid emulator at the test field of Huawei Technologies Co., Ltd. in Shanghai (China).

More details on the setup can be found in the measurement report /3/. A transformer was neither used during the measurement nor in the simulation. The grid emulator initiated the two-phase voltage dips in such a way that the phasor diagram represents the fault as it would be on LV-side of a Dy transformer. The evaluation was done with the measured values at the inverter terminals (400-V-side) and the simulation results at the inverter representation of PowerFactory rated to 400 V.

All cases mentioned in Table 5-3 were performed and validated for the fixed step sizes 1 ms and 2 ms.

The tolerances stated in the FGW TG4 /C/ were not exceeded in all of the performed validations. For the “overview of validation” according to appendix A.1 of the FGW TG4 /C/ please see Annex 1 of Table 9-1. Additionally the comparison graphs between measurement and simulation are gathered in Annex 2 of Table 9-1.

Table 5-3 Validated tests for grid fault model

Test no. acc. TG3 /B/	Affected Phases	Voltage [%]	P [p.u., P/Pn]	Q [p.u., Q/Pn]	duration [ms]	Test no. Meas. Report /3/
0.1	3	3	1.01	-0.01	529.4	31
0.2	3	3	0.20	0.00	509.3	33
0.3	2	3	1.01	-0.01	518.4	35
0.4	2	3	0.20	0.00	520.5	37
25.1	3	25	1.01	-0.01	1159.9	39
25.2	3	25	0.20	0.00	1160	41
25.3	2	25	1.01	-0.01	1160.2	43
25.4	2	25	0.20	0.00	1159.9	45
50.1	3	50	1.01	-0.01	2089.9	47
50.2	3	50	0.20	0.00	2089.8	49
50.3	2	50	1.01	-0.01	2090.2	51
50.4	2	50	0.20	0.00	2090.3	53
50.5	3	50	1.01	-0.01	2089.9	55
50.6	2	50	1.01	-0.01	2089.9	57
75.1	3	75	1.01	-0.01	3079.8	59
75.2	3	75	0.20	0.00	3079.8	61
75.3	3	75	0.20	-0.10	3079.9	63
75.4	3	75	0.20	0.10	3079.7	65
75.5	3	75	0.20	0.00	3079.8	67
75.6	2	75	1.01	-0.01	3079.8	69
75.7	2	75	0.20	0.00	3079.8	71
75.8	2	75	0.20	0.00	3079.8	73
80.1	3	80	1.01	-0.01	3179.3	75
80.2	2	80	1.01	-0.01	3179.6	77
85.1	3	87	0.20	0.00	60196.7	79
110.1	2	115	1.01	-0.01	5299.7	85
110.2	2	115	0.20	0.00	5299.8	87
110.3	3	112	0.20	0.00	60196.2	89
115.1	3	115	1.01	-0.01	5299.7	81
115.2	3	115	0.20	0.00	5299.8	83

5.1.2 Plausibility simulations

Plausibility simulations with the simulation model of the generating unit for three-phase and two-phase voltage dips, as well as a double-dip, were performed according to the requirements of FGW TG4 /C/. The simulations performed are listed in Table 5-4. Different form the setup of the validation for plausibility a voltage divider was used in the simulation for reaching the test voltage. The grid voltage was set to the rated voltage (400V or 480V) of the corresponding inverter. The impedances were calculated in accordance of FGW TG8 /D/ Annex E.

Table 5-4 Plausibility simulations

Test no. acc. TG4 /C/	Pre-fault Voltage [%]	Affected Phases	Remaining voltage [%]	P [p.u., P/Pn]	Q[1)] [p.u., Q/Pn]	duration [ms]	k-factor	DNV GL Case no.
P1.01	100	3	94	0.90	-0.51	60000	0	800
P1.02	100	3	91	0.90	-0.51	60000	0	801
P1.03	100	3	86	0.90	-0.51	60000	0	802
P1.04	100	3	80	0.90	-0.51	2832	0	803
P1.05	100	3	75	0.90	-0.51	2665	0	804
P1.06	100	3	35	0.90	-0.51	1324	0	805
P1.06a	100	3 [2)]	35	0.90	-0.51	1324	0	806
P1.07	100	3	30	0.90	-0.51	1156	0	807
P1.08	100	3	15	0.90	-0.51	653	0	808
P1.09 [5)]	100	3	10	0.90	-0.51	485	0	809
P1.10 [5)]	100	3	5	0.90	-0.51	318	0	810
P2.01	105	3	94	1.00	0.51	60000	10	811
P2.02	105	3	91	1.00	0.51	60000	10	812
P2.03	105	3	86	1.00	0.51	60000	10	813
P2.04	105	3	80	1.00	0.51	2832	10	814
P2.05	105	3	75	1.00	0.51	2665	10	815
P2.06	105	3	35	1.00	0.51	1324	10	816
P2.07	105	3	30	1.00	0.51	1156	10	817
P2.08	105	3	15	1.00	0.51	653	10	818
P2.09 [5)]	105	3	10	1.00	0.51	485	10	819
P2.10 [5)]	105	3	5	1.00	0.51	318	10	820
P3.01	95	3	91	0.10	0.00	60000	1	821
P3.02	95	3	86	0.10	0.00	60000	1	822
P3.03	95	3	80	0.10	0.00	2832	1	823
P3.04	95	3	65	0.10	0.00	2329	1	824
P3.05	95	3	60	0.10	0.00	2162	1	825
P3.06	95	3	50	0.10	0.00	1826	1	826
P3.07	95	3	45	0.10	0.00	1659	1	827
P3.08	95	3	35	0.10	0.00	1324	1	828
P3.09	95	3	30	0.10	0.00	1156	1	829
P3.10	95	3	15	0.10	0.00	653	1	830

Test no. acc. TG4 /C/	Pre-fault Voltage [%]	Affected Phases	Remaining voltage [%]	P [p.u., P/Pn]	Q[1] [p.u., Q/Pn]	duration [ms]	k-factor	DNV GL Case no.
P3.11 [5]	95	3	10	0.10	0.00	485	1	831
P3.12 [5]	95	3	5	0.10	0.00	318	1	832
P4.01	105	2	94	0.50	-0.51	60000	3	833
P4.02	105	2	91	0.50	-0.51	60000	3	834
P4.03	105	2	86	0.50	-0.51	60000	3	835
P4.04	105	2	80	0.50	-0.51	3000	3	836
P4.05	105	2	45	0.50	-0.51	1888	3	837
P4.06	105	2	35	0.50	-0.51	1517	3	838
P4.06a	105	2 [2]	35	0.50	-0.51	1517	3	839
P4.07	105	2	30	0.50	-0.51	1332	3	840
P4.08	105	2	15	0.50	-0.51	776	3	841
P4.09 [5]	105	2	10	0.50	-0.51	591	3	842
P4.09a [5]	105	2 [4]	10	0.50	-0.51	591	3	843
P4.10 [5]	100	2	5	0.50	-0.51	405	3	844
P5.01	100	2 [3]	94	1.00	0.51	60000	10	845
P5.02	100	2 [3]	89	1.00	0.51	60000	10	846
P5.03	100	2 [3]	86	1.00	0.51	60000	10	847
P5.04	100	2 [3]	80	1.00	0.51	3000	10	848
P5.05	100	2 [3]	75	1.00	0.51	3000	10	849
P5.06	100	2 [3]	35	1.00	0.51	1517	10	850
P5.07	100	2 [3]	30	1.00	0.51	1332	10	851
P5.08	100	2 [3]	15	1.00	0.51	776	10	852
P5.09 [5]	100	2 [3]	10	1.00	0.51	591	10	853
P5.09a [5]	100	2 [3], [4]	10	1.00	0.51	591	10	854
P5.10 [5]	100	2 [3]	5	1.00	0.51	405	10	855

[1] negative value means underexcited and a positive value overexcited

[2] Voltage phase angle of the voltage source is set to 30°

[3] With earth connection

[4] In comparison to the other dips where the faulty phases are 1 and 2, the faulty phases are 2 and 3.

[5] Not required for VDE-AR-N 4110 /A/

The tables of assessing the k-factor calculation required by FGW TG4 /C/ can be found in the Annex 4 of Table 9-1. In the following is an example of the k-factor with k = 3 presented in the Figure 5-1. The other presentation of the k = 0, 1, 10 can be found in Annex 4 of Table 9-1.

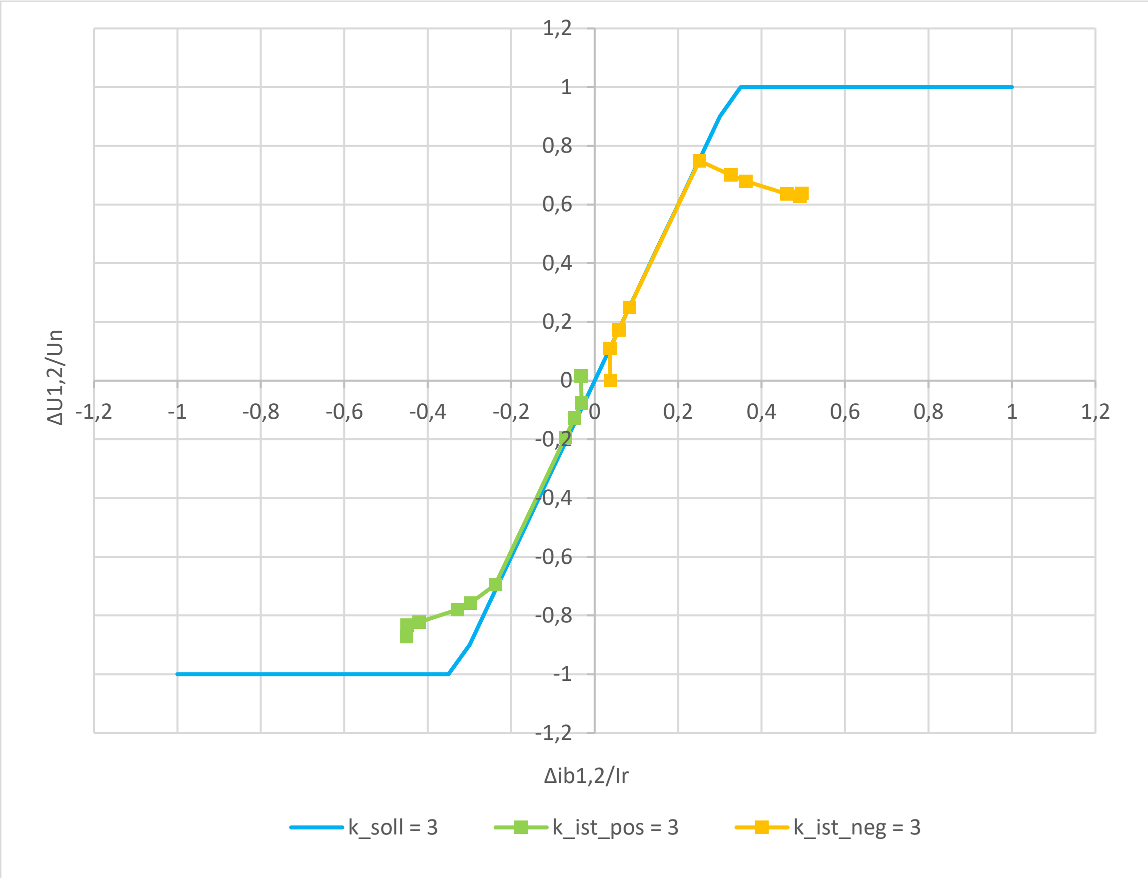


Figure 5-1 Graphical representation of the resulting k-factor with k = 3 acc. FGW TG4 /C/

In few test, especially the test with k = 10, "toggling" (fast frequent switching between FRT-mode and normal operation) was observed during the fault when the voltages are close to the stationary voltage area, after fault clearance, the model returned to the pre fault operation point. The model containing a parameter of a hysteresis to solve such an issue but a corresponding parameter is not available in the parameter list of the physical PGU /7/. Before adjusting these parameters the manufacturer should be contacted.

It was observed that the k-factor in some of the plausibility test was not reached. This is due to the current limitation which is explained in detail in CR-GCC-TR8-06046-A066.

In none of these simulations carried out could any indication of instability (except toggling) or implausible behaviour be observed.

5.1.3 Test of the model in a PGS

According to FGW TG4 /C/ the model is to be tested in a PGS-setup. For this, the manufacturer has chosen /6/ the setup shown in Figure 5-2 and described in FGW TG4 /C/. In this configuration the all simulation listed in Chapter 5.5.3 of FGW TG4 /C/ was performed. The ten instances of the model were inserted. The SUN2000-36KTL (400 V) was used.

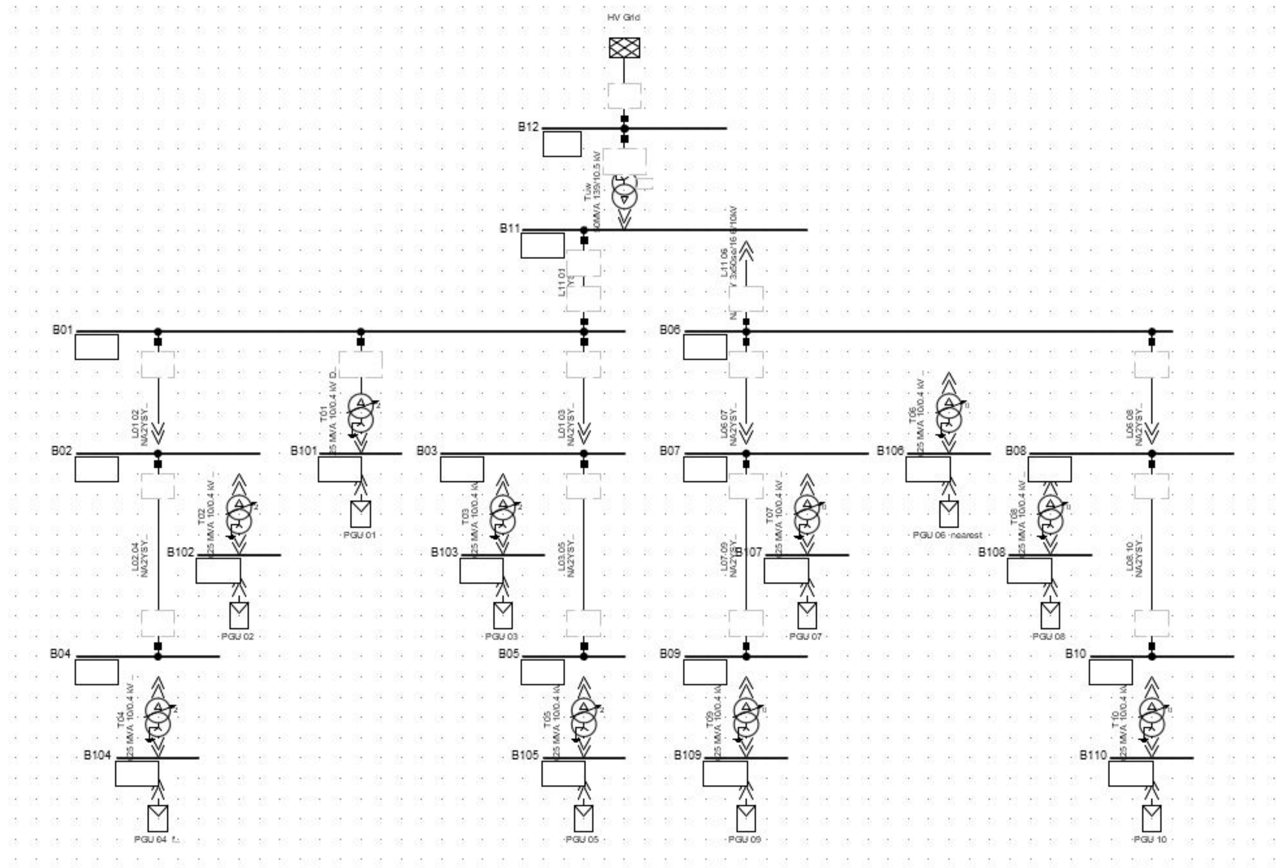


Figure 5-2 Setup chosen by the manufacturer and defined in FGW TG4 /C/

The submitted simulations were randomly sample wise checked for plausibility. The simulation model behaves plausibly and did not show any instabilities. The observed simulation time was acceptable.

5.2 Assessment of the model regarding normal operation

For all simulations performed in this section the model mentioned in section 6.1 was used. In this chapter only the behaviour during normal operation was assessed.

The validations were carried out for all variants mentioned in the following:

- SUN2000-33KTL-A
- SUN2000-36KTL-A with 400 V
- SUN2000-36KTL-A with 480 V

Each variant is not explicitly addressed in the individual subchapters. Reference is only made to individual variants if there are special aspects of one or more variants that need to be mentioned.

If not stated otherwise the standard parameters of the model were used in this section.

5.2.1 Validation of the simulation model

The simulation model of the Huawei SUN2000-33KTL-A and SUN2000-36KTL during normal operation was assessed according to the requirements of FGW TG4 /C/ respectively VDE-AR-N 4110 /A/, tests which can be replicated with the simulation model (see chapter 4.3 and the model documentation /5/) were simulated and compared to the corresponding measurement results of the Huawei SUN2000-36KTL-A (400 V) which are documented in the measurement report /4/.

The basis for comparison, and consequently for validation, is the data of the tests listed in Table 5-5, which are taken from the measurement report /4/. All data were provided in digital form by the measurement institute.

The validation of the simulation model is based on the tests mentioned in Table 5-5 and the requirements of the FGW TG4 /C/. The test setup used during the measurements was transferred to the software environment. In both situations the PGU was connected to the grid emulator without a transformer. The measurement was done in the test field of Huawei Technologies Co., Ltd. in Shanghai (China). The grid emulator is represented as a controlled voltage source and an impedance calculated based on the voltage changes caused by current changes.

Since the model cannot take the set points as signal, the set point signals of the measurement were transferred to a corresponding set of parameter events. During the measurements of the P(f) functionality the grid frequency was changed by the grid simulation, this is reflected in the simulation by changing the frequency of the grid emulator model.

All cases mentioned in Table 5-5 were performed and validated for the fixed step sizes 2 ms and 1 ms.

The tolerances stated by the VDE-AR-N 4110 /A/ and FGW TG8 /D/ were not exceeded for any of the performed validations. Except the test of active power adaption at overfrequency and underfrequency.

Test 505: (Active power adaption at over frequency)
During the measurement The reactive power and current showing a reaction on a frequency change. This reaction is not shown by the simulation model. Due to this difference the limits are exceeded. This is an abnormal behaviour during the measurements and can be accepted.
Note: The simulation model does not distinguish between available power and set point so no ramping up to the available power occurs. If this behaviour is to be reproduced, it can be created with a parameter event which sets the active power set point to the present available active power directly after the frequency has recovered. During the measurement two different power gradients was used. First the gradient which applies to the active power change due to frequency changes and the second

gradient applies to the active power change due to a setpoint change which occurs after the frequency test routine. Because the “P_Control\RateP” influencing or limiting the “Pf_Control\Pt_slope”. This was managed by using a corresponding parameter event. This also applies to test 506.

The functionality of the P(f) is affected and was successful validated. Please find graphical representation in Annex 2 of Table 9-1.

The comparison graphs for the validation are attached in Annex 2 of Table 9-1. The setpoint is an auxiliary signal which was used to calculate the time of the set point change. For all graphs the nominal active power, nominal active current and nominal voltage of the Huawei SUN2000-36KTL-A (400 V) were used to rate the values shown in the graphs. The same ratings were used for the maximum deviation tables which can be found in annex 4 of Table 9-1.

The features of the Q(U)-characteristics as well the “reactive power with voltage limitation” was not validated. Further information can be found in CR-GCC-TR8-06046-A067 and chapter 4.3.

Table 5-5 Validated tests of model for normal operation

Test no.	Chapter in FGW TG 3	Chapter in measurement report	Description of the test	Validation result [1)]	DNV GL Case no.
-	4.1.2	4.1.1.2	Active power change (Settling time and gradient – maximum gradient)	+	501
-	4.1.2	4.1.2.3	Active power change (Settling time and gradient – minimum gradient)	+	502
-	4.1.2	4.1.1.3	Active power change (Settling time and gradient – minimum gradient)	+	503
-	4.1.2	4.1.1.2	Active power change (Settling time and gradient – maximum gradient)	+	504
-	4.1.2	4.1.1.1	Active power change (Setting accuracy (set-point control))	+	507
-	4.1.3	4.1.2.1	Active power adaption at over frequency	+	505
-	4.1.3	4.1.2.2	Active power adaption at under frequency	+	506
-	4.2.4	4.2.2.1	Reactive power change (Settling accuracy)	+	511
-	4.2.4	4.2.2.2	Reactive power change (Settling time – fast response)	+	513
-	4.2.4	4.2.2.3	Reactive power change (Settling time – slow response)	+	514
	4.2.7	4.2.5.3	Reactive power with voltage limiting function (Qref = - 0.33 p.u.)	o	508
	4.2.7	4.2.5.2	Reactive power with voltage limiting function (Qref = 0.33 p.u.)	o	509
	4.2.7	4.2.5.1	Reactive power with voltage limiting function (Qref = 0 p.u.)	o	510
	4.2.5	4.2.3.1	Q(U) control (voltage regulation) (Settling time – fast response)	o	515
	4.2.5	4.2.3.2	Q(U) control (voltage regulation) (Settling time – slow response)	o	516

1) "+" means successful validated, "-" means not successful validated; "o" means out of scope

5.2.2 Plausibility simulations

Plausibility simulations with the simulation model of the generating unit to test of the steady- state operation according to FGW TG4 /C/ chapter 5.5.2.2 was performed successful.

According to the FGW TG4 /C/ chapter 5.5.4 the plausibility test for active power reduction with over-frequency are optional and was not performed.

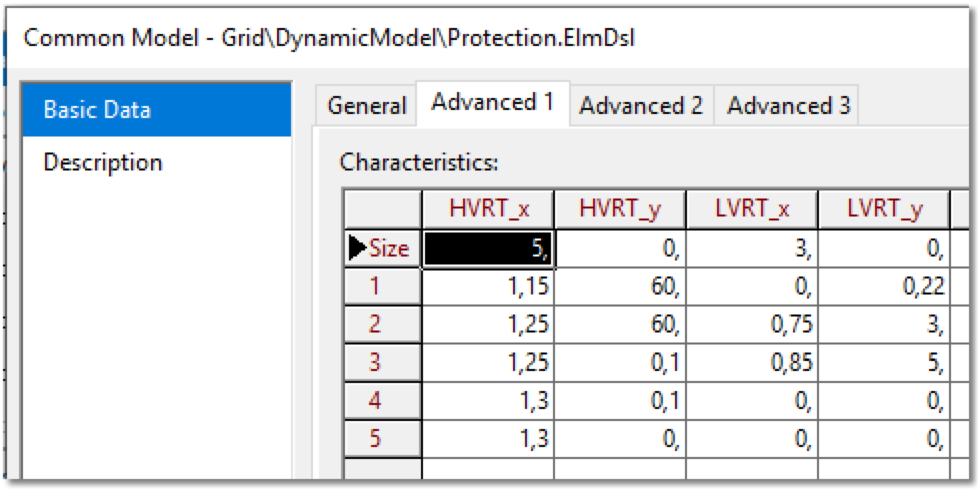
5.3 Plausibility simulation of the grid protection

The grid protection of the model was tested on its functionality. For this plausibility simulations the following simulations were carried out for each protection level:

1. The trigger level was slightly not exceeded
2. The trigger level was slightly exceeded.

In each case the time was applied was longer than the time set in the protection level. The protection levels and settings are reflecting the protection levels and settings of the physical PGU. An fall back ratio is not implemented in the model. None of these simulations has shown an unexpected behaviour.

The self-protection is not implemented in the model rather a Maximum under- and overvoltage capability curve is implemented. The default settings can be found in Figure 5-3. This capability curve could also lead to a trip and shut down of the inverter.



	HVRT_x	HVRT_y	LVRT_x	LVRT_y
Size	5,	0,	3,	0,
1	1,15	60,	0,	0,22
2	1,25	60,	0,75	3,
3	1,25	0,1	0,85	5,
4	1,3	0,1	0,	0,
5	1,3	0,	0,	0,

Figure 5-3 Maximum under- and overvoltage capability curve implemented in the simulation model

6 CONDITIONS

6.1 Use of the simulation model for project certification

For assessments in terms of project certification, the simulation model of the Huawei SUN2000-33KTL-A and SUN2000-36KTL shall only be used in the certified version. The model "Huawei_VDE4110_SUN2000-36KTL_Enc_V1.2.pfd" is to be used. In order to identify the simulation model clearly, a check sum (MD5) is used, which is contained in the following table.

Table 6-1 File name of the assessed simulation model with the corresponding check sum.

File name	Check sum (MD5)
Huawei_VDE4110_SUN2000-36KTL_Enc_V1.2.pfd	278eff5f966a0ea04e5917f95b909f7d

Changes of the simulation model, system design (as stated in the certification reports CR-GCC-TR8-06046-A066 and CR-GCC-TR8-06046-A067), software or the manufacturer's quality system are to be approved by DNV GL.

7 CONCLUSIONS

The received simulation model mentioned in section 6.1 were assessed according to the criteria of the FGW TG4 /C/. Under consideration of the conditions given in section 6.1, the simulation model of the inverter Huawei SUN2000-33KTL-A and SUN2000-36KTL of Huawei Technologies Co., Ltd. fulfils the requirements for simulation models as given in the regulations cited in section 2 and there are no objections to use the simulation model for simulations in the context of project certificates according to the VDE-AR-N 4110 /A/.

8 REFERENCES

/1/	ISO 9001:2015 Certificate no. 01 100 1933213 issued to Huawei Technologies Co., Ltd. for the design, manufacture and service of inverters	5 pages	dated 2020-04-09
/2/	Declaration of conformity for ISO 9001	1 page	dated 2020-05-19
/3/	Measurement report: Fault ride-through tests on a PV inverter of the type HUAWEI SUN2000-36KTL according to FGW TG3 Rev. 25, Report No.: 10157045-A-4-A	271 pages	dated 2020-04-15
/4/	Measurement of power quality and power control characteristics of a PV inverter of the type HUAWEI SUN2000-36KTL according to FGW TG3 Rev. 25, report no. 10157045-A-3-A	108 pages	dated 2020-04-17
/5/	User Manual of DIgSILENT Model for Huawei Inverter SUN2000-36KTL, Issue: V1.3, Grid Code: VDE 4110	19 pages	dated 2020-05-25
/6/	VCS-06046-0_33KTL Rev. 27	43 pages	dated 2020-05-29
/7/	Parameter list of SUN2000-36KTL & SUN2000-33KTL-A, V1.5	11 pages	dated 2020-05-28
/8/	Overview on the necessary documentation and data for the Prototype Confirmation of power generating units (PGU) in accordance to the VDE-AR-N-4110/4120 e Guideline, Version V1.1	7 pages	dated 2018-07-18
/9/	User Manual for different variants of SUN2000-(29.9KTL, 33KTL-A, 36KTL and 42 KTL), Issue 11	119 pages	dated 2019-06-08

9 ANNEX

Table 9-1 Overview of annexes

No.	Content	Filename	MD5-Checksum
1	Overview of validation results for grid fault model according to annex A.1 of FGW TG4	A065_Annex_1_FRT.zip	1d370932e3beecbed55dbb8338b303de
2	Comparison graphs for FRT and normal operation validation	A065_Annex_2_Graphs.zip	af58f50c49919667181de4d2e59d6137
3	Overview of maximum deviations for normal operation model validation	A065_Annex_3_QS.zip	e18b7214795ca3dded51811276b7c70e
4	Overview of the plausibility results	A065_Annex_4_Plausi.zip	2a89bf1dd00ae6d0a4e2d9dbf6e0bda0
5	Simulation Modell	Huawei_VDE4110_SUN2000-36KTL_Enc_V1.2.pfd	278eff5f966a0ea04e5917f95b909f7d
6	Model Documentation	User Manual for SUN2000-36KTL DIgSILENT model of VDE4110_V1.3.pdf	d0442a182c7c3592486cb8d7b389765d

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HUAWEI SUN2000-33KTL-A AND SUN2000-36KTL

Certification report: Fault ride-through

Huawei Technologies Co., Ltd.

Report No.: CR-GCC-TR8-06046-A066-0
Date: 2020-06-04

Project name:	Huawei SUN2000-33KTL-A and SUN2000-36KTL	DNV GL - Energy
Report title:	Certification report:	Germanischer Lloyd Industrial
	Fault ride-through	Services GmbH,
Customer:	Huawei Technologies Co., Ltd.,	Renewables Certification
	Bantian, Longgang District,	Brooktorkai 18
	Shenzhen 518129,	20457 Hamburg
	P.R. China	Germany
		Tel: +49 40 36149 0
Contact person:	Qingbin Chen	DE 228 282 604
Date of issue:	2020-06-04	
Project No.:	10157033	
Organisation unit:	Grid Code Compliance	
Report No.:	CR-GCC-TR8-06046-A066-0	

Applicable contract(s) governing the provision of this report: Short Form Agreement 180686-SFA-20190423 and Huawei Purchase Order 101754419.

Objective: Verification of the fault ride-through capability of the photovoltaic inverters Huawei SUN2000-33KTL-A and SUN2000-36KTL.

Prepared by:	Verified and approved by:
Digitally signed by Scholz, Mirco Date: 2020.06.04 10:47:20 +02'00'	Digitally signed by Wehrend, Torge Date: 2020.06.04 10:21:34 +02'00'
Mirco Scholz Senior Engineer	Torge Wehrend Senior Engineer

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Keywords:
GCC, VDE-AR-N 4110, FGW TG8, photovoltaic inverter

Rev. No.	Date	Reason for Issue	Prepared by	Verified and approved by
0	2020-06-04	First issue	Mirco Scholz	Torge Wehrend

Table of contents

1 EXECUTIVE SUMMARY

The purpose of this certification report is to document the assessment of the low voltage ride-through (LVRT) as well as the high voltage ride-through (HVRT) capability of the photovoltaic inverters of the type Huawei SUN2000-33KTL-A and SUN2000-36KTL. In place of LVRT and HVRT, the report will also use the general term fault ride-through (FRT). Grid code requirements other than the FRT capability are not part of this report and are assessed within the scope of the certification report CR-GCC-TG8-06047-A067. The documented results of the type tests and the corresponding manufacturer's documentation were assessed according to the assessment criteria of the guidelines in section 2. The result of the assessment is stated in the end of this certification report, which gives a recommendation as part of the final certification decision.

2 ASSESSMENT CRITERIA

The assessment of the FRT capability of the generating unit is based on the following:

/A/ VDE-AR-N 4110: Technische Regeln für den Anschluss von Kundenanlagen an das Mittelspannungsnetz und deren Betrieb (TAR Mittelspannung), VDE Verband der Elektrotechnik Elektronik Informationstechnik e.V., vom November 2018
(VDE-AR-N 4110 Technical requirements for the connection and operation of customer installations to the medium voltage network (TCR medium voltage)

/B/ FGW TG3: Technische Richtlinie für Erzeugungseinheiten und -anlagen, Teil 3: Bestimmung der elektrischen Eigenschaften von Erzeugungseinheiten und -anlagen, Speicher sowie für deren Komponenten am Mittel-, Hoch- und Höchstspannungsnetz, Fördergesellschaft Windenergie und andere Dezentrale Energien (FGW), Revision 25, vom 01.09.2018
(FGW Technical Guidelines, Part 3: Determination of the Electrical Characteristics of Power Generating Units and Systems, Storage Systems as well as their Components in Medium, High and Extra-High Voltage Grids)

/C/ FGW TG8: Technische Richtlinie für Erzeugungseinheiten und -anlagen, Teil 8: Zertifizierung der elektrischen Eigenschaften von Erzeugungseinheiten und -anlagen, Speicher sowie für deren Komponenten am Stromnetz, Fördergesellschaft Windenergie und andere Dezentrale Energien (FGW), Revision 9, vom 01.02.2019
(FGW Technical Guidelines, Part 8: Certification of the Electrical Characteristics of Power Generating Units and Systems, Storage Systems as well as their Components on the Grid)

3 SCOPE OF ASSESSMENT

The assessment of the fault ride-through capability of the generating units contains an assessment of the following:

- Completeness of the documents and measurements.
- Plausibility of the documents received.
- Compliance with the test conditions of the requirements and guidelines listed in section 2.
- Assessment of the measurement results against the requirements and guidelines listed in section 2.

4 ASSESSMENT OF FAULT RIDE-THROUGH CAPABILITY

4.1 Description of the generating unit

The generating units Huawei SUN2000-33KTL-A and SUN2000-36KTL convert electrical energy generated by photovoltaic modules (DC) to three-phase alternating current (AC). Power control on the DC side is implemented by a Maximum Power Point (MPP) tracking system. The rated output voltage of the SUN2000-33KTL-A is 400 V while the SUN2000-36KTL has two output voltage ratings, 400 V and 480 V. All variants are technically equal to the SUN2000-36KTL 400 V version according to the definition in the FGW TG8 /C/. The inverter type SUN2000-36KTL running at 400 V was tested for the default rated active power of 36 kW. On the SUN2000-36KTL the maximum active power limit can also be increased up to the apparent power limit of 40 kVA.

Detailed descriptions and schematics are given in the Huawei document "Overview on the necessary documentation" /7/ as well as in the User Manual /8/.

The electrical data of the generating unit is summarised in the following section.

4.2 Technical data of main components

The following is an overview of technical data for the main components of the generating unit, as specified by the manufacturer.

4.2.1 General data

Generating unit	**SUN2000-33KTL-A**	**SUN2000-36KTL**
No. of phases	3-phase	3-phase
Maximum apparent power	33 kVA	40 kVA
Rated active power*)	30 kW	36 kW (PQ-Mode 2) (40 kW @ cos φ=1, PQ-Mode 1)
Rated AC voltage (phase-to-phase)	400 V	400 V / 480 V
Rated frequency	50 Hz	50 Hz
Rated current	43.5 A	52.0 A (@ 400 V in PQ-Mode 2) 43.4 A (@ 480 V in PQ-Mode 2)

*) The specified rated active power values allow for a power factor of 0.9 at full load and rated voltage (PQ-Mode 2). For the SUN2000-36KTL it is possible to set the rated active power identical to the rated apparent power (PQ-Mode 1). Project planners should note that PQ-Mode 1 decreases the reactive power capability down to zero at full load. The maximum active power limits are therefore 30 kW for the SUN2000-33KTL-A and 40 kW for the SUN2000-36KTL. The FRT testing was carried out on the SUN2000-36KTL operating in PQ-Mode 2.

4.2.2 DC input

Generating unit	**SUN2000-33KTL-A**	**SUN2000-36KTL**
Min. MPP voltage	200 V	200 V
Max. MPP voltage	1000 V	1000 V
Max. DC input voltage	1100 V	1100 V
Max. DC input current	88 A	88 A

4.2.3 Inverter

Manufacturer	Huawei	Huawei
Type name	SUN2000-33KTL-A	SUN2000-36KTL
Generic type	Transformerless	Transformerless
Pulsing frequency of inverter	16 kHz	16 kHz
Generic type of power control	MPP-Tracking	MPP-Tracking
Software version	V200R002	V200R002

4.2.4 Unit transformer

The transformer is not part of the generating unit and so is not part of this assessment.

4.2.5 Grid protection

The grid protection is integrated into the control of the generating unit and is described in the Huawei document "Description of the Function Blocks of the Voltage Protection" /14/.

4.2.6 Disconnection device

Manufacturer	Panasonic	Panasonic
Type name	HE1aN-W-DC12V-Y6	HE1aN-W-DC12V-Y6

4.2.7 Parameters of the generating unit

All parameters are documented in the "Parameter list of SUN2000-36KTL & SUN2000-33KTL-A" /5/.

4.3 Performed tests, test setup

The voltage dip tests were performed on a SUN2000-36KTL photovoltaic inverter by DNV GL Renewables Advisory at a test bench in Shanghai according to the requirements of the FGW TG3 /B/. The undervoltages and overvoltages were generated by a grid emulator (controlled voltage source) directly connected to the 400 V terminals of the inverter.

The 2-phase faults described in this report were realised on the LV side by the customer's grid emulator in such a way as if the fault had occurred on the MV side of a delta-star (Dy) transformer. A two-phase fault on the MV side (type C) therefore translates to a fault of type D on the LV side. (Refer to Figure D-3 out of the FGW TG3 /B/ below, source: Bollen and FGW).

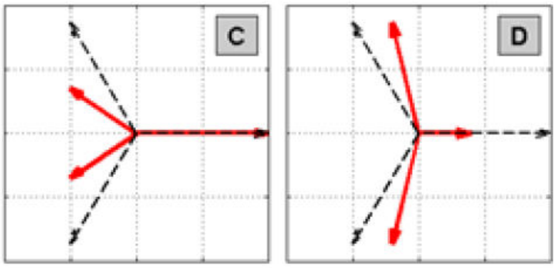

Figure D–3: Fault types C and D compliant with (two-pole faults without connection to the ground – before and after Dy transformer) based on [20]

Figure 4–1 Transformation of a phase-to-phase fault clear of earth through a Dy transformer

The FRT tests were performed in accordance with the requirements of the FGW TG3 /B/. All tests required by FGW TG3 /B/ have been performed.

4.4 Assessment according to FGW TG8, Rev. 9 (A.1.2.7.3.1)

The following tables summarise the general assessment criteria and the results of the assessment. The tables were extracted from the FGW TG8 /C/. For this reason, the numbering given is not consecutive. The other tables on remaining on the grid, feed-in of fault current, limited dynamic grid support, multiple faults, and contribution to short-circuit current can be found in the corresponding chapters of this report.

General criteria:

No.	Evaluation criterion	Acceptance criterion	Result of assessment
1	Self-protection allows operation between the lower and upper FRT boundary curves.	The tests required by the VDE regulation /A/ have been successfully completed	Compliant. See measurement report /6/.
2	FRT tests were successfully carried out with pre-fault reactive power inside the range of -10 % P_{rE} and +10 % P_{rE}.	True	Compliant. See measurement report /6/.
3	An FRT test was successfully carried out with the maximum underexcited and one with the maximum overexcited reactive power according to the manufacturer's specification (or with cos φ ≤ 0.95 overexcited or underexcited, as long as the capacity of the PGU is higher).	True	Compliant. See measurement report /6/.
4	The behaviour of the PGU or the component in the event of abrupt voltage changes was verified by a voltage swell of at least 10 % U_n to a value > 110 % U_n for symmetrical voltage increases and to ≥ 110 % U_n as the greatest phase-to-phase voltage for asymmetrical voltage increases with a duration of ≥ 5 s.	Minimum duration ≥ 5 s	Compliant. See measurement report /6/.
4.1	Starting from 2021-01-01, should the PGU be commissioned as part of a PGS, ride-through of a symmetrical voltage swell by at least 15 % U_n to a value > 115 % U_n for ≥ 5 s or ≥ 115 % U_n for ≥ 60 s has to be proved additionally in the form of a manufacturer's declaration.	True	Compliant. See manufacturer’s declaration /7/.

No.	Evaluation criterion	Acceptance criterion	Result of assessment
4.2	It is shown under which assumptions a ride-through of a symmetrical voltage swell of at least 15 % U_n up to a value > 115 % U_n for ≥ 5 s or ≥ 115 % U_n for ≥ 60 s is possible or not possible.	True	No assumptions. Is always possible.
5	The correct behaviour in the transition from dynamic to quasi-stationary operation of the generating units must be demonstrated for a symmetrical voltage dip with a minimum duration of ≥ 60 s by reducing the grid voltage to a value between 85 % and 90 % U_n.	True	Compliant. See measurement report /6/.
6	The correct behaviour in the transition from dynamic to quasi-stationary operation of the generating units must be demonstrated for a symmetrical voltage swell by increasing the grid voltage to a value ≥ 110 % U_n for ≥ 60 s.	True	Compliant. See measurement report /6/.
7	During the fault, the PGU feeds a reactive current as required (see the following table for type 2).	True	Compliant. See A and B in table below.
8	The PGU can ride through multiple faults in accordance with the requirements.	True	Compliant. See measurement report /6/.

The following table applies to type 2:

No.	Additional evidence	Acceptance criterion	Result of assessment
A	The tests according to FGW TG3 /B/ were carried out without disconnecting the PGU from the grid. With that, the FRT capability of the auxiliary drives used in the measurement is proven.	True	All tests required according to FGW TG3 /B/ were performed without disconnection from the grid. See measurement report /6/.
B	A voltage-time characteristic (capacity of the PGU) is available. The manufacturer's specification should at least correspond to the required capacity defined in the VDE regulation /A/.	Manufacturer’s information available. (if necessary under conditions at PGS level)	Specification has been made and corresponds to the required capacity. See Figure 4–2 below as well as manufacturer’s declaration /7/..

The voltage time characteristics for HVRT (OVRT) and LVRT (UVRT) are given in the figure below.

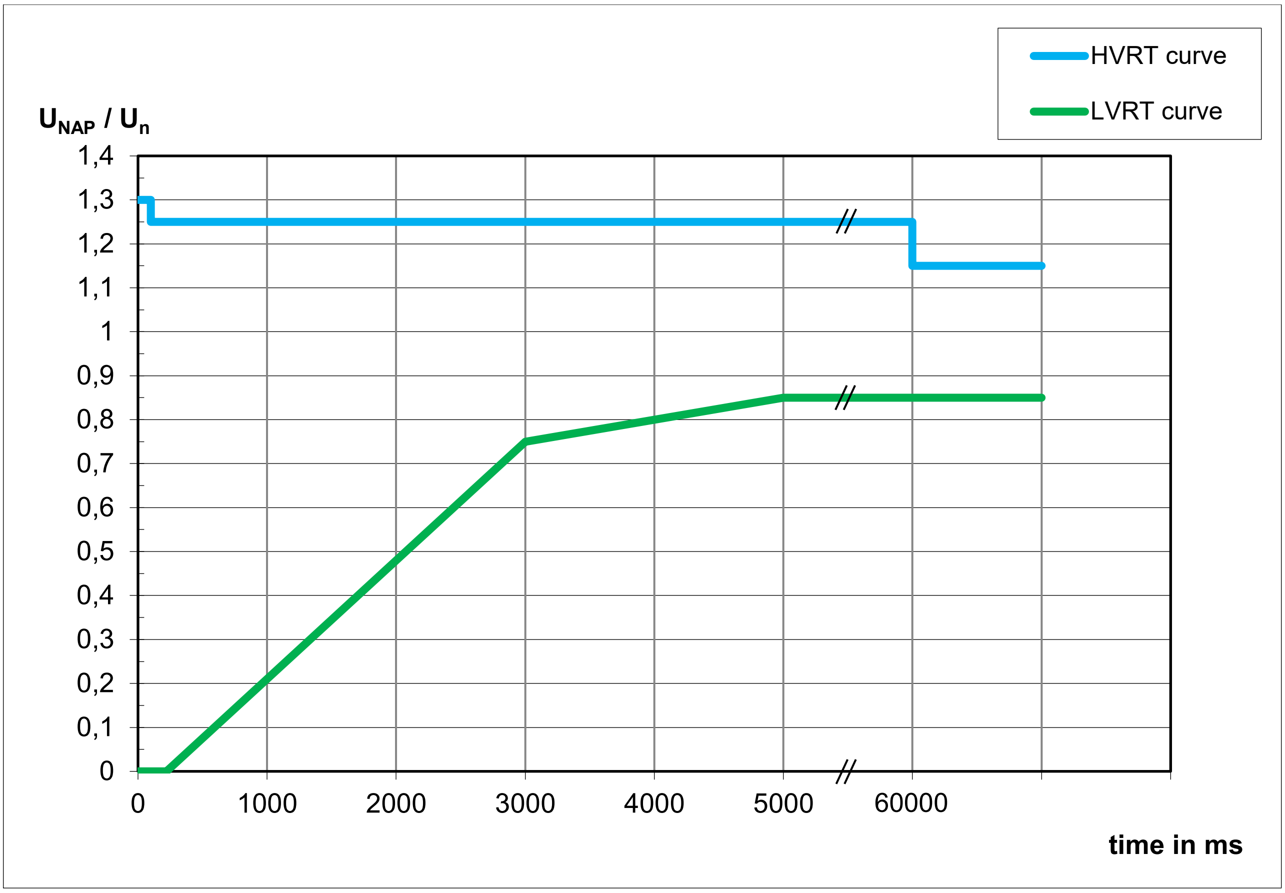

Figure 4–2 HVRT and LVRT voltage over time characteristics

The points defining the curves shown above have been specified in the manufacturer's declaration /9/ and are given below.

HVRT curve	
time in ms	U_{NAP}/U_n
0	1.3
100	1.3
100	1.25
6000	1.25
6000	1.15
7000	1.15

LVRT curve	
time in ms	U_{NAP}/U_n
0	0
220	0
3000	0.75
5000	0.85
7000	0.85

4.5 Remaining on the grid

For type 2 PGUs the following applies:

No.	Evaluation criterion	Acceptance criterion	Result of assessment
Remaining on the grid			
1.1	The PGU does not become unstable and does not disconnect from the mains as long as all line-to-line voltages are within the limit curve required by the VDE regulation /A/.	The tests required by the VDE regulation /A/ have been successfully completed.	All required FRT tests were successfully completed. See measurement report /6/.
1.2	All UVRT (LVRT) and OVRT (HVRT) tests have been fully completed.	True	All UVRT and OVRT tests were carried out completely. See measurement report /6/.
1.3	The PGU did not disconnect from the grid during all UVRT tests.	True	In all UVRT tests there was no disconnection from the grid. See measurement report /6/.
1.4	The PGU did not disconnect from the grid during all OVRT tests.	True	In all OVRT tests there was no disconnection from the grid. See measurement report /6/.

None of the documented FRT tests (two-phase or three-phase), including tests with a pre-fault reactive current, led to a shut-down of the generating unit. All tests according to FGW TG3 /B/ were carried out twice. The generating unit injected reactive current as required by VDE-AR-N 4110 /A/ as a result of a continuous voltage regulation (see section 4.6) and did not consume any more inductive reactive power than before the fault.

4.6 Reactive current control

During two-phase and three-phase faults, the inverter injects reactive current in both the positive and negative sequence, in accordance with the characteristics given by VDE-AR-N 4110 /A/. The positive and negative sequence reactive current fed into the fault is proportional to the change in positive and negative sequence voltage, in both the overvoltage and undervoltage cases.

The proportionality constant (k-factor), which determines the magnitude of the injected reactive current, was set to 2 for most of the tests. The adjustability of the k-factor was verified, in accordance with FGW TG3 /B/, with further tests at partial power as well as with the k-factor set to 4. The k-factor applies to the reactive current control in both the positive and the negative sequence, but there are different k-factors for each of the LVRT and HVRT cases. The pre-fault reactive current was correctly taken into consideration for the calculation of the additional reactive current during the faults. Tests were also carried out with limited dynamic grid support activated.

For asymmetrical faults, the sum of the absolute values of reactive current in the positive and the negative sequence is limited to 1.0 p.u. in order to prevent any of the phase currents reaching values above 1 p.u.

Faults are detected by using two voltage thresholds for detecting over voltage and under voltage, as well as a threshold for detecting abrupt voltage changes. In all cases, the phase voltages are assessed. The LVRT threshold is set to 0.9 p.u., while the HVRT threshold is set to 1.1 p.u. The FRT mode is also triggered for voltage steps larger than 0.05 p.u. compared to the last-second average voltage.

According to VDE-AR-N 4120 /A/, the PGU is required to "thermally be able to attain any arbitrary point on the FRT curve at least 4 times one directly after the other without disconnecting from the network". This capability has been experimentally demonstrated during tests with a worst-case setup.

In the following Figure 4–3 to Figure 4–15 are graphs of specific results of the FRT tests carried out on the test rig.

4.6.1 Graphs of LVRT (UVRT) tests

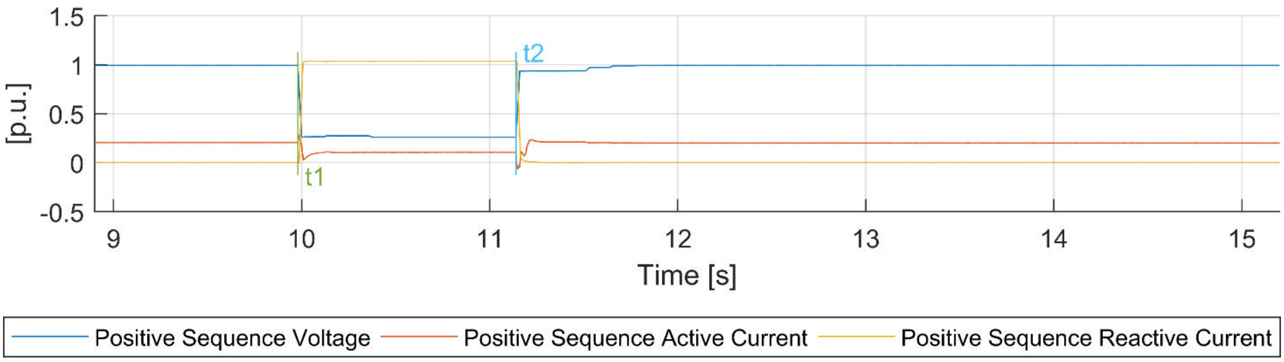

Figure 4–3 Positive sequence values of voltage, active and reactive current, test no. 41, 3-phase, partial load, fault voltage 25% Un, k=2.

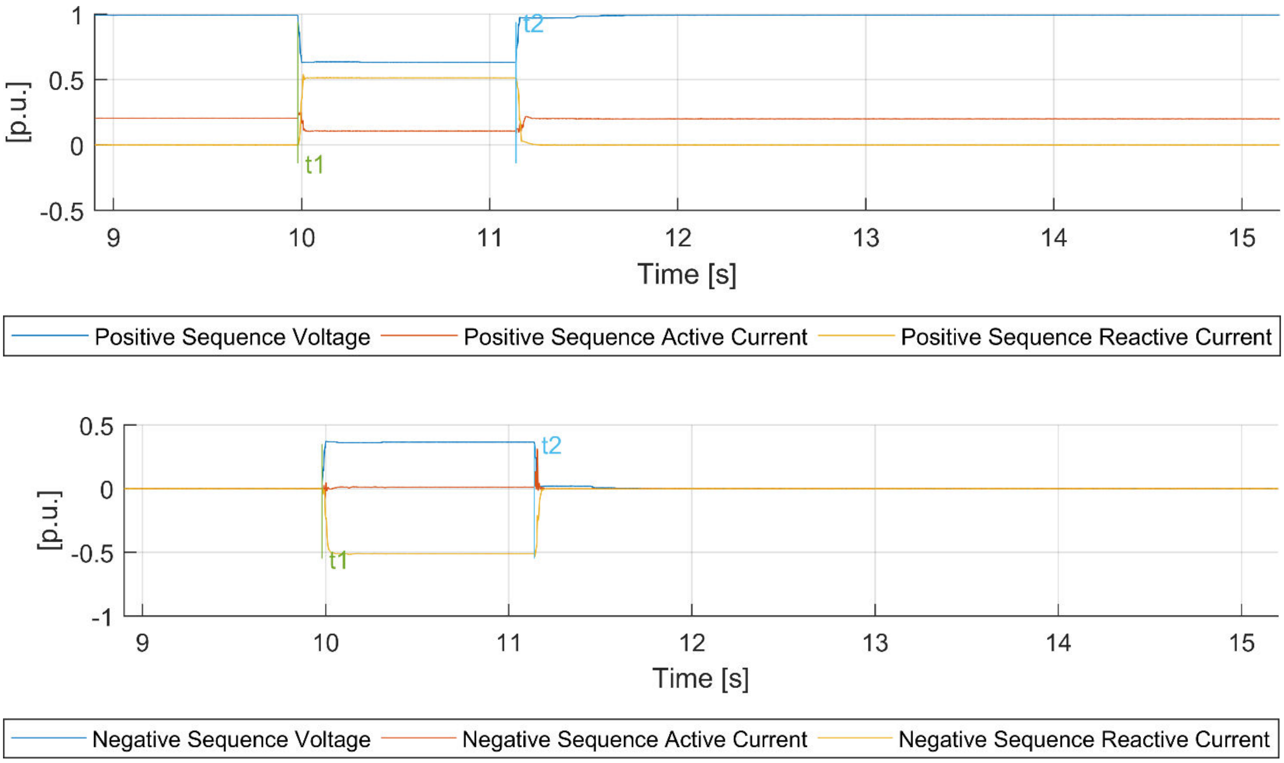

Figure 4–4 Positive and negative sequence values of voltage, active and reactive current, test no. 45, 2-phase, full load, fault voltage 25% U_n, k=2.

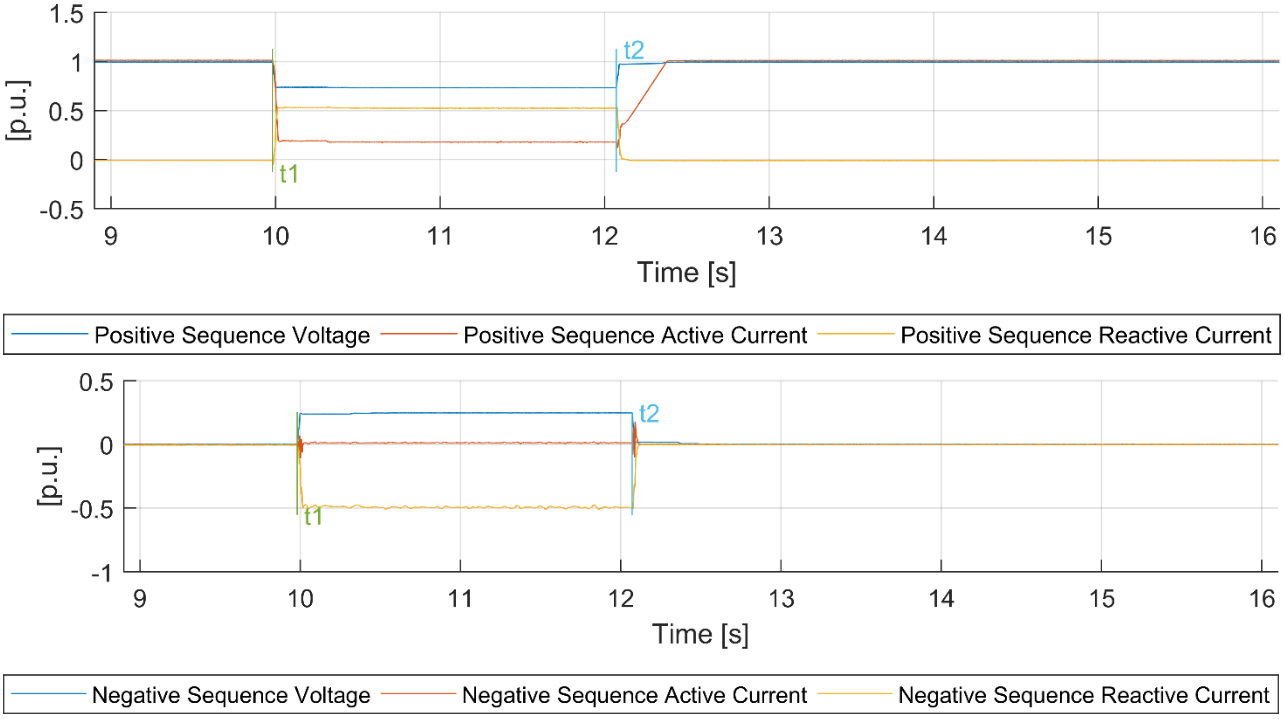

Figure 4–5 Positive and negative sequence values of voltage, active and reactive current, test no. 51, 2-phase, full load, fault voltage 50% U_n, k=2. Faulted phases changed.

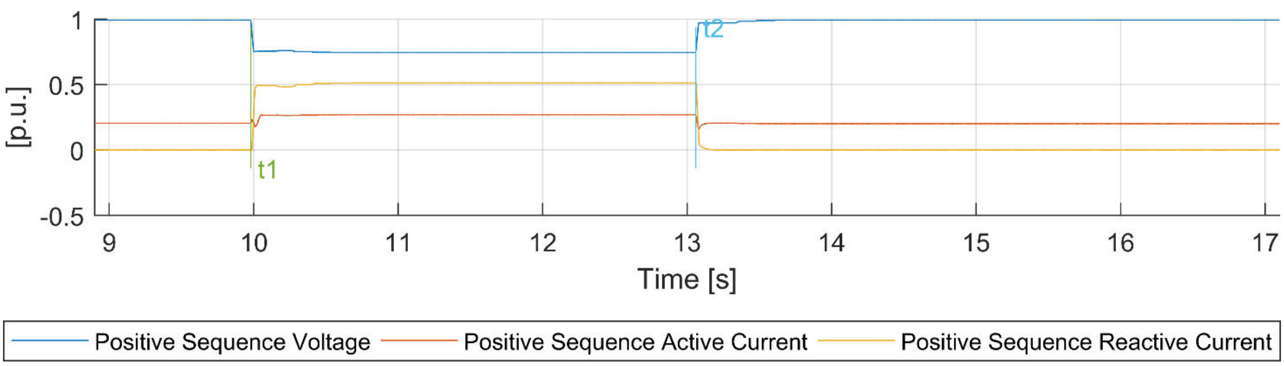

Figure 4–6 Positive sequence values of voltage, active and reactive current, test no. 61, 3-phase, partial load, fault voltage 75% U_n, k=2.

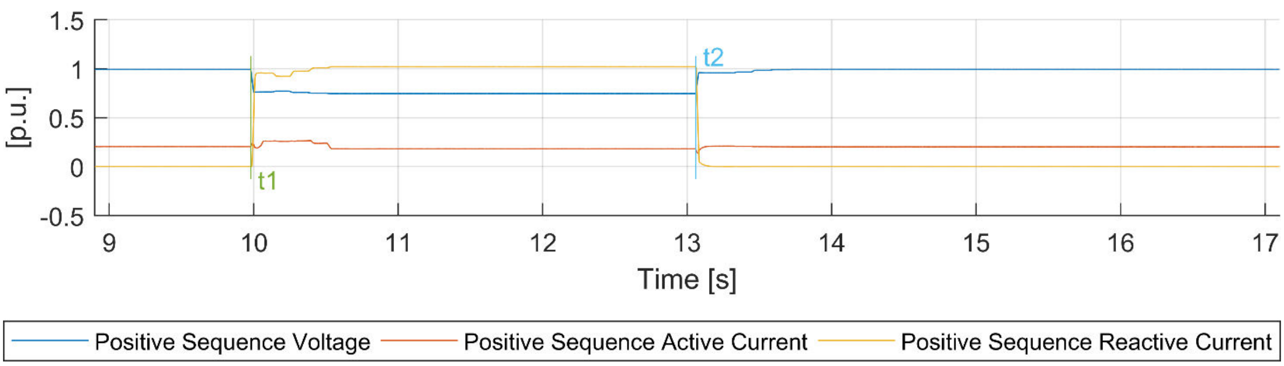

Figure 4–7 Positive sequence values of voltage, active and reactive current, test no. 67, 3-phase, partial load, fault voltage 75% U_n, k=4.

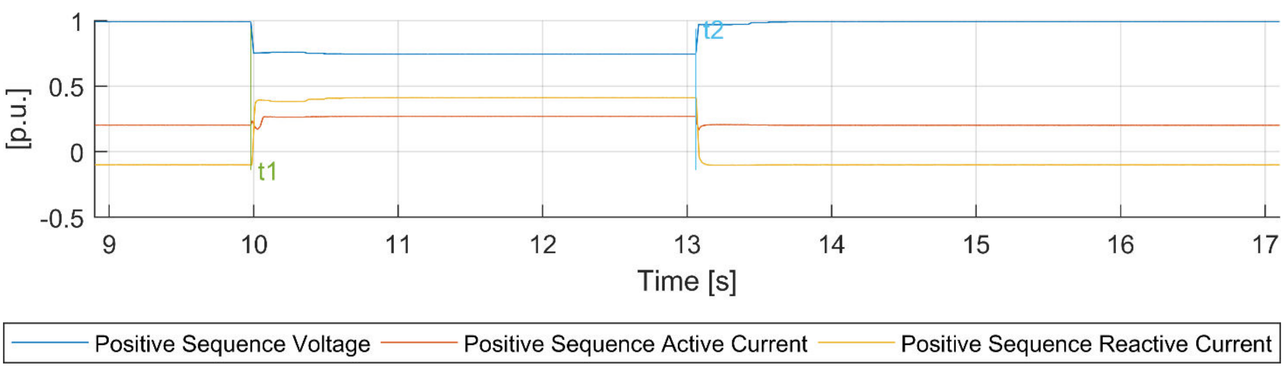

Figure 4–8 Positive sequence values of voltage, active and reactive current, test no. 63, 3-phase, partial load, fault voltage 75% U_n, k=2. Pre-fault Q (inductive).

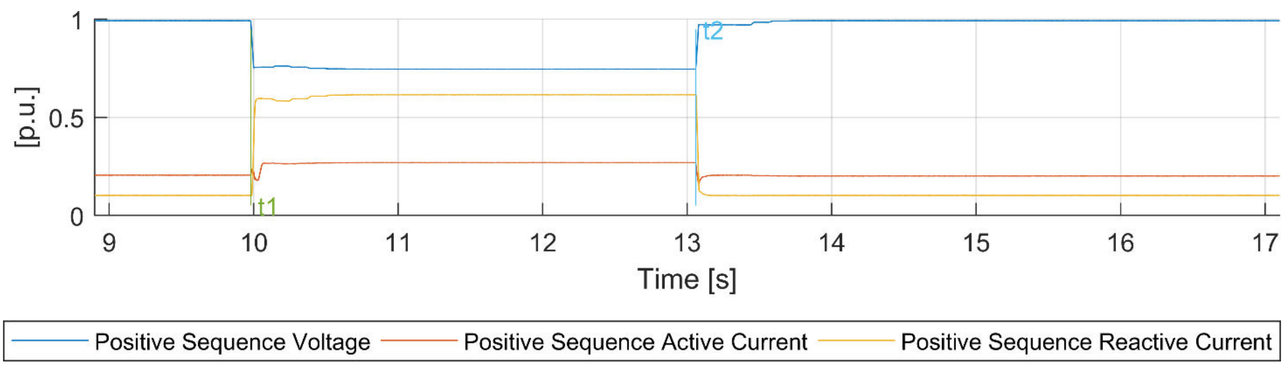

Figure 4–9 Positive sequence values of voltage, active and reactive current, test no. 65, 3-phase, partial load, fault voltage 75% U_n, k=2. Pre-fault Q (capacitive).

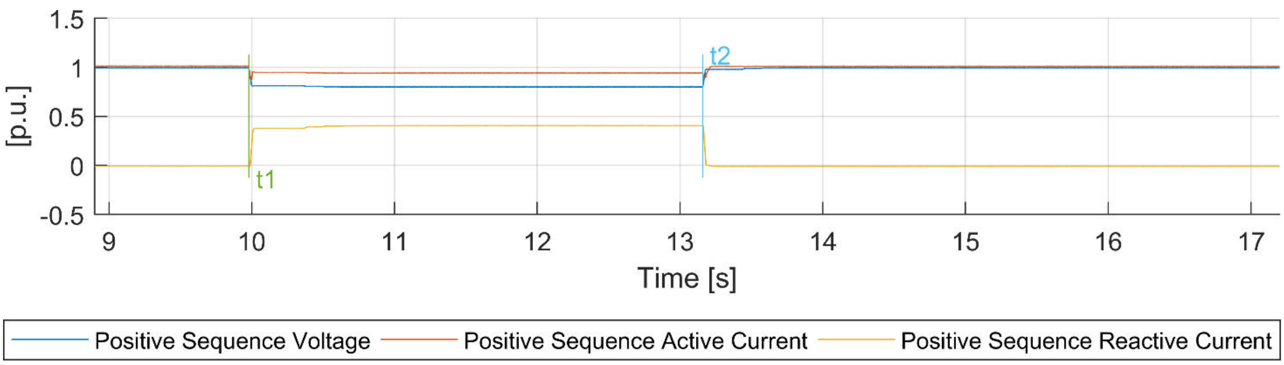

Figure 4–10 Positive sequence values of voltage, active and reactive current, test no. 75, 3-phase, partial load, fault voltage 50% U_n, k=2 but with limited dynamic grid support activated.

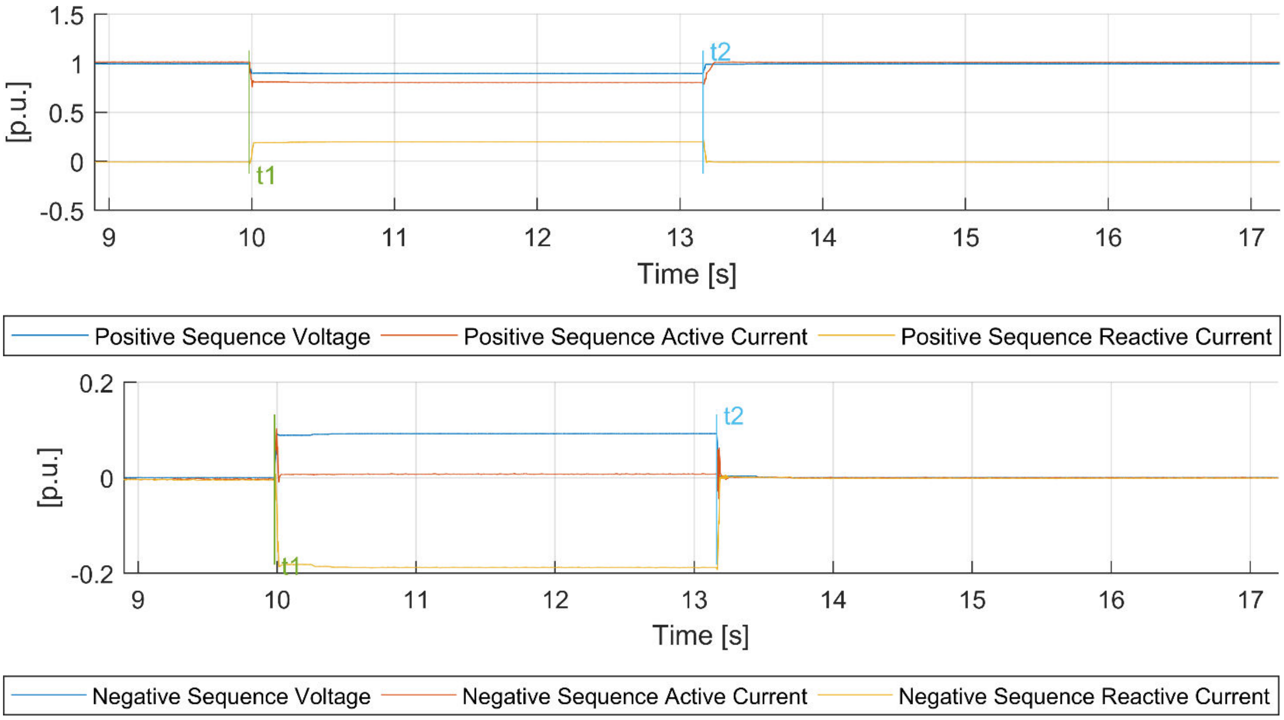

Figure 4–11 Positive and negative sequence values of voltage, active and reactive current, test no. 77, 2-phase, full load, fault voltage 50% U_n, k=2. but with limited dynamic grid support activated.

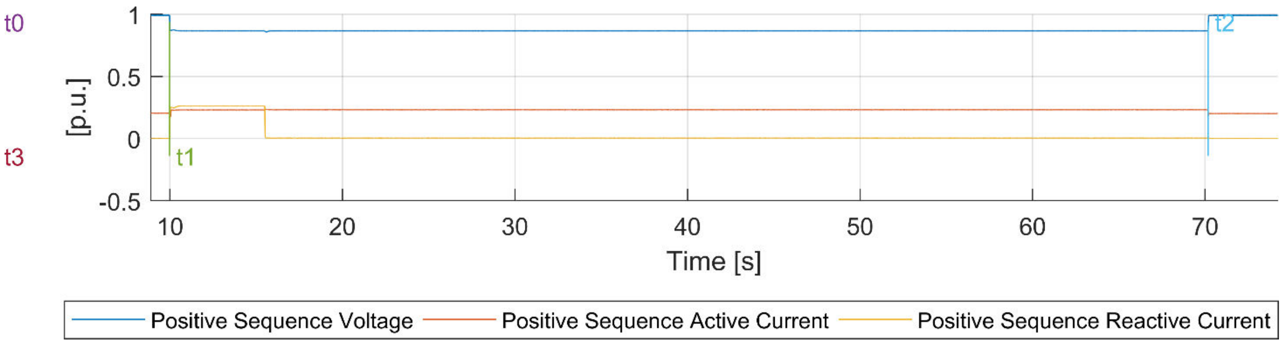

Figure 4–12 Positive sequence values of voltage, active and reactive current, test no. 79, 3-phase, partial load, fault voltage 86% U_n, k=2.

4.6.2 Graphs of HVRT (OVRT) tests

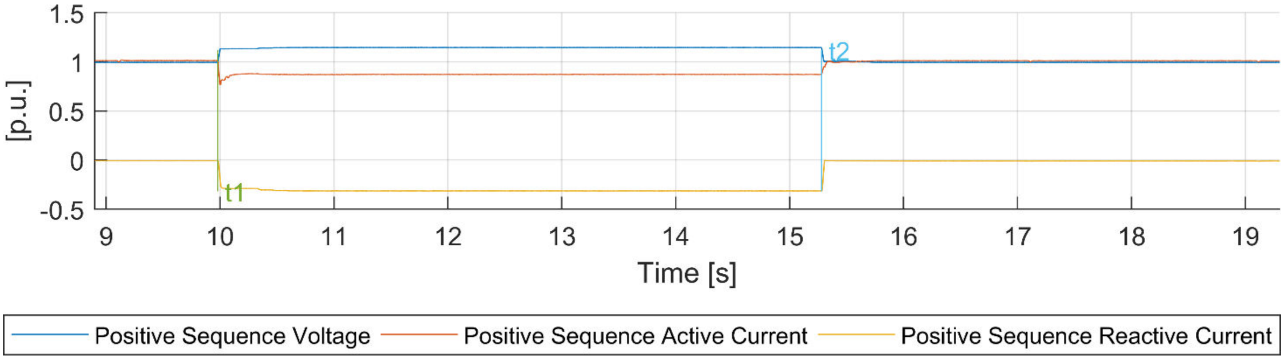

Figure 4–13 Positive sequence values of voltage, active and reactive current, test no. 81, 3-phase, full load, fault voltage 115% U_n, k=2.

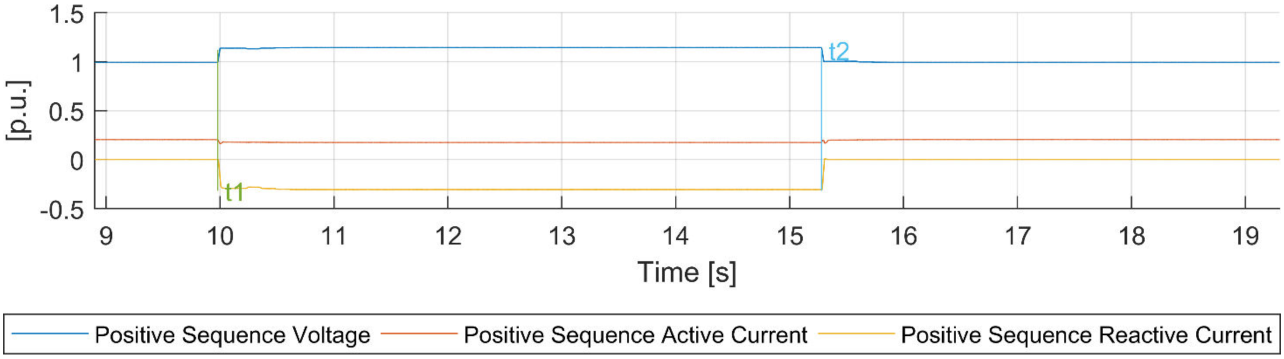

Figure 4–14 Positive sequence values of voltage, active and reactive current, test no. 83, 3-phase, partial load, fault voltage 115% U_n, k=2.

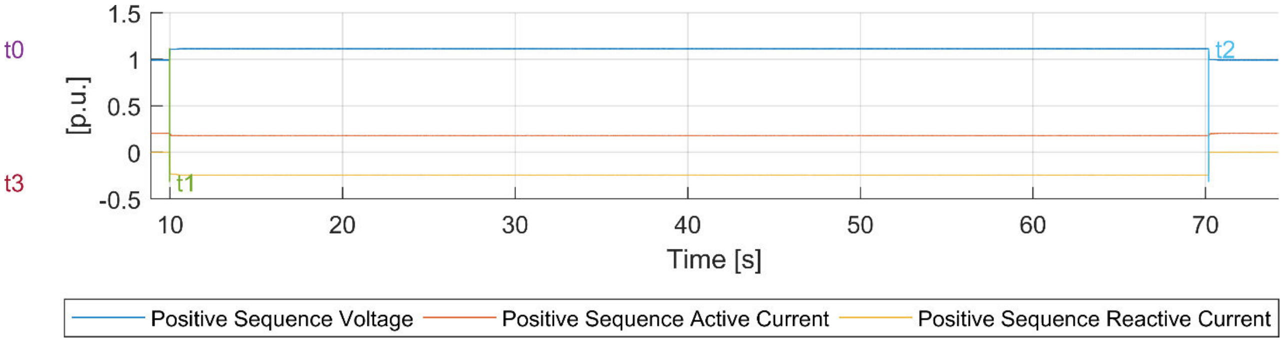

Figure 4–15 Positive sequence values of voltage, active and reactive current, test no. 89, 3-phase, partial load, fault voltage 112% U_n, k=2.

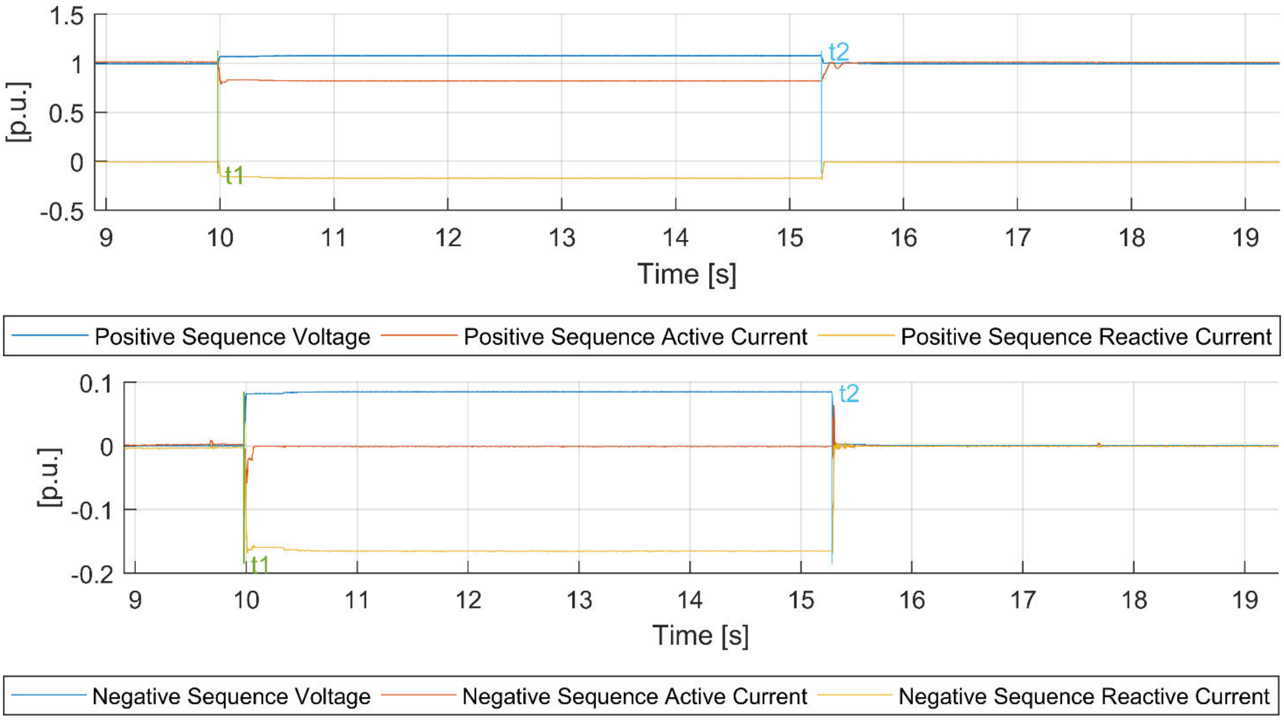

Figure 4–16 Positive and negative sequence values of voltage, active and reactive current, test no. 85, 2-phase, full load, fault voltage 115% U_n, k=2. but with limited dynamic grid support activated.

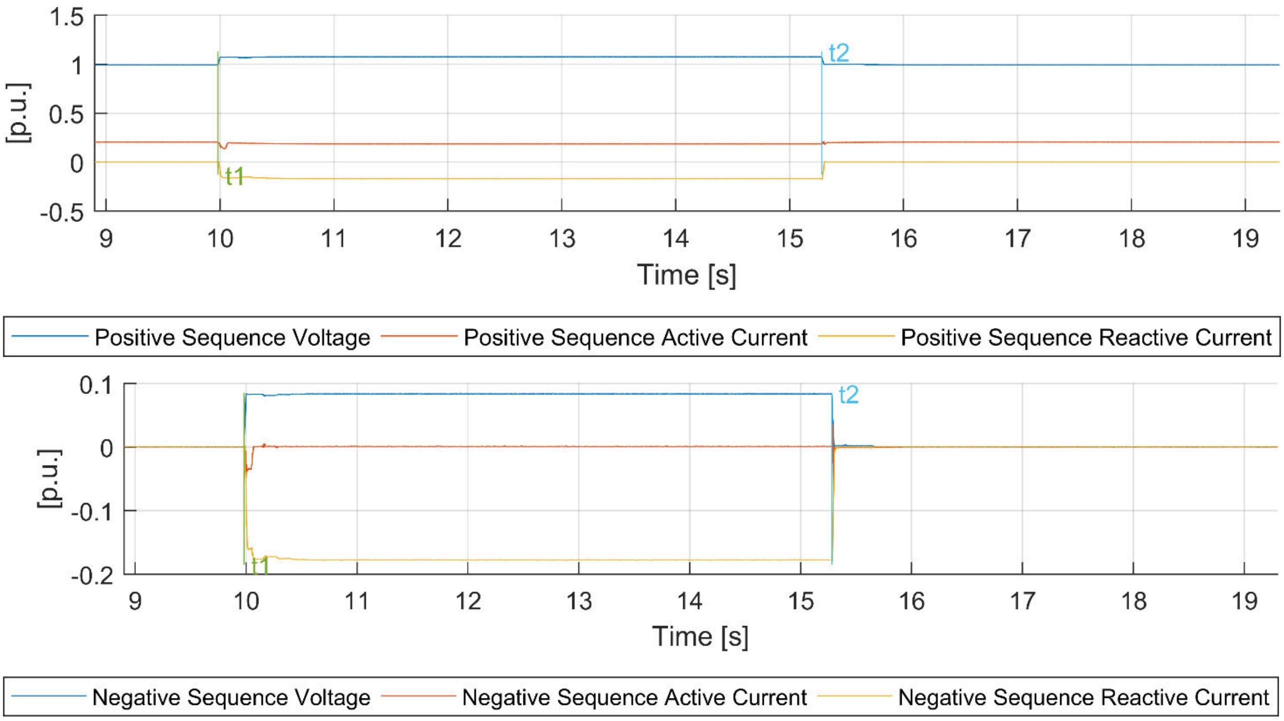

Figure 4–17 Positive and negative sequence values of voltage, active and reactive current, test no. 87, 2-phase, partial load, fault voltage 115% U_n, k=2. but with limited dynamic grid support activated. Faulted phases changed.

4.6.3 Feed-in of fault current

No.	Evaluation criterion	Acceptance criterion	Result of assessment
Feed-in of fault current			
Note: It is also permissible to have continuous dynamic grid support in the sense of the following requirements, which is permanently active and active in parallel with steady-state voltage maintenance, independent of fulfilment of the criteria for the fault start and end.			
7.1	The rise time of max 30 ms of the additional reactive current in the positive and negative phase sequence system after the start of the fault is provided for each measurement in the measurement report according to TG3 and meets the requirements.	True *)	All rise times are ≤ 30 ms for the tests described in the measurement report /6/.*)
7.2	The settling time of max 60 ms of the additional reactive current in the positive and negative phase sequence system after the start of the fault is provided for each measurement in the measurement report according to TG3 and meets the requirements.	True *)	All settling times are ≤ 60 ms for the tests described in the measurement report /6/ *)
7.3	For all measurements according to TG3 where the required k-factor may not be possible to be reached due to a current limitation, a reactive current having the value of the rated current must be injected on each (affected) phase. (VDE 4110 /A/ section 10.2.3.3.2, 7th bullet point)	True	Proof of this is given below.
7.4	The additional positive and negative reactive current fed into the grid must comply with the limits specified in Annex C.1. of VDE 4110 /A/ (To be proven for voltage excursions with fault voltages ≥ 15% U_n bis 120% U_n).	The limits according to Appendix C.1 of the VDE 4110 /A/ were observed for all measurements.	Tolerance bands are not exceeded in any of the tests. See measurement report /6/.
7.5 – 7.10	Not relevant for solar converters.	-	-
7.11	The rise time of the active current after the end of the fault may be a maximum of 1 s. (VDE 4110 /A/ section 11.2.5.7)	True	The rise time of the active current after fault clearance is significantly less than 1 s for all tests. See measurement report /6/.
7.12	Continuous dynamic grid support is used.	Details provided below	Specification is made.

*) according to VDE regulation /A/ voltage dips down to a remaining voltage of 0 % are not assessed for reactive current.

Note to 7.1 and 7.2: The injected reactive current of the inverter was assessed for two-phase and three-phase faults with a view to rise time and settling time according to FGW TG3 /B/ and FGW TG8 /C/. The voltage dips performed with a remaining voltage magnitude of less than 15 % were not considered for assessment of the reactive current injection. For all two-phase and three-phase faults, the determined rise times and settling times were below 50 ms and 80 ms respectively. This assessment is based on the fact that the times stated in the measurement report /6/ have been measured in the fundamental frequency positive sequence system which includes an additional 20 ms for calculation of the RMS value. This means that the rise and settling times to be assessed are determined by subtracting 20 ms off the rise and settling times reported in the measurement report. According to the VDE regulation /A/, the required rise and settling times are therefore considered to have been met.

Note to 7.3: During the tests nos. 39, 41, 43 and 45 fault voltages of 25 % were emulated which led to the k factor being limited to approximately 1.4. In all cases the reactive current on each of the faulted phases had at least the rated current of the PGU. This can be seen from the magnitude and phase displacement between voltage and current on each of the unhealthy phases as shown in Figure 4–18, Figure 4–19, Figure 4–20 and Figure 4–21 below.

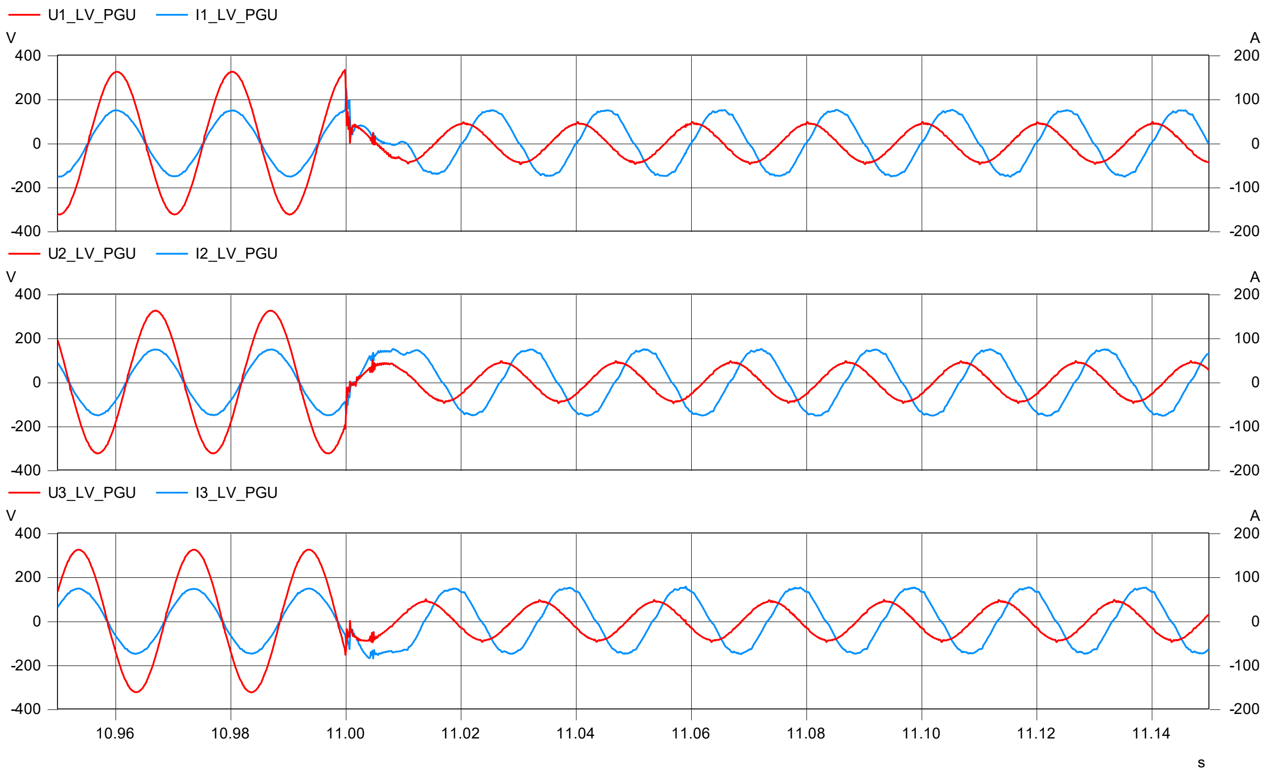

Figure 4–18 Instantaneous voltage and current on all three phases, test no. 39, 3-phase, full load, fault voltage 25% U_n, k=2.

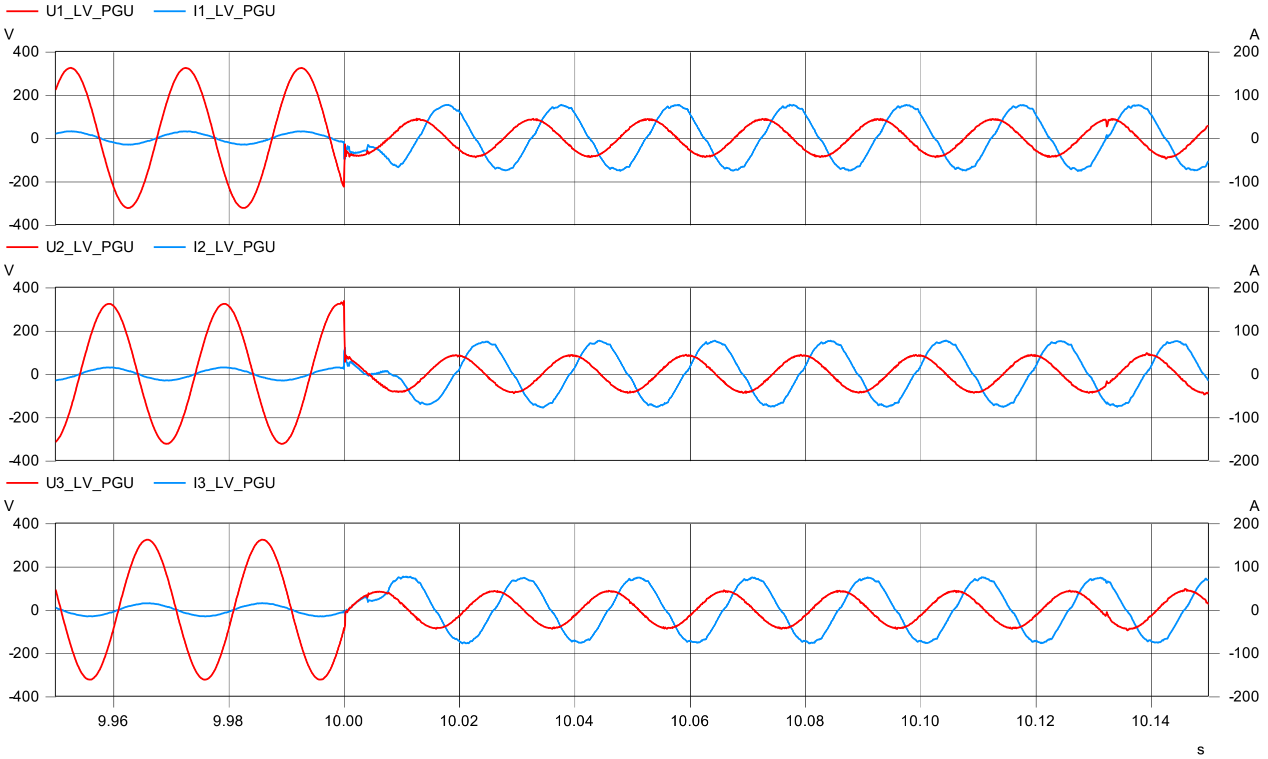

Figure 4–19 Instantaneous voltage and current on all three phases, test no. 41, 3-phase, partial load, fault voltage 25% U_n, k=2.

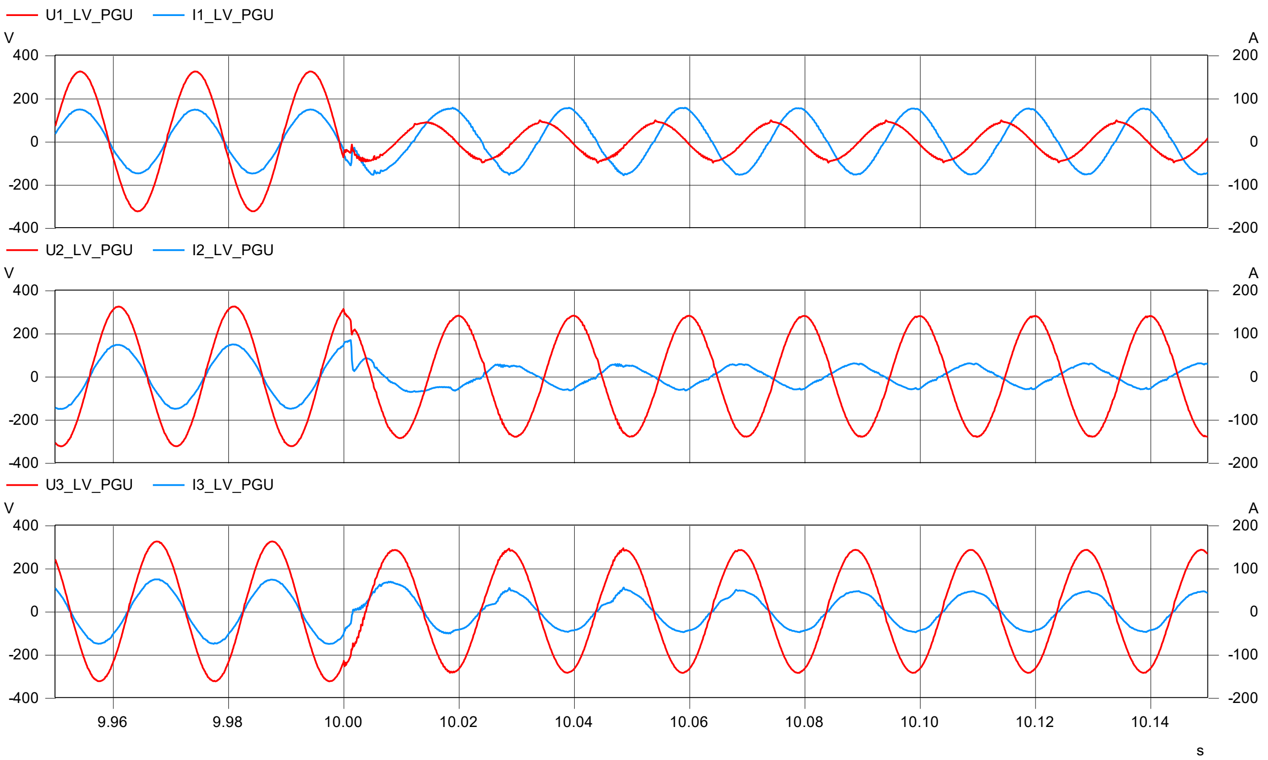

Figure 4–20 Instantaneous voltage and current on all three phases, test no. 43, 2-phase, full load, fault voltage 25% U_n, k=2.

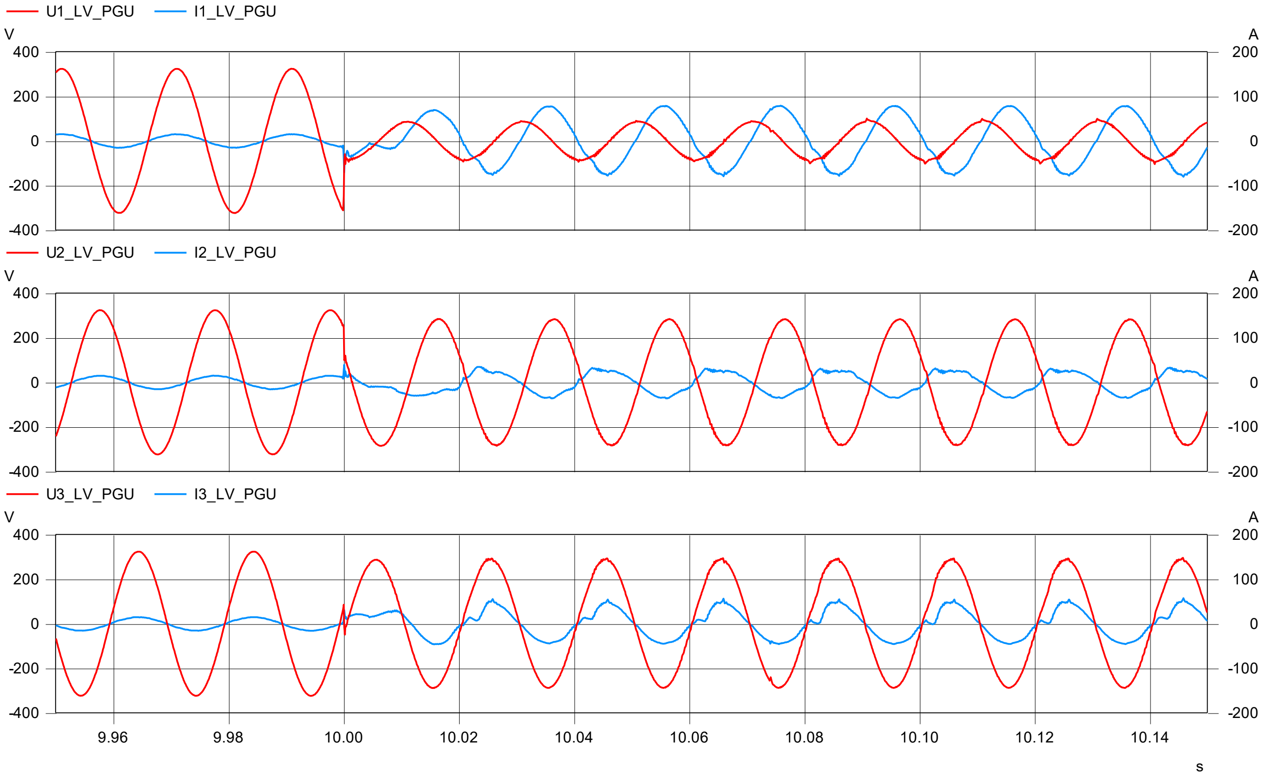

Figure 4–21 Instantaneous voltage and current on all three phases, test no. 45, 2-phase, partial load, fault voltage 25% U_n, k=2.

It should be noted that for 2-phase faults on the high-voltage side of a Dy transformer only one phase is affected significantly on the low side as already shown in Figure 4–1 of this report. Due to the Dy vector group of the transformer, the affected line-to-neutral phase on the low side is in phase with the affected phase-to-phase voltage on the high side of the same transformer.

<u>Note to 7.4:</u> The FRT control strategy implemented in the tested solar inverter is given in Figure 4–22 below and is compliant to the VDE regulation /A/.

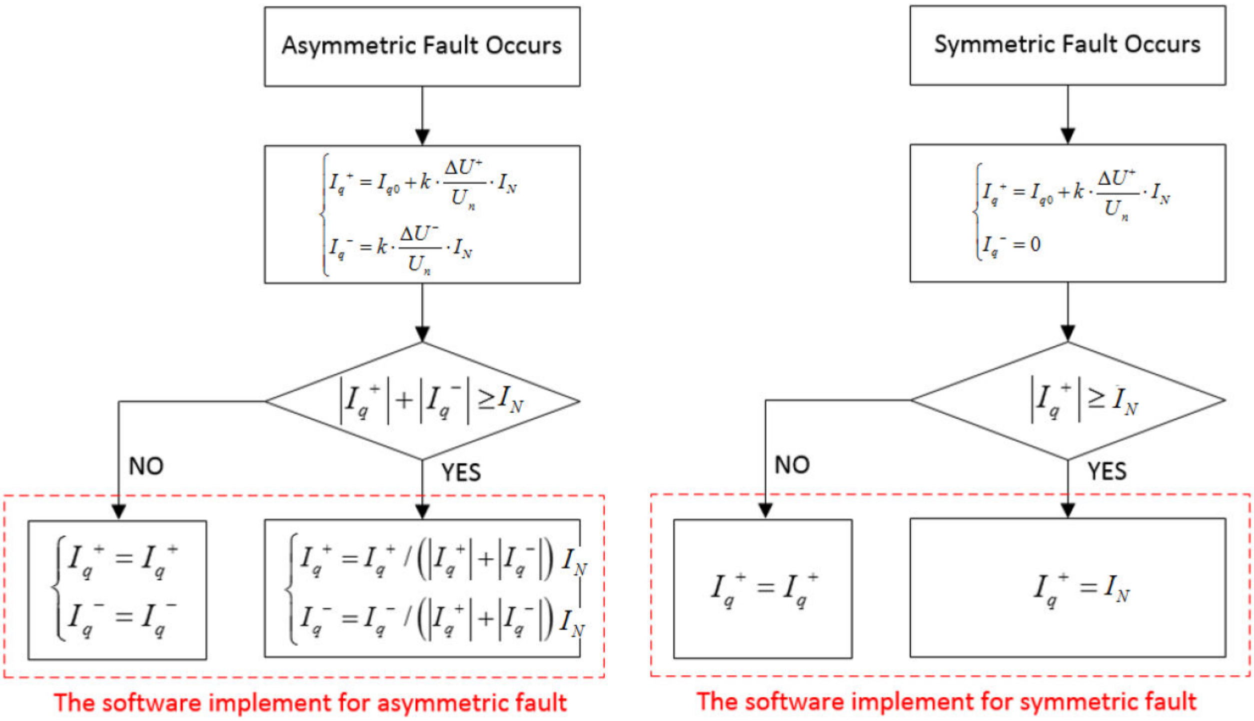

Figure 4–22 Control strategy for FRT /11/

The tests documented in the measurement report /6/ demonstrate that the control strategy depicted in the figure above was followed.

No.	Additional evidence	Acceptance criterion	Result of assessment
C	The proportionality factor k is adjustable between 2 and 6 in steps of 0.5 or smaller.	True (Manufacturer's declaration)	The k-factor can be adjusted between 0 and 10 in steps of 0.1 for LVRT and between 0 and 6 for HVRT. In both cases the step size is 0.1. See parameter list /5/.
D	The adjustability of the k-factor must be proven through tests with different k-factors (k=2 and k=4). They have to be carried out in accordance with TG3.	True	The adjustability has been proven by the corresponding tests. See measurement report /6/.

The proportionality factor, designated as k, which determines the level of the reactive current fed into the grid, was set to a value of k = 2 in the majority of the tests. The k factor can be set between 0 and 10. To prove the adjustability, the tests required according to FGW TG3 /B/ were carried out with the numbers 75.5 (dip number 67) and 75.8 (dip number 73) with k = 4.

The pre-fault reactive current was correctly taken into account by the FRT controller for the calculation of the additional reactive current during FRT events. This has also been proven by the tests 75.3 (dip number 63) and 75.4 (dip number 65) as required by the FGW TG3 /B/. The reactive power before the emulated fault was ±3.6 kVAr. The active power output during these tests was 0.2 p.u. which corresponds to a power factor of 0.45 and 0.1 p.u. reactive power.

For three-phase voltage dips < 0.15 p.u., the reactive current is not assessed. In these special cases (referring to dip numbers 31 and 33) an apparent current of 1.04 p.u. was injected, 0.99 p.u. of this being reactive current and 0.30 p.u. being active current.

4.6.4 Limited dynamic grid support

No.	Evaluation criterion	Acceptance criterion	Result of assessment
Limited dynamic grid support			
4.1	All required UVRT (LVRT) tests according to FGW TG3 /B/ have been carried out completely with regard to the limited dynamic grid support.	True	The required tests were carried out completely and successfully. See measurement report /6/.
4.2	The PGU type 2 can meet the requirements for limited dynamic grid support.	True	These requirements can be met. See measurement report /6/.
4.3	The maximum apparent current of 10 % Ir is not exceeded after onset of the fault until the end of the fault (for a voltage dip down to between 45 % Un and 60 % Un).	True	This requirement can be met. See measurement report /6/.
2.12	Full dynamic network support is fulfilled according to the requirements above 0.7 Un.	True	This requirement can be met. See measurement report /6/.

The optional function of limited dynamic network support as required by the VDE-AR-N 4110 /A/ has been implemented and successfully proven by the tests 50.5 (dip number 55), 50.6 (dip number 57), 80.1 (dip number 75) and 80.2 (dip number 77) as defined in the FGW TG3 /B/.

4.6.5 Multiple faults

No.	Evaluation criterion	Acceptance criterion	Result of assessment
Multiple faults			
8.1	If the behaviour in case of multiple faults has not been mathematically proven by the manufacturer, the proof can alternatively be provided by measurement, i.e. by applying the test sequence for multiple faults in accordance with the requirements of Table 14 of the VDE regulation /A/ at $P \geq 75\ \%\ P_{rE}$ without disconnection from the grid.	True	Not required as 8.2 below is fulfilled.
8.2	Type 2 PGUs must be able to ride through any sequence of grid faults.	The PGU is able to dissipate $P_{E\ max}$ for 2 s	This requirement can be met. See Huawei test report /12/.
8.3	On the basis of a manufacturer's declaration, it must be demonstrated in a comprehensible manner that the PGU is capable of running through another multiple fault after 30 minutes.	True	This requirement can be met. See Huawei test report /12/.

4.7 Contribution to short-circuit current

Assessment criteria according to FGW TG8 /C/ (A.1.2.7.4.1):

No.	Evaluation criterion	Acceptance criterion	Result of assessment
1	The short-circuit current after three-phase faults according to VDE 4110 section 11.2.9 /A/ is specified as follows.	True	Specification is given.
1.1	At onset of fault: short-circuit current as highest instantaneous value i_p and as RMS value.	True	Specification is given.
1.2	The short-circuit current (1-period RMS value) after three-phase faults was reported for the times shown in Table 16 of the VDE 4110 /A/. (i.e. 20, 100, 150, 300, 500 and 1000 ms)	True	Specification is given.
1.3	The peak short-circuit current i_p was determined from the measured data according to DIN EN 60909-0 (VDE 0102).	True	Specification is given.
1.4	The initial short-circuit alternating current I_k'' was determined and specified according to DIN EN 60909-0 (VDE 0102).	True	Specification is given.
2	The necessary parameters for calculating the short-circuit alternating currents according to DIN EN 60909-0 (VDE 0102) are shown.	True	Specification is given.

No.	Additional evidence	Acceptance criterion	Result of assessment
A	All time curves of the currents for three-pole faults are shown.	True	Specification is given.
B	Manufacturer's specifications according to Table 15 of the VDE regulation /A/.	Specification is given.	Specification is given.

(* This is the value given in the manufacturer's declaration /9/ and corresponds to a k setting of 2. From this $\underline{Z}_{(2)PF}$=1/k.

Table 4-1 contains the required information on the theoretical values of the short-circuit currents based on the manufacturer's specifications.

Description	Symbol	Value
RMS value of the source current for three-phase faults	I_{skPF}	52.0 A
RMS value of the source current for two-phase faults	$I_{(1)sk2PF}$	52.0 A
RMS value of the source current for single-phase faults	$I_{(1)sk1PF}$	52.0 A
Negative-sequence short-circuit impedance (manufacturer’s information) for integer k-factors only	$\underline{Z}_{(2)PF}$	0.5 (*

(* This is the value given in the manufacturer's declaration /9/ and corresponds to a k setting of 2. From this $\underline{Z}_{(2)PF}=1/k$.

Table 4-1 Theoretical data on the short-circuit currents of the PGU based on the manufacturer's declaration /9/ according to DIN EN 60909-0.

The short-circuit currents measured and averaged according to FGW TG3 /B/ are given in the measurement report /6/. Table 4-2 below summarises the measured short-circuit currents for the 3-phase FRT tests as required by FGW TG3 /B/. These include:

- Peak current i_p at the onset of the fault.
- The single-period RMS values of the short-circuit currents at the specified times (20 ms, 100 ms, 150 ms, 300 ms, 500 ms and 1000 ms after the onset of the fault depending on the duration of the fault).

The RMS and peak values stated below are the maximum values of all three phases, scaled to the rated current of $I_{n,AC}$ = 52.0 A (at 400 V), for the SUN2000-36KTL assuming a rated power of 36 kW. The values were measured at the terminals of the generating unit during two-phase and three-phase voltage dip tests as well as voltage swell tests. These tests were performed at partial and rated power with the k-factor set to k=2 and k=4. Due to the technical equivalence of the SUN2000-33KTL-A with the SUN2000-36KTL these maximum short-circuit currents can also be applied to the smaller inverter type as long as the currents are scaled down accordingly (or applied in p.u.).

Test conditions							Time after onset of fault in ms					
TG3 test case no.	U in % (no-load test)	P in p.u. (pre-fault)	Q in p.u. (pre-fault)	k	Dura-tion of fault in s	i_p in A peak	20	100	150	300	500	1000
							Contribution to short-circuit current in A RMS					
0.1	3	1.01	-0.01	2	0.53	2.45	1.14	1.04	1.04	1.04	0.85	-
0.2	3	0.20	0.00	2	0.51	-1.56	0.81	1.04	1.04	1.04	1.04	-
25.1	25	1.01	-0.01	2	1.16	2.39	1.16	1.04	1.04	1.04	1.04	1.04
25.2	25	0.20	0.00	2	1.16	1.48	0.92	1.05	1.04	1.04	1.05	1.05
50.1	50	1.01	-0.01	2	2.09	-2.17	1.11	1.05	1.05	1.05	1.04	1.04
50.2	50	0.20	0.00	2	2.09	-1.45	0.86	1.04	1.04	1.04	1.04	1.04
50.5	50	1.01	-0.01	2	2.09	-2.04	0.47	0.06	0.06	0.06	0.06	0.06
75.1	75	1.01	-0.01	2	3.08	1.81	1.03	1.03	1.03	1.03	1.03	1.03
75.2	75	0.20	0.00	2	3.08	-0.77	0.44	0.56	0.56	0.57	0.58	0.58
75.3	75	0.20	-0.10	2	3.08	0.63	0.37	0.47	0.47	0.47	0.49	0.49
75.4	75	0.20	0.10	2	3.08	-0.90	0.51	0.65	0.65	0.65	0.67	0.67
75.5	75	0.20	0.00	4	3.08	1.43	0.74	0.99	0.97	1.01	1.04	1.04
80.1	75	1.01	-0.01	2	3.18	-1.64	1.01	1.02	1.02	1.02	1.03	1.03
85.1	86	0.20	0.00	2	60.20	0.41	0.26	0.34	0.34	0.34	0.35	0.35
115.1	115	1.01	-0.01	2	5.30	-1.44	0.86	0.91	0.92	0.93	0.93	0.93
115.2	115	0.20	0.00	2	5.30	-0.48	0.30	0.35	0.35	0.34	0.35	0.36
110.3	115	0.20	0.00	2	60.20	-0.42	0.27	0.30	0.30	0.30	0.30	0.31

Table 4-2 Maximum measured values of short-circuit currents during three-phase voltage dips and voltage swells

4.8 Transferability

In addition to the tested unit SUN2000-36KTL (having a rated active power of 36 kW at 400 V), this assessment also includes the voltage level 480 V for the same unit, as well as the variant SUN2000-33KTL (with a rated active power of 30 kW at 400 V). Huawei Technologies Co., Ltd. has submitted documentation /10/ with descriptions of the relevant similarities and differences between these variants.

All variants share the same values for the following parameters:

- maximum input voltage (1100 V)
- highest operating voltage (1000 V)
- MPPT voltage range (200–1000 V)
- maximum input current (per MPPT) (22 A)
- maximum short-circuit current (per MPPT) (30 A)
- maximum inverter back-feed current to the PV array (0 A)
- no. of inputs (8)
- no. of MPP trackers (4)

The generating units described in this certification report are identical in terms of hardware, control and software, thus fulfilling the requirements for transferability as stated in the FGW TG8 /C/. The different voltage levels will not affect the FRT behaviour significantly. The results of the FRT tests performed on the SUN2000-36KTL can therefore be applied to SUN2000-33KTL-A. The short-circuit current contributions are to be transferred in accordance with the information given in section 4.7.

5 CONDITIONS

Any changes of the system design, software or the manufacturer's quality system are to be approved by DNV GL.

6 CONCLUSIONS

Different voltage dip tests and overvoltage tests (with different magnitudes of remaining voltage, different durations and at different active power operating points) were performed with a photovoltaic inverter SUN2000-36KTL of Huawei Technologies Co., Ltd., according to the requirements of the FGW TG3 /B/. The measurement data received were assessed according to the criteria of section A.1.2.7.3.1 of the FGW TG8 /C/.

Under consideration of the conditions given above, the photovoltaic inverters SUN2000-33KTL-A and SUN2000-36KTL of Huawei Technologies Co., Ltd. fulfil the requirements on the aforementioned criteria as given in the regulations cited in section 2 of this certification report.

7 REFERENCES

/1/	Manufacturer's certificate of the specific data of the generating unit SUN2000-33KTL-A, Version V1.0	3 pages	dated 2020-03-18
/2/	Manufacturer's certificate of the specific data of the generating unit SUN2000-36KTL, Version V1.0	3 pages	dated 2020-03-18
/3/	ISO 9001:2015 Certificate no. 01 100 1933213 issued to Huawei Technologies Co., Ltd. for the design, manufacture and service of inverters	5 pages	dated 2020-04-09
/4/	Declaration of conformity for ISO 9001	1 page	dated 2020-05-19
/5/	Parameter list of SUN2000-36KTL & SUN2000-33KTL-A, Version V1.5	11 pages	dated 2020-05-28
/6/	Measurement report: Fault ride-through tests on a PV inverter of the type HUAWEI SUN2000-36KTL according to FGW TG3 Rev. 25, Report No.: 10157045-A-4-A	271 pages	dated 2020-04-15
/7/	Overview on the necessary documentation and data for the Prototype Confirmation of power generating units (PGU) in accordance to the VDE-AR-N-4110/4120 e Guideline, Version V1.1	7 pages	dated 2018-07-18
/8/	User Manual for different variants of SUN2000-(29.9KTL, 33KTL-A, 36KTL and 42 KTL), Issue 11	119 pages	dated 2019-06-08
/9/	Manufacturer's declaration for compliance to technical requirements of the VDE-AR-N 4110:2018-11, Version V1.4	19 pages	dated 2020-05-28
/10/	Product declaration for transferability: SUN2000-36KTL, SUN2000-33KTL-A, Version V1.0	3 pages	dated 2020-04-16
/11/	Description of voltage ride-through (VRT) function, Version V1.0	3 pages	dated 2019-04-16
/12/	FRT multiple fault test, Version V1.0	3 pages	dated 2020-05-21
/13/	Description of the function blocks of the voltage protection, Version V1.2	5 pages	dated 2020-05-22
/14/	Verifying Comments Sheet (VCS) VCS-06046-0, revision 27	47 pages	dated 2020-05-29

8 ANNEX

Table 8-1 Overview of attached documents

No.	Content	Filename	MD5-Checksum
1	Parameter list of SUN2000-36KTL & SUN2000-33KTL-A, Version V1.5	Huawei_SUN2000-36KTL_Parameter list_V1.5.pdf	aebd0dad4c35a183cfc1ca4894c6ed73

About DNV GL

HUAWEI SUN2000-33KTL-A AND SUN2000-36-KTL

Certification Report: Control Behaviour and other Grid Code Requirements

Huawei Technologies Co., Ltd.

Report No.: CR-GCC-TR8-06046-A067-0
Date: 2020-06-05

Project name:	Huawei SUN2000-33KTL-A and SUN2000-36-KTL	DNV GL - Energy
Report title:	Certification Report:	Germanischer Lloyd Industrial
	Control Behaviour and other Grid Code	Services GmbH,
	Requirements	Renewables Certification
Customer:	Huawei Technologies Co., Ltd.,	Brooktorkai 18
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Date of issue:	2020-06-05	
Project No.:	10157033	
Organisation unit:	Grid Code Compliance	
Report No.:	CR-GCC-TR8-06046-A067-0	

Applicable contract governing the provision of this report: Short Form Agreement 180686-SFA-20190423

Objective: Verification of the electrical control behaviour and grid code requirements other than low voltage ride through- capability of the photovoltaic inverters Huawei SUN2000-33KTL-A and SUN2000-36-KTL.

Prepared by:

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Rev. No.	Date	Reason for Issue	Prepared by	Verified and approved by
0	2020-06-05	First issue	Sofien Ben Saad	Torge Wehrend

Table of contents

1 EXECUTIVE SUMMARY

The purpose of this certification report is the documentation of the assessment of the control behaviour, including power quality, for the photovoltaic inverters Huawei SUN2000-33KTL-A and SUN2000-36-KTL. The Fault Ride Through (FRT) capability is not part of this report and is assessed within the scope of the certification report CR-GCC-TR8-06046-A066. The documented results of the type tests and the corresponding manufacturer documentation were assessed according to the assessment criteria of the mentioned guidelines in section 2. The final result of the assessment is stated in the end of this certification report, which gives a recommendation as part for the final certification decision.

2 ASSESSMENT CRITERIA

The assessment of the control behaviour of the generating unit is based on the following:

/A/ VDE-AR-N 4110, Technische Regeln für den Anschluss von Kundenanlagen an das Mittelspannungsnetz und deren Betrieb (TAR Mittelspannung), VDE Verband der Elektrotechnik Elektronik Informationstechnik e.V., vom November 2018
(VDE-AR-N 4110 Technical requirements for the connection and operation of customer installations to the medium voltage network (TAR medium voltage), in the following: VDE-AR-N 4110)

/B/ Technische Richtlinie für Erzeugungseinheiten und -anlagen, Teil 3: Bestimmung der elektrischen Eigenschaften von Erzeugungseinheiten und -anlagen, Speicher sowie für deren Komponenten am Mittel-, Hoch- und Höchstspannungsnetz, Fördergesellschaft Windenergie und andere Dezentrale Energien (FGW), Revision 25, vom 01.09.2018
(FGW Technical Guidelines, Part 3: Determination of the Electrical Characteristics of Power Generating Units and Systems, Storage Systems as well as their Components in Medium, High and Extra-High Voltage Grids, in the following: FGW TG3)

/C/ Technische Richtlinie für Erzeugungseinheiten und -anlagen, Teil 8: Zertifizierung der elektrischen Eigenschaften von Erzeugungseinheiten und -anlagen, Speicher sowie für deren Komponenten am Stromnetz, Fördergesellschaft Windenergie und andere Dezentrale Energien (FGW), Revision 9, vom 01.02.2019
(FGW Technical Guidelines, Part 8: Certification of the Electrical Characteristics of Power Generating Units and Systems, Storage Systems as well as their Components on the Grid, in the following: FGW TG8)

/D/ Technische Richtlinie für Erzeugungseinheiten und -anlagen, Teil 3: Bestimmung der elektrischen Eigenschaften von Erzeugungseinheiten und -anlagen, Speicher sowie für deren Komponenten am Mittel-, Hoch- und Höchstspannungsnetz, Fördergesellschaft Windenergie und andere Dezentrale Energien (FGW), Revision 24, vom 01.03.2016
(FGW Technical Guidelines, Part 3: Determination of the Electrical Characteristics of Power Generating Units and Systems, Storage Systems as well as their Components in Medium, High and Extra-High Voltage Grids, in the following: FGW TG3)

3 SCOPE OF ASSESSMENT

The assessment of the control behavior and other grid code requirements (this contains all grid code requirements, with the exception of the behavior of the generating unit during grid faults) of the generating unit contains the following:

- Completeness of documents and measurements.
- Plausibility of the documents received.
- Compliance of the test conditions of the documents listed in section 2.
- Assessment of the measurement results concerning the requirements of the documents listed in section 2.

4 VERIFICATION OF CONTROL BEHAVIOUR AND OTHER GRID CODE REQUIREMENTS

4.1 Schematic description of the generating unit

The generating units Huawei SUN2000-33KTL-A and SUN2000-36-KTL convert electrical energy generated by photovoltaic modules (DC) to three-phase alternating current (AC). Power control on the DC side is implemented by a Maximum Power Point (MPP) tracking system. The rated output voltage of the SUN2000-33KTL-A is 400 V while the SUN2000-36KTL has two output voltage ratings, 400 V and 480 V. All variants are technically equal to the SUN2000-36KTL 400 V version according to the definition in the FGW TR8 /C/. The inverter type SUN2000-36KTL running at 400 V was tested for the default rated active power of 36 kW. On the SUN2000-36KTL the maximum active power limit can also be increased up to the apparent power limit of 40 kVA.

Detailed descriptions and schematics are given in the Overview of Necessary Documents /11/ as well as the User Manual /9/.

The electrical data of the generating unit is summarised in the following section.

4.2 Technical data of main components

The following is an overview of technical data for the main components of the generating unit, as specified by the manufacturer.

4.2.1 General data

Generating Unit	**SUN2000-33KTL-A**	**SUN2000-36KTL**
No. of phases	3-phase	3-phase
Maximum apparent power	33 kVA	40 kVA
Rated active power*)	30 kW	36 kW (PQ-Mode 2) (40 kW @ cos φ=1, PQ-Mode 1)
Rated AC voltage (phase-to-phase)	400 V	400 V / 480 V
Rated frequency	50 Hz	50 Hz
Rated current	43.5 A	52.0 A (@ 400 V in PQ-Mode 2) 43.4 A (@ 480 V in PQ-Mode 2)

*) The specified rated active power values allow for a power factor of 0.9 at full load and rated voltage (PQ-Mode 2). For the SUN2000-36KTL it is possible to set the rated active power identical to the rated apparent power (PQ-Mode 1). Project planners should note that PQ-Mode 1 decreases the reactive power capability down to zero at full load. The maximum active power limits are therefore 30 kW for the SUN2000-33KTL-A and 40 kW for the SUN2000-36KTL, respectively.

4.2.2 DC Input

Generating Unit	**SUN2000-33KTL-A**	**SUN2000-36KTL**
Min. MPP voltage	200 V	200 V
Max. MPP voltage	1000 V	1000 V
Max. DC input voltage	1100 V	1100 V
Max. DC input current	88 A	88 A

4.2.3 Inverter

Manufacturer	Huawei	Huawei
Type name	SUN2000-33KTL-A	SUN2000-36KTL
Generic type	Transformerless	Transformerless
Pulse rate of inverter	16 kHz	16 kHz
Generic type of power control	MPP-Tracking	MPP-Tracking
Software version	V200R002	V200R002

4.2.4 Unit Transformer

The transformer is not part of the generating unit and consequently has not been part of the assessment.

4.2.5 Grid protection

The grid protection is integrated into the control of the generating unit and is described in the Huawei document "Description of the Function Blocks of the Voltage Protection" /10/.

4.2.6 Disconnection device

Manufacturer	Panasonic	Panasonic
Type name	HE1AN-W-DC12V-Y6	HE1AN-W-DC12V-Y6

4.2.7 Parameters of the generating unit

All parameters are documented in the "Parameter list of SUN2000-36KTL & SUN2000-33KTL-A" dated 2020-05-28, V1.5 /7/ see Table 9-1.

4.3 Performed tests, test setup

The measurements of the control behaviour, including power quality, were performed at a SUN2000-36KTL (running at 400 V rated output voltage) photovoltaic inverter by DNV GL Renewables Advisory at a test bench in Shanghai according to the requirements of the FGW TG3 /B/. The inverter was connected to a DC source, representing the PV modules, at the DC side and to a grid simulator (converter based controlled voltage source), representing the grid, at the AC side. The tests are documented in the measurement reports /2/ and /4/, and the corresponding extract from the measurement report /3/.

All PGU units share the same hardware and firmware, and also have identical disconnection devices installed. Due to the technical equality, the measurement results can be transferred to the SUN2000-33KTL-A and the SUN2000-36KTL running at 480 V rated output voltage /1/. This is described in detail in the corresponding sections.

The tests were performed in accordance with the requirements of the FGW TG3 /B/. All tests required by FGW TG3 /B/ have been performed.

5 VERIFICATION OF CONTROL BEHAVIOUR AND OTHER GRID CODE REQUIREMENTS

5.1 Operating Range

5.1.1 Quasi-stationary operation

The following generally applies:

No.	Evaluation Criteria	Acceptance Criteria	Assessment result
1	Quasi-steady-state operation in the frequency and voltage range according to Figure 4 of VDE-AR-N 4110 /A/ is possible.	True	Compliant, by manufacturer declaration and measurement report
1.1	Details of the capability of the PGU as a voltage-time characteristic curve.	Details provided	Compliant, see annex 4 in manufacturer declaration /1/
1.2	Verification of the manufacturer's information for quasi-steady-state voltage range based on example measurements completed in accordance with 11.2.4	Details provided	Compliant, by measurement report /2/, section 4.2.1
1.3	The requirement for operation ≥ 60 seconds between 85% U_n and 90% U_n as well as 110% U_n and 115% U_n) is met.	Measurement according to 11.2.5 carried out successfully	Compliant, please refer to FRT report CR-GCC-TR8-06046-A066
2	The PGU is suitable for operation in the PGS in accordance with 10.2.1.2	Details provided	Compliant, see manufacturer declaration and measurements /1/

For PV-PGU <100 kW the following applies:

No.	Evaluation Criteria	Acceptance Criteria	Assessment result
1.2	Verification of the manufacturer’s information for quasi-steady-state frequency and voltage range based on example measurements completed.	Details provided	Compliant, by measurement report /2/ section 4.6

5.1.2 Polar wheel and/or grid oscillation

The following generally applies:

No.	Evaluation Criteria	Acceptance Criteria	Assessment result
1	Grid oscillation: Evidence of the capability of the PGU for dynamic grid support successfully provided.	True	Compliant, please refer to FRT report CR-GCC-TR8-06046-A066

5.1.3 Assessment

Huawei Technologies Co., Ltd. confirms that the Huawei SUN2000-33KTL-A and SUN2000-36-KTL can operate within the requirements stated in figure 4 and chapter 10.2.1.2 of VDE-AR N 4110 /A/. Up to 6 different operating points have been measured as shown in the measurement report /2/.

For the voltage ranges 110-115 % and 85-90 % this is also verified in testing, as further assessed in the FRT report CR-GCC-TR8-06046-A066. Measurements confirm that the genset can withstand the required voltage and frequency gradients (<5 % U_n/min, and <0.5 % f_n/min) while operation inside the quasi static window without interrupting any operational performance /1/.

Due to the technical equality, all PGU units can be operated in the voltage and frequency range required by /A/, as well as the corresponding gradients. This was confirmed by the manufacturer /11/.

5.2 System perturbations

5.2.1 Rapid voltage variations

The following generally applies:

No.	Evaluation Criteria	Acceptance Criteria	Assessment result
1	The voltage-effective switching factor dependent on the grid impedance phase angle $k_U(\psi)$ is identified.	No evaluation; data only shown	Compliant, see /2/ chapter 4.3.1
2	The flicker-effective switching factor dependent on the grid impedance phase angle $k_f(\psi)$ is identified.	No evaluation; data only shown	Compliant, see /2/ chapter 4.3.1
3	The frequency of the switching operations is shown.	True	Compliant, see /2/ chapter 4.3.1

5.2.2 Flicker

The following generally applies:

No.	Evaluation Criteria	Acceptance Criteria	Assessment result
1	The flicker coefficient depending on grid impedance phase angle $c(\psi)$ identified.	No evaluation; data only shown	Compliant, see /2/ chapter 4.3.2

5.2.3 Harmonics and interharmonics

The following generally applies:

No.	Evaluation Criteria	Acceptance Criteria	Assessment result
1	Details of harmonic currents provided.	No evaluation; data only shown	Compliant, see /2/ chapter 4.3.3.1
2	Details of interharmonic currents provided.	No evaluation; data only shown	Compliant, see /2/ chapter 4.3.3.2
3	Details of higher-frequency currents provided.	No evaluation; data only shown	Compliant, see /2/ chapter 4.3.3.3
4	Statement of levels as a function of active power starting from technical minimum power	True	Compliant, however minimum required number of 10-min data sets for each bin has not been measured according to FGW Rev. 25. See 5.2.2
5	Provided the alternative procedure under TG 3 is used, all variables determined are stated.	True	Not applicable, as alternative procedure was not used.

5.2.4 Asymmetries

The following generally applies:

No.	Evaluation Criteria	Acceptance Criteria	Assessment result
1	Positive and negative phase sequence system of the feed-in current must be provided as a function of the apparent power.	Details provided	Compliant, see /2/ chapter 4.3.4
2	Limit value is not exceeded according to /A/	Quotient of the currents from positive and negative phase sequence system ≤ 1.5%	Not compliant (see section 5.2.5 and note below)
Note: If the limit value is exceeded as part of the unit certification, the 1-minute mean has to be disclosed as a function of apparent power. It is then evaluated within the framework of system certification.			

For Type 2 PGUs the following applies:

No.	Evaluation Criteria	Acceptance Criteria	Assessment result
1	Positive and negative phase sequence system of the feed-in current must be provided for each 10 % power bin (from 10 % to 100 % P_{rE}) as a function of the apparent power as 1-minute mean values.	Details provided	Compliant, see /2/ chapter 4.3.4

5.2.5 Assessment

The measurement of power quality (flicker, switching operations and harmonics, current asymmetry) have been performed for the SUN2000-36KTL (running at 400 V rated output voltage in PQ-Mode 2) according to FGW TG3 /B/ completely and are presented in the measurement report /2/. Some important results are presented below. An assessment of the results must be carried out within the scope of project certification at the grid connection point of the specific generating power plant.

For the voltage changes caused by switching operation, main results of the measurements are presented in Table 5-1. Flicker results are found in Table 5-2. The harmonic currents and voltages, including inter-harmonics and higher frequency current components, has been measured for different harmonics and power bins. The Quotient of the currents from positive and negative phase sequence system is shown in Table 5-3. The minimum required number of datasets according to /B/ was not recorded. However, if it can be proven that the results from the measurement have very little variance within each power bin, the measurement results can be accepted for the assessment.

Table 5-1 Test results for switching operation at $P_{available}$ = P_{n}. /2/

	Switch-in				Switch-off			
Grid impedance angle, ψ_k	**30°**	**50°**	**70°**	**85°**	**30°**	**50°**	**70°**	**85°**
Flicker form factor, $k_f(\psi_k)$	0.03	0.02	0.03	0.03	0.14	0.11	0.07	0.05
Voltage variation factor, $k_U(\psi_k)$	0.87	0.66	0.38	0.17	0.89	0.67	0.37	0.15

Table 5-2 Flicker coefficient per power bin (95th percentile) /2/

P_{bin} in %	**0**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
Grid impedance angle ψ_K in °						**Flicker coefficient c (ψ_K)**					
30	0.19	0.95	1.56	1.55	1.54	1.54	1.53	1.54	1.53	1.51	1.50
50	0.19	0.78	1.22	1.21	1.21	1.23	1.22	1.23	1.23	1.21	1.22
70	0.19	0.59	0.79	0.78	0.79	0.82	0.81	0.82	0.82	0.81	0.82
85	0.19	0.47	0.51	0.50	0.51	0.56	0.52	0.52	0.53	0.52	0.54

Table 5-3 Unbalances of the current vs. power bin, mean values /2/

Active power bin	**Average active power**	**Average voltage pos. comp.**	**Average voltage neg. comp.**	**Average current pos. comp.**	**Average current neg. comp**	**Asymmetry of current**	**Max. asymmetry of current for P ≥ 10 % of P_N**
% of Pn	**in kW**	**in V**	**in V**	**in A**	**in A**	**in %**	**in %**
0	0.07	230.20	0.06	0.42	0.02	5.64	1.52
10	3.61	230.24	0.06	5.23	0.07	1.40	
20	7.27	230.26	0.07	10.53	0.10	0.92	
30	10.88	230.28	0.07	15.76	0.12	0.76	
40	14.49	230.30	0.10	20.97	0.14	0.67	
50	18.14	230.31	0.10	26.25	0.16	0.61	
60	21.77	230.32	0.10	31.51	0.18	0.57	
70	25.36	230.34	0.10	36.69	0.20	0.54	
80	28.93	230.36	0.10	41.86	0.22	0.52	
90	32.54	230.38	0.10	47.08	0.24	0.51	
100	36.12	230.41	0.10	52.25	0.26	0.51	

The maximum unbalance of the current for P ≥ 10 % of P_N was measured to 1.52 %, which oversteps the limit of 1.5 % stipulated by VDE-AR-N 4110 /A/. However, this limit is only exceeded by 0.02%, which is far lower than the measurement error of 0.2% outlined in /2/. Due to this the results are deemed compliant in regards to the requirements of /A/.

Due to the technical equality, the power quality measurements are also valid for the SUN2000-33KTL-A and the SUN2000-36KTL running at 480 V rated output voltage. The results shall be transferred by scaling to the corresponding rated current.

5.3 Reactive power

5.3.1 Reactive power provision

The following generally applies:

No.	Evaluation Criteria	Acceptance Criteria	Assessment result
1	Every setpoint value specified by the grid operator can be achieved within the required reactive power range (Figure 5). Note: In case the PGU does not meet the requirement, it has to be met at the level of the PGS at the latest.	≤ 4 min	Compliant, by manufacturer declaration
2	The types of setpoint value specifications and interfaces for control of the reactive power provision are documented.	Details provided	Compliant, following interfaces for control of the reactive power provision are provided on the PGU level: a) Connect a mobile phone that runs the SUN2000 app to the inverter using a Bluetooth module, a WLAN module, or a USB data cable. b) Connect the inverter to Smartlogger via RS485. Control functions: - Power factor fix control - Reactive power fix control - Q-P characteristic curve - Q-U characteristic curve
3	Details of the Q-step response via a step response for the interface/setpoint value combinations.	Details provided	Compliant, by manufacturer declaration
4	Representation of the reactive power capability as a function of the voltage and feed-in active power as an illustration and in a table. (Data for 0.85 U_n – 1.15 U_n provided in 5% steps)	True	Compliant, see section 5.3.3

5	PQ characteristic is verified for 'max underexcited', 'max overexcited' and 'Q=0'.	True	Compliant, see /4/ chapter 4.2.1
6	Active power reduction may be parametrised to the benefit of reactive power feed-in.	Details provided	Compliant, by manufacturer declaration. Parametrizable through parameters P_{limit} and P_{max}. The reactive power is prioritized versus the active power /1/
7	Voltage-independence is verified for at least two conclusive operating points each for underexcited and overexcited operating ranges.	True	Compliant, see /4/ chapter 4.2.1

5.3.2 Procedure for reactive power feed-in

The following generally applies:

No.	Evaluation Criteria	Acceptance Criteria	Assessment result
1	The type of setpoint value specifications and interfaces for control of the reactive power provision is stated.	Details provided	Compliant, the following reactive power control functions are implemented on the PGU level /1/: a) Settable Q-parameter (range: +/- 60%Pmax) b) Settable cosφ-set-parameter (range: +/- 0,8) (* c) Configurable Q(U)-characteristic line (No. of supporting points: 10) (* d) Configurable Q(P)-characteristic line (No. of supporting points: 10)

2	In the event the communication with the PGS controller is disturbed, PGU can be operated with a predefined value or process.	Details provided	Compliant, the PGU will remain in operation with the last setpoint value

(* not within the scope of this report and certificate.

A selection of additional requirements from A.1.2.4.2.2 (requirements originally specified for the PGS controller, only for information)

No.	Evaluation Criteria	Acceptance Criteria	Assessment result
1	A remote and/or manual switchover between the control processes is possible.	True	Process not available at unit level. Fulfil the requirement only in combination with plant controller
2	When switching over between control processes the new setpoint value should not be reached faster than the required PT1 behaviour and not more slowly than in 4 minutes.	$Q_{target} \geq t_{on}$ & $Q_{target} \leq$ 4 min	Not relevant, no switching between different control Processes was tested. Needs to be fulfilled on the PGS controller level
3	Qualitatively, the control behaviour must take place according to PT1 behaviour. Each reactive power value resulting from the control behaviour specified by the grid operator must be possible to provide, adjusted between 6 s and 60 s (for Type 1 between 10 s and 60 s).	True	Compliant only for required time, but since the unit is sufficiently fast, the requirements of the PT1 behavior could be achieved together with a plant controller at project level
7	Tolerance after settling of the reactive power value of ±2% P_{inst}; (or ±4% P_{inst} for systems with $S_{A,max}$ < 300 kVA) is complied with. If limits are exceeded due to dynamic voltage variations on the grid, these have to be assessed by the certification body.	True	Compliant, by measurement report

A selection of additional requirements for the Q(U) control from A.1.2.4.2.2

NOTE: The test for Q(U) control was not carried out correctly, as the characteristic curve of the PV unit was not implemented according to the requirements of /A/. Therefore, the following assessment is shown for informative purposes only, should the certificate be used for other international markets. The assessment results are not taken into consideration for the final compliance assessment according to the requirements of the VDE-AR-N-4110 /A/.

No.	Evaluation Criteria	Acceptance Criteria	Assessment result
8	Interface for the specified voltage U_{Q0}/U_C present. The specified voltage can be stipulated in steps of 0.5 U_C.	Details provided	No interface available. Requirement cannot be evaluated, Fulfil the requirement only in combination with plant controller
9	Voltage dead band can be set in steps of maximum 0.5 % U_C.	±0% ... ±5% U_C	No dead band implemented. Requirement cannot be evaluated, Fulfil the requirement only in combination with plant controller
10	Q(U) characteristic / gradient m can be defined via value pair.	Details provided	Compliant, the Q(U) characteristic curve is free programmable with up to 10 supporting points /1/
11	The gradient m can be set within the value range (according to VDE-AR N 4110 /A/)	$5 \leq m \leq 16.5$	Compliant, by adjusting parameters 34-38 /7/
12	After adapting the specified voltage U_{Q0}/U_C the resulting setpoint value has to be approached within ≤ 4 min.	True	Requirement cannot be evaluated, but the unit is fast enough to meet the requirements

A selection of additional requirements for the Q(P) control from A.1.2.4.2.2

No.	Evaluation Criteria	Acceptance Criteria	Assessment result
13	Q(P) characteristic curve can be defined via at least 10 interpolation points / value pairs ($Q_{EA,target}/P_{b,inst}$).	True	Compliant, see manufacturer declaration and parameter list /7/

A selection of additional requirements for reactive power with limitation function from A.1.2.4.2.2

NOTE: The test for Q with limiting function control was not carried out correctly, as the characteristic curve of the PV unit was not implemented according to the requirements of /A/. Therefore, the following assessment is shown for informative purposes only, should the certificate be used for other international markets. The assessment results are not taken into consideration for the final compliance assessment according to the requirements of the VDE-AR-N-4110 /A/.

No.	Evaluation Criteria	Acceptance Criteria	Assessment result
14	Interface for the specification of the reactive power value $Q_{ref}/P_{b\ inst}$ is avaible	Details provided	No interface available. Requirement cannot be evaluated, Fulfil the requirement only in combination with plant controller
15	The reactive power value $Q_{ref}/P_{b\ inst}$ can be specified in steps of 1 % $Q/P_{b\ inst}$	Details provided	Requirement cannot be evaluated, Fulfil the requirement only in combination with plant controller
16	Procedure $Q_{U\ max}$ definable via value pairs	Details provided	Requirement cannot be evaluated, Fulfil the requirement only in combination with plant controller. Reactive power with voltage limiting function uses the Q(U) characteristic curve which is free programmable up to 10 supporting points

17	For stability reasons, gradients m greater than the limit value are not permitted ($m \geq 24$)	True	Requirement cannot be evaluated, Fulfil the requirement only in combination with plant controller. Reactive power with voltage limiting function uses the Q(U) characteristic curve. The required gradient and setting time can be provided via suitable configuration of the Q(U) characteristic line
18	After adapting the reactive power value Q_{ref}/P_{binst} the resulting setpoint value has to be approached within ≤ 4 min	True	Requirement cannot be evaluated, but the unit is fast enough to meet the requirements, Fulfil the requirement only in combination with plant controller. Reactive power with voltage limiting function uses the Q(U) characteristic curve. The required setting time can be provided via suitable configuration of the time constant parameter

5.3.3 Assessment

5.3.3.1 Reactive Power capability

As already indicated in chapter 4.1, the control includes different PQ-Modes. In PQ-Mode 1 the inverters make use of the full apparent power as active power. This applies to the SUN2000-36KTL only. Consequently, the theoretical Q-capability at full load is zero (power factor of one) for this case. In PQ-Mode 2 the rated active power of the inverters is limited to the values stated in 4.2.1. Consequently, the inverters can operate at a power factor of 0.9 at full load (and rated voltage). Furthermore, it is possible to permanently limit the active power to a specific in-between value, in order to, on a project level, enable maximum possible rated active power, while still meeting specific reactive power requirements at grid connection point.

Consequently, the reactive power capability at full load depends on the fixed rated apparent power, the chosen limited (or rated) active power (PQ-Mode 1, PQ-Mode 2 or individual limitation) and the voltage. For the SUN2000-36KTL the reactive power capability has been measured for both configurations (active power limited to 36 kW (PQ-Mode 2) and max. active power at 40 kW (PQ-Mode 1). The changed rated output voltage of the SUN2000-36KTL to 480 V does not have any impact on the reactive power capability, the dynamics or the accuracy. For the remaining types, the given values are based on a manufacturer declaration and the rated apparent power.

The maximum reactive power (inductive and capacitive) for the full active power range was measured for the SUN2000-36KTL in PQ-Mode 2, changing active power from 0 % to 100 % P_n in steps of 10 %. The inverter can provide up to 24 kVAr reactive power, capacitive or inductive (both in generator reference system) up to 32 kW. Above 32 kW the inverter's reactive power capacity is reduced, which is due to the 40 kVA apparent power limitation. The results of the measurements, together with the manufacturer specification, is shown in Figure 5-1 and stated in Table 5-6. In general, the measurement results confirm the theoretical capability.

The power provision is limited by the maximum apparent current and maximum apparent power. The reactive power is prioritized versus the active power. A maximum reactive power provision of 60% S_{max} (using Q set-point) or cosφ = 0.8 (using cosφ set-point) is possible.

At overvoltage the apparent / active power threshold limits the injected power. At undervoltage the apparent current limitation will also contribute. Continuous provision is possible within the voltage range $0.8U_n$ - $1.2U_n$ and the frequency range between 47.5 and 51.5 Hz.

A permanent active power reduction can be applied by setting parameters P_{limilt} and P_{maxref} (the following applies: $P_{limilt} \leq P_{maxref} \leq P_{max}$. Default: $P_{limilt} = P_{maxref} = P_{max}$). Following interfaces for control of the active power provision are provided on the PGU level:

- Fixed active power derated
- Active power percentage derating

As required by the FGW TG8 /C/, the manufacturer Huawei Technologies Co., Ltd. also provided information on the reactive power capability in the 0.85-1.15% voltage range of the inverters /1/. This is shown in Figure 5-1 for the SUN2000-36KTL for PQ-Mode 1 and Figure 5-2 for the PQ-Mode 2. The corresponding values can be calculated with consideration to the rated active power.

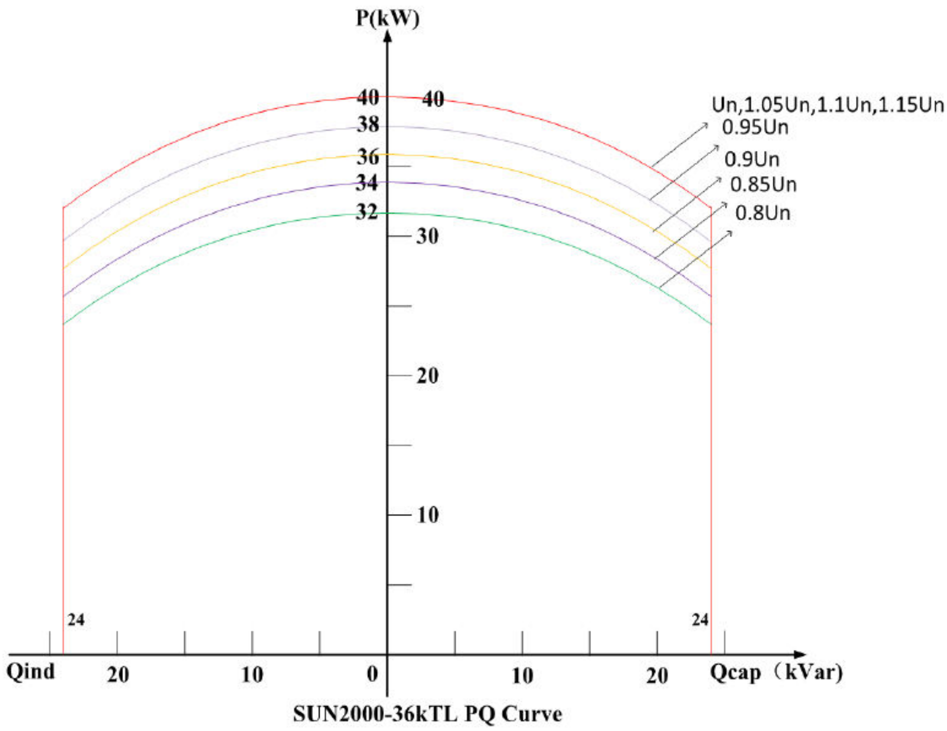

Figure 5-1 Reactive power capability of the Huawei SUN2000-36KTL according to manufacturer declaration (PQ-Mode 1) /1/.

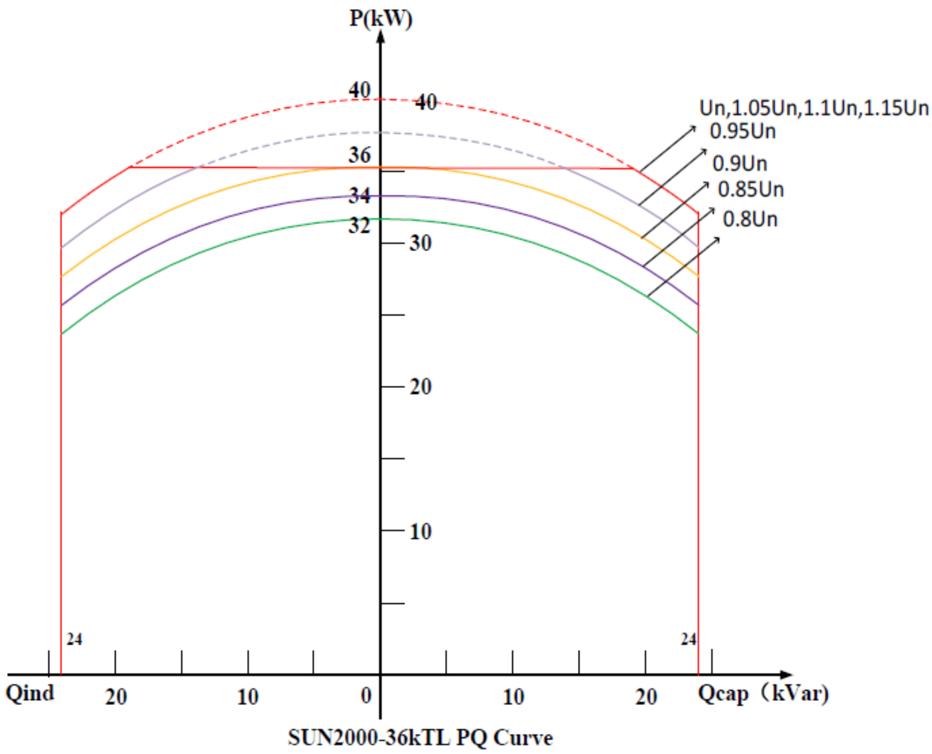

Figure 5-2 Reactive power capability of the Huawei SUN2000-36KTL according to manufacturer declaration (PQ-Mode 2) /1/.

The reactive power capability was measured on the SUN2000-36KTL in PQ-Mode 2, for which the results are shown in Figure 5-3 and Table 5-4.

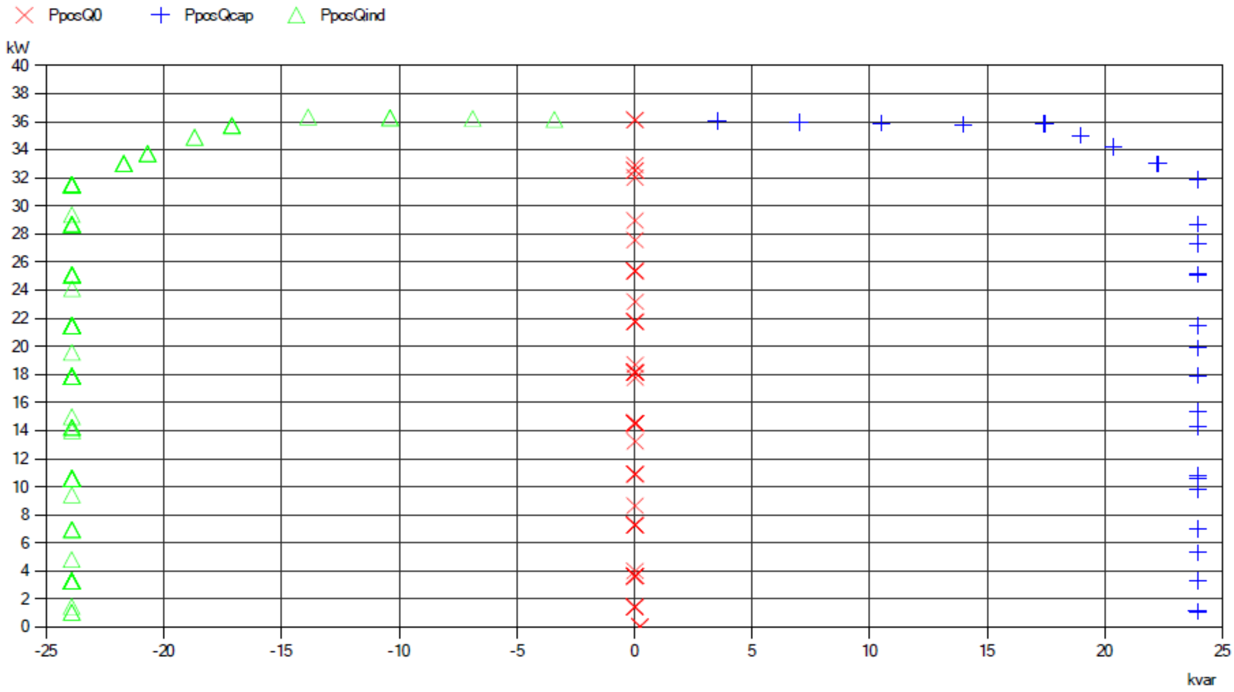

Figure 5-3 Reactive power capability of the Huawei SUN2000-36KTL (PQ-Mode 2, rated power of 36 kW) according to measurements /4/.

Table 5-4 Reactive power capability in the voltage independent PQ diagram according to measurements results /4/.

P [%]	Q_{max} measurement [kvar]			Q_{min} measurement [kvar]		
	P [kW]	capacitive	Cos φ	P [kW]	inductive	Cos φ
0	1.10	23.94	0.0460	1.14	-23.93	0.0477
10	3.34	23.95	0.1380	3.28	-23.93	0.1357
20	6.96	23.95	0.2791	6.92	-23.92	0.2778
30	10.61	23.95	0.4050	10.55	-23.92	0.4037
40	14.28	23.95	0.5121	14.22	-23.92	0.5109
50	17.90	23.95	0.5985	17.87	-23.92	0.5985
60	21.46	23.96	0.6672	21.46	-23.92	0.6679
70	25.12	23.97	0.7235	25.06	-23.92	0.7233
80	28.69	23.96	0.7676	28.68	-23.92	0.7679
90	32.09	23.68	0.8045	31.98	-23.23	0.8086
100	35.55	13.11	0.9295	35.94	-11.73	0.9428

The reactive power capability at PQ-Mode 1 (Maximum active power equal to maximum apparent power, P_n = 40 kW) was also measured, for which the results are shown in Figure 5-4 and Table 5-5.

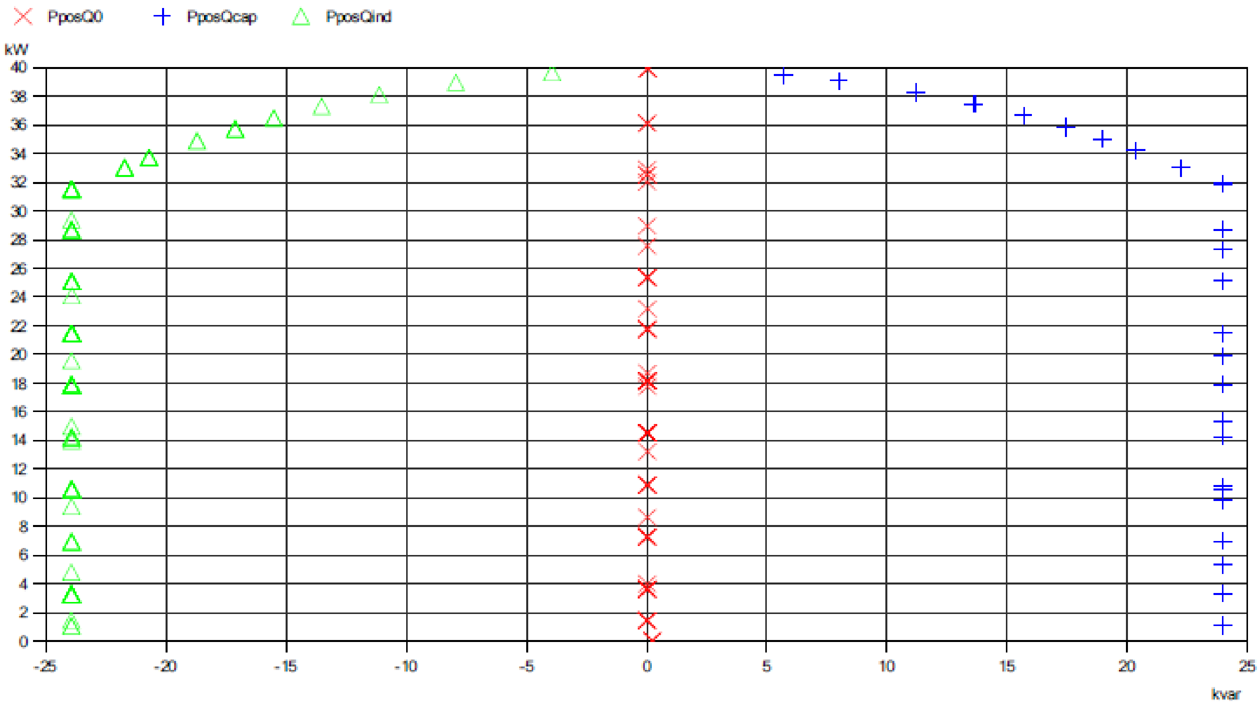

Figure 5-4 Reactive power capability of the Huawei SUN2000-36KTL (PQ-Mode 1, rated power of 40 kW) according to measurements /4/.

Table 5-5 Reactive power capability in the voltage independent PQ diagram according to measurements results /4/.

P [%]	Q_{max} measurement [kvar]			Q_{min} measurement [kvar]		
	P [kW]	**capacitive**	**Cos φ**	**P [kW]**	**inductive**	**Cos φ**
0	1.10	23.94	0.046	1.14	-23.93	0.048
10	3.34	23.95	0.138	3.28	-23.93	0.136
20	7.01	23.95	0.281	6.96	-23.92	0.279
30	10.62	23.95	0.405	10.63	-23.92	0.406
40	16.07	23.95	0.557	16.03	-23.92	0.557
50	21.46	23.96	0.667	21.43	-23.92	0.667
60	25.12	23.97	0.724	25.06	-23.92	0.723
70	28.69	23.96	0.768	28.68	-23.92	0.768
80	32.09	23.68	0.805	31.98	-23.23	0.809
90	35.85	17.21	0.901	36.10	-16.22	0.912
100	38.96	8.28	0.978	38.92	-7.67	0.987

For both measurements above in the case of maximum inductive reactive power capability, only 4 1-min data sets were recorded for the 0% active power bin, although 7 are required by /B/. This is not seen as critical, due to the stable test conditions outlined in chapter 3 of the measurement report /4/.

The maximum inductive and capacitive reactive power was measured for different active power and voltage levels from for verification of the voltage dependent PQ diagram as follows:

a) Overexcited/variable voltage (P_{max} at inflection)

b) Underexcited/variable voltage (P_{max} at inflection)

c) Overexcited/variable voltage (P=0.5 p.u.)

d) Underexcited/variable voltage (P=0.5 p.u.)

e) Normal operation/variable voltage (P_{max} at Q=0)

The result of the measurements is shown in the following Table 5-6.

Table 5-6 Reactive power capability in the voltage dependent PQ diagram according to measurement results /2/.

Operating point	Active power in p.u.	Voltage in p.u.	Reactive power in p.u.	Displacement factor
Overexcited / Variable voltage	0.618	0.807	0.666	0.681
	0.698	0.857	0.665	0.724
	0.773	0.906	0.664	0.759
	0.846	0.956	0.664	0.787
	0.901	1.005	0.663	0.805
	0.901	1.054	0.663	0.805
	0.901	1.104	0.663	0.805
	0.901	1.153	0.664	0.805
Underexcited / Variable voltage	0.600	0.799	-0.674	0.665
	0.676	0.845	-0.675	0.708
	0.754	0.896	-0.676	0.745
	0.826	0.944	-0.675	0.774
	0.891	0.997	-0.676	0.797
	0.890	1.047	-0.676	0.797
	0.890	1.096	-0.675	0.797
	0.890	1.146	-0.675	0.797
Overexcited / Variable voltage	0.510	0.806	0.664	0.609
	0.510	0.858	0.667	0.608
	0.510	0.905	0.667	0.607
	0.510	0.955	0.667	0.608
	0.510	1.003	0.668	0.607
	0.510	1.053	0.668	0.607
	0.510	1.103	0.668	0.607
	0.510	1.152	0.668	0.607
Underexcited / Variable voltage	0.500	0.798	-0.673	0.596
	0.500	0.844	-0.673	0.596
	0.500	0.894	-0.673	0.596
	0.500	0.942	-0.673	0.596
	0.500	0.994	-0.672	0.596
	0.500	1.044	-0.672	0.597
	0.500	1.094	-0.672	0.596
	0.500	1.144	-0.672	0.597
Q = 0 mode / Variable voltage	0.900	0.798	-0.007	1.000
	0.960	0.850	-0.007	1.000
	1.014	0.898	-0.007	1.000
	1.072	0.949	-0.007	1.000
	1.127	0.998	-0.008	1.000
	1.132	1.047	-0.007	1.000
	1.131	1.098	-0.007	1.000
	1.131	1.146	-0.007	1.000

In Figure 5-5 the corresponding reactive power capability for the SUN2000-33KTL-A is shown. As for the other cases, it is based on the rated apparent power, which is reduced linearly with the voltage. The corresponding values can be calculated with consideration to the rated active power.

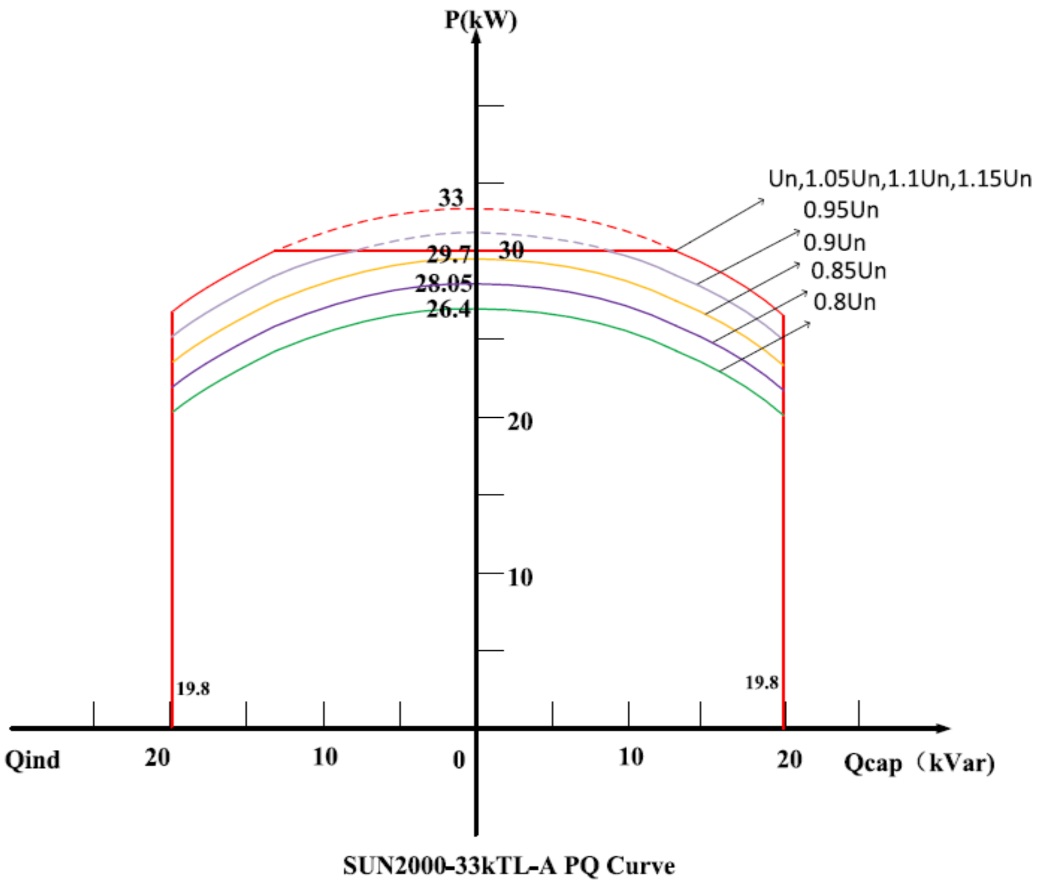

Figure 5-5 Reactive power capability of the SUN2000-33KTL-A (rated power of 30 kW) according to manufacturer information /1/.

5.3.3.2 Reactive power following set points

The results for the deviations between setpoint and actual values as well as the results for the settling times of two different parameter settings (corresponding to 1000 % Q_{max}/s and 1.7 % Q_{max}/s) are shown in Table 5-7, Table 5-8 and Table 5-9.

Table 5-7 Setting accuracy for reactive power setpoint (Q-fixed reactive power value) /2/

Reactive power	Accuracy at 50 % P_N [% P_N]
50% $Q_{max,cap}$	-0.17
50% $Q_{max,ind}$	0.67

Table 5-8 Settling times for the reactive power setpoint when using fast settings (Q-fixed reactive power value) /2/

Reactive power Step	Set dynamic	Settling time in [s]
Q = 0 → $Q_{max,overex.}$	1000 % Q_{max}/s	0.23
$Q_{max,overex.}$ → $Q_{max,underex.}$		0.51
$Q_{max,underex.}$ → Q = 0		0.16
Longst measured settling time		0.51

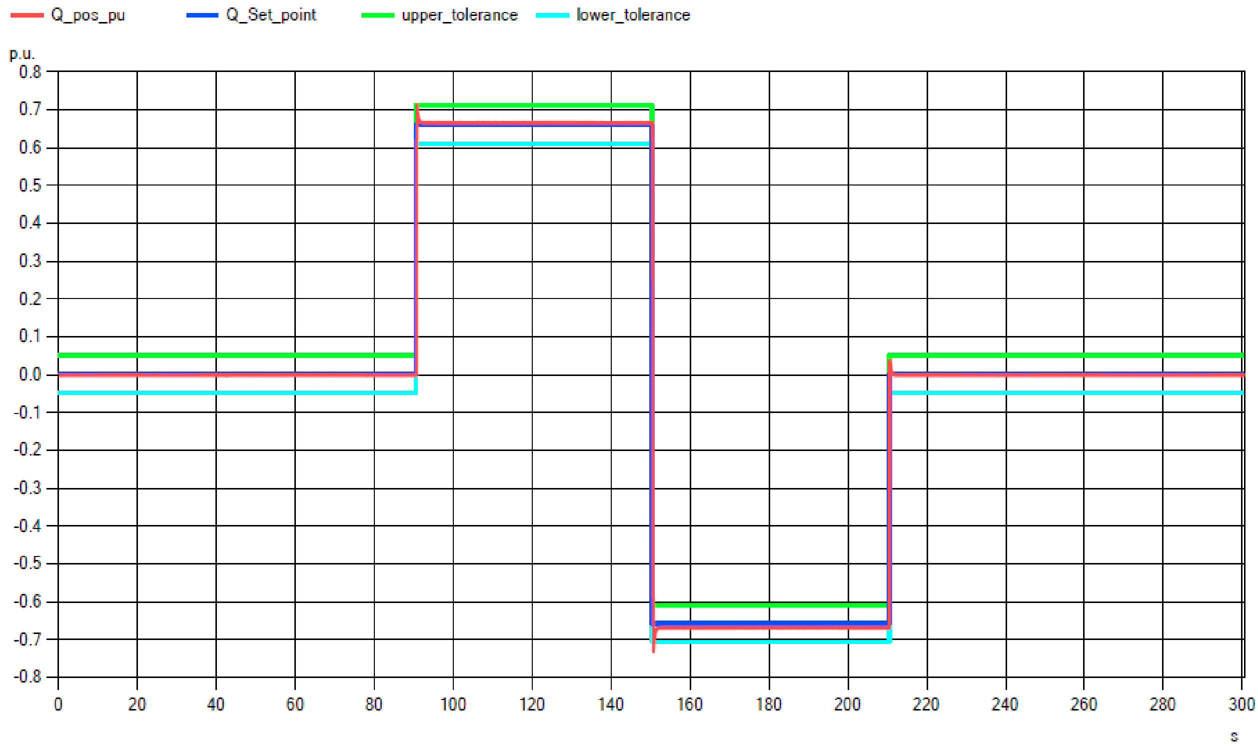

Figure 5-6 Transition function from max. capacitive to max. inductive reactive power of the SUN2000-36KTL taken from measurement report /2/ (Fastest settling time)

Table 5-9 Settling times for the reactive power setpoint using slow settings (Q-fixed reactive power value) /2/

Reactive power Steps	Set dynamic	Settling time in [s]
Q = 0 → $Q_{max,overexc.}$	1.7 % Q_{max}/s	53.97
$Q_{max,overexc.}$ → $Q_{max,underexc.}$		112.32
$Q_{max,underexc.}$ → Q = 0		54.68
Longest measured settling time		112.32

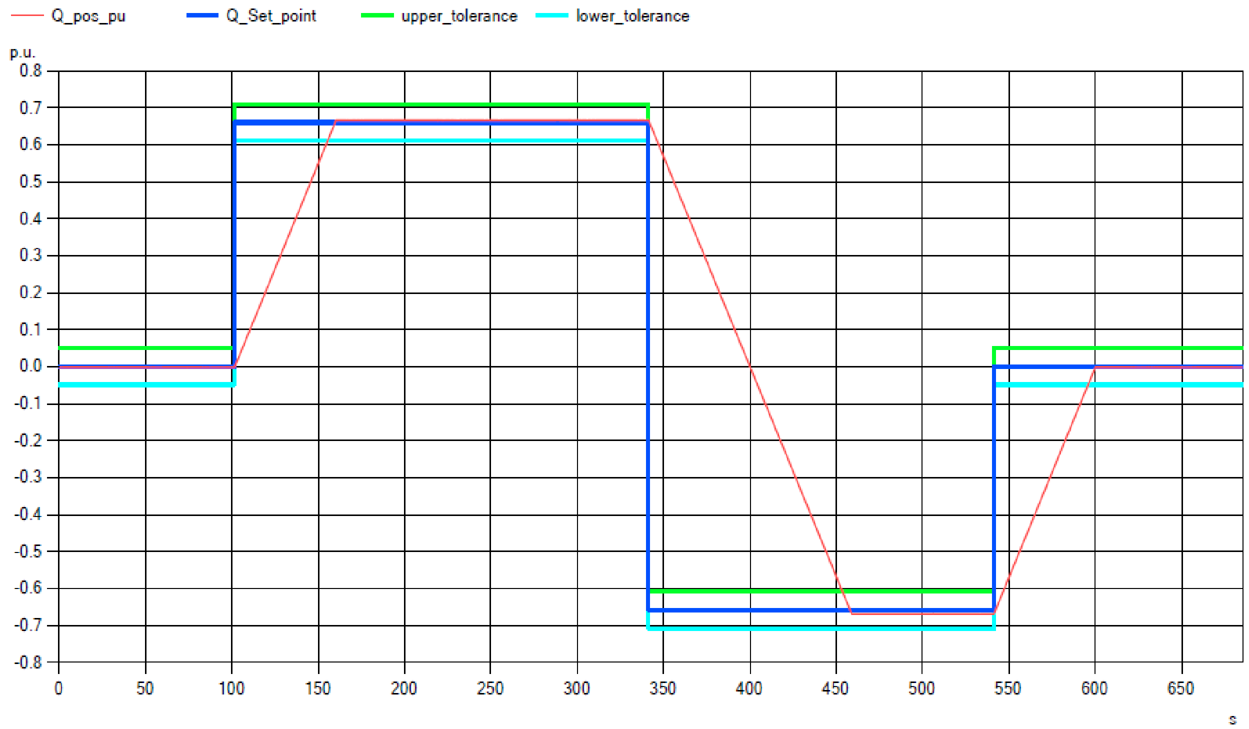

Figure 5-7 Transition function from max. capacitive to max. inductive reactive power of the SUN2000-36KTL taken from measurement report /2/ (slowest settling time)

Q(U) control

The test for Q(U) control was not carried out correctly, as the corresponding characteristic curve of the PV unit was not implemented according to the requirements of /A/. Testing of the dead band and curve shift was not tested and is not implemented. The following results are shown for informative purposes only, should the certificate be used for other international markets.

The operation mode of a Q(U) characteristic curve was measured with the fastest settling time at 55 % P_n. The results for the fastest settling times for the Q(U) characteristic are listed in Table 5-10.

Table 5-10 Settling time for the Q(U) characteristic curve based on the measurement results /2/

Step	Set dynamic	Settling time in [s]
1.00 U_N → 0.97 U_N	3 τ =1 s	2.23
0.97 U_N → 1.03 U_N		2.25
1.03 U_N → 1.00 U_N		2.23
Longest measured settling time		2.25

In addition, the operation mode of a Q(U) characteristic curve was measured with the slowest settling time 55 % P_n. The results for the fastest settling times for the Q(U) characteristic are listed in Table 5-10.

Table 5-11 Settling time for the Q(U) characteristic curve based on the measurement results /2/

Step	Set dynamic	Settling time in [s]
1.00 U_N → 0.97 U_N	3 τ =60 s	52.21
0.97 U_N → 1.03 U_N		52.74
1.03 U_N → 1.00 U_N		45.96
Longest measured settling time		52.74

Q(P) control

For this measurement the characteristic curve was taken from TR3 /B/ and the active power setpoint was set to 45 %, 55 %, 75 % and 95 % in successive steps. The output active power to follow accordingly as summarized in the table below. The results for the deviations between setpoint and actual values are shown in Table 5-12. The results for the settling times are shown in Table 5-13.

Table 5-12 Accuracy for the Q(P) characteristic curve based on the measurement results /2/

Setpoint in p.u.	Required Q in p.u.	Measured Q in p.u.	Q deviation in p.u.
0.45	0.000	-0.002	-0.002
0.55	-0.025	-0.028	-0.003
0.75	-0.190	-0.195	-0.005
0.95	-0.330	-0.337	-0.007

Table 5-13 Settling time for the Q(P) characteristic curve based on the measurement results /2/

Step change	45 % → 55 %	55 % → 75 %	75 % → 95 %
Settling time in s	0.00	0.73	0.69

Reactive power Q with voltage limitation

The test for Q with limiting function control was not carried out correctly, as the corresponding characteristic curve of the PV unit was not implemented according to the requirements of /A/. The test was carried out by adjusting the supporting points of the Q(U) function curve. The following results are shown for informative purposes only, should the certificate be used for other international markets.

The test was carried out for three different Q_{ref} settings: Q_{ref} = 0.0 p.u., Q_{ref} = 0.33 p.u. and Q_{ref} = -0.33 p.u.. The measured voltage, the corresponding calculated reactive power, the actual reactive power and its deviation for each applied step are shown in Table 5-14.

Table 5-14 Accuracy for the Q(U) characteristic curve based on the measurement results, Q_{ref} = 0.0 p.u. /2/

Measured voltage in p.u.	Q setpoint value in p.u.	Q actual value in p.u.	Deviation in p.u.
0.994	0.000	-0.002	-0.002
0.955	0.000	-0.003	-0.003
0.930	0.330	0.316	-0.014
1.031	0.000	-0.024	-0.024
1.054	-0.326	-0.335	-0.009
0.994	0.000	-0.002	-0.002

Table 5-15 Accuracy for the Q(U) characteristic curve based on the measurement results, Q_{ref} = 0.33 p.u. (capacitive) /2/

Measured voltage in p.u.	Q setpoint value in p.u.	Q actual value in p.u.	Deviation in p.u.
0.996	0.330	0.331	0.001
0.938	0.330	0.331	0.001
1.015	0.330	0.320	-0.010
1.034	0.031	-0.006	-0.037
1.055	-0.318	-0.336	-0.018
0.996	0.330	0.331	0.001

Table 5-16 Accuracy for the Q(U) characteristic curve based on the measurement results, Q_{ref} = -0.33 p.u. (inductive). /2/

Measured voltage in p.u.	Q setpoint value in p.u.	Q actual value in p.u.	Deviation in p.u.
0.996	-0.330	-0.336	-0.006
0.976	-0.330	-0.336	-0.006
0.957	-0.011	-0.008	0.003
0.937	0.316	0.320	0.004
1.057	-0.330	-0.336	-0.006
0.996	-0.330	-0.336	-0.006

Conclusions

The reactive power provision by fixed set-point control was performed for the SUN2000-36KTL in PQ-Mode 2, with the required accuracy. The tests were performed at an active power operating point of 50 % of rated active power (36 kW). The longest reactive power response time of the SUN2000-36KTL was 0.51 s for the fastest time setting and 112.32 for the slowest time setting (during a step from maximum inductive reactive power to maximum capacitive reactive power). Since the relevant gradient is set as a p.u.-value, based on the chosen rated active power, the same response time is expected for the SUN2000-33KTL-A and SUN2000-36KTL at 480 V. The accuracy in the worst case is 0.67 % P_n.

The observed set point changes show a reactive power change without any overshoots and with faster settling time following the requested PT1 behavior. Since the shape of the different steps does not meet all the requirements of PT1 behavior at the unit level. But since the unit is sufficiently fast, the requirements of the PT1 behavior could be achieved together with a plant controller at project level.

The reactive power provision by Q(P) control was performed for the SUN2000-36KTL in PQ-Mode 2. The tests were performed at an active power operating points of 45 %, 55 %, 75 % and 95 % of rated active power. The longest reactive power response time of the SUN2000-36KTL was 0.73 s (during a step from 55 % to 75 % of rated active power). Since the relevant gradient is set as a p.u.-value, based on the chosen rated active power, the same response time is expected for the SUN2000-33KTL-A and SUN2000-36KTL at 480 V. The accuracy was measured, and the maximum deviation was determined to be -0.7 % P_n.

The reactive power provision by Q(U) control and Q with voltage limiting function were performed for the SUN2000-36KTL in PQ-mode 2. Although the PV unit has these control options available, the test procedures in order to prove their functionalities according to the requirements of the VDE-AR-N-4110 /A/ were not implemented correctly. As a result, the results obtained from these tests are not evaluated for the final assessment for this certification. Certification for these control functions must be proven on a plant controller at project level.

The parameters defining the gradients and response times are equal for all PGU units, the set values refer to the respective rated power(s) of the PGU. Due to the technical equality, the power quality measurements are also valid for the SUN2000-33KTL-A and the SUN2000-36KTL running at 480 V rated output voltage.

5.4 Active power

5.4.1 General information and grid safety management

The following generally applies:

No.	Evaluation Criteria	Acceptance Criteria	Assessment result
1	Power gradient for increasing and reducing the active power.	0.33% P_{rE}/s ≤ gradient ≤ 0.66% P_{rE}/s (in case of setpoint values specified by third parties also more slowly, for power increase however not more slowly than 4% P_{rE}/min.)	Compliant, however one gradient was measured to be 0.67%, see 5.4.2. Can be adjusted by parameter no. 10 (active power change gradient)
2	Even progression of power increase/reduction	True	Compliant, see /2/ chapter 4.1.1.2 and 4.1.1.3
3	Interfaces for specifying active power (grid operator, direct seller) implemented separately as well as the concept checked to make sure lowest active power value is accepted (even if specifications overlap in time).	True	Not compliant, only one interface for specifying active power implemented on the PGU. Separate specifying active power by grid operator and direct seller is not possible. For prioritization of different setpoints must be carried out on the plant level e.g. in the superimposed plant controller
4	Control deviation at PGU terminals identified.	True and deviation ≤ 5% P_{inst}	Compliant, see /2/ chapter 4.1.1.1
5	The maximum active power output is identified as a mean value over 200 ms, 1 minute and 10 minutes.	True	Compliant, see /4/ chapter 4.1.1

6	If active power output is dependent on environmental conditions (temperature, atmospheric pressure), these interrelationships were shown in the form of a manufacturer's declaration.	True	Compliant, see /1/ annex 5
7	If the power gradient is implemented at the PGS controller level, the settling time of the PGU due to an active power step from 90% to 10% P_{rE} and from 10% to 90% P_{rE} must be measured.	No evaluation– data only shown	Compliant, see /2/ chapter 4.1.1.2

5.4.1.1 Active power output as a function of grid frequency

The following generally applies:

No.	Evaluation Criteria	Acceptance Criteria	Assessment result
1	PGU and controllable consumer units respond according to the requirement, if the grid frequency is outside of the tolerance band of ± 200 mHz.	True	Compliant, by measurement /2/
1.1	The frequency measurement meets the requirements with respect to accuracy and sampling.	$\lvert\Delta f\rvert \leq$ 10 mHz in the settled condition $\lvert\Delta f\rvert \leq$ 50 mHz for fast frequency changes $\Delta t_{Sampl} \leq$ 200 ms for fast frequency changes	Compliant
1.2.1	The active power operating point can be increased in the range between $f_{Start<}$ to $f_{Stop<}$. The upper threshold can be adjusted between 49.5 Hz and 49.8 Hz. If available, standard values must be given.	P(f) increase is possible in the range 49.5 Hz $\leq f_{Start<} \leq$ 49.8 Hz to $f_{Stop<}$ = 47.5 Hz.	Compliant, adjustable in the range of 40 Hz to 60 Hz, for more details see parameter list /7/
1.2.2	The active power operating point can be reduced in the range between $f_{Start>}$ to $f_{Stop>}$. The lower threshold can be adjusted between 50.2 Hz and 50.5 Hz. If available, standard values must be given.	P(f) reduction is possible in the range 50.2 Hz $\leq f_{Start>} \leq$ 50.5 Hz to $f_{Stop>}$ = 51.5 Hz.	Compliant, adjustable in the range of 45 Hz to 55 Hz, for more details see parameter list /7/
1.2.3	The initial time delay T_V of the frequency-dependent active power variation is not more than 2 s, otherwise consultation with the grid operator is required.	$T_V \leq$ 2 s or justification to the grid operator.	Compliant, the initial time delay of the frequency-dependent active power variation is defined as 0 ms

No.	Evaluation Criteria	Acceptance Criteria	Assessment result
1.2.4	Conditions for T_V and $T_{an90\%}$ are met.	After $T_V + 0.1 (T_{an90\%} - T_V)$ at least 9% ΔP are produced; after $T_{an90\%}$ at least 90% ΔP are produced.	Compliant
1.3	The statics of the frequency-dependent active power variation is adjustable in the frequency ranges defined under 1b1 and 1b2 between 2% and 12%. Type testing takes place at a static value of 5%.	$2\ \% \leq S = \frac{\frac{\Delta f}{fn}}{\frac{\Delta P}{Pref}} \leq 12\%$ $S_{Standard} = 5\ \% \ (= 40\ \%\ P_{ref}/Hz)$	Compliant, the required gradient (or droop) of the frequency dependent active power derating can be defined using the Parameters *Trigger frequency of over frequency derating*, *Cuttoff frequency of over frequency derating* and *Cutoff power of over frequency derating* /7/
1.4	In the frequency ranges between $f_{Start<}$ and $f_{Stop<}$ and/or $f_{Start>}$ and $f_{Stop>}$ (see 1b1 and 1b2) the PGU tracks up and down the characteristic curve with respect to power output.	True	Compliant, by measurement /2/ chapter 4.1.2.1 and 4.1.2.2
1.5	The active power reduction is possible down to the technical minimum power of the PGU.	True	Compliant, the min. active power in case of overfrequency derating can be limited using parameter *Cutoff power of overfrequency deating*. The PGU can be operated by an active power setpoint of 0

No.	Evaluation Criteria	Acceptance Criteria	Assessment result
1.6	Manufacturer’s declaration documents: • The PGU can be operated another 5 s without active power increase above $f_{Stop>}$. • Separation from the grid only takes place for reasons of self-protection.	True	Compliant, the PGU can remain in operation in case that the grid frequency increases above f_{Stop}> but not triggered by the grid protection or self-protection, in this case the active power will be kept at the power level defined by parameter *Cutoff power of overfrequency derating* /7/
1.7	Transition from critical to normal grid conditions only takes place under the stipulated conditions.	Within 10 min after the frequency returns to the range of 50 Hz ± 0.2 Hz a reduction of active power to P_{mom} may take place with max. 10% $P_{b,Inst}$/min.	Compliant, see chapters 4.1.2.1 and 4.1.2.2 in measurement report
2	PGU transit through fast frequency changes (RoCoF) without disconnecting from the grid.	Manufacturer’s declaration documents: ±2.00 Hz/s in rolling 0.5 s window; ±1.50 Hz/s in rolling 1.0 s window; ±1.25 Hz/s in rolling 2.0 s window can be transited without disconnection from the grid. Otherwise the framework conditions for fulfilment of the requirement have to be shown in the certificate.	Compliant by manufacturer declaration /1/
2.1	Manufacturer’s declaration documents: In the range between 50 Hz and the curve in Figure 17 /A/, PGUs do not reduce their active power.	True	Compliant by manufacturer declaration /1/

No.	Evaluation Criteria	Acceptance Criteria	Assessment result
3	Below 49.5 Hz gas or steam power plants as well as combustion engines do not reduce their maximum active power output by more than the specified value.	Max. permissible P-reduction $10\% * P_{b,Inst} * \frac{49{,}5\,Hz - f}{1\,Hz}$ for f < 49.5 Hz	Not relevant for PV inverter
4	Manufacturer's declaration documents: Combustion engines and gas turbines reduce their active power by a maximum of 3% P_{rE} until returning to above 49.5 Hz in the dynamic short- term range as presented in Figure 17.	True	Not relevant for PV inverter
5	Gas turbines or combustion engine PGUs vary their active power output with at least the specified gradient.	$dP/dt \geq 66$ % P_n/min for $P_n \leq 2$ MW; $dP/dt \geq 20$ %P_n/min for Pn > 2 MW	Not relevant for PV inverter

Further evidence:

No.	Evaluation Criteria	Acceptance Criteria	Assessment result
A	Setting ranges for the active power reduction (f_{Start}>, f_{Stop}>, f_{Start}<, f_{Stop}<, static, "operating on the characteristic") are stated.	Shown in manufacturer's declaration.	Compliant, see parameter list /7/
B1	On the characteristic curve according to Figure 25, the points 1., 2., 3., 4.1 and 5. In the **overfrequency** range were achieved in the indicated sequence.	True. The initial active power feed-in is at least 50% P_{rE}. The steps are held for at least 30 s.	Compliant, see chapter 4.1.2.1 in measurement report
B2	At each of the steps, a pause took place for at least the time required to demonstrate that no undamped power oscillations took place.	True, if decaying resonance behaviour evident.	Compliant, see chapter 4.1.2.1 in measurement report
B3	Rise and settling times have been determined for the steps from 2 to 3 and 3 to 4.1. They meet the specifications.	The rise and settling times determined meet the specifications.	Compliant, see chapter 4.1.2.1 in measurement report
B4	The active power gradient has been determined for the step from 4.1 to 5. This meets the specifications.	The determined active power gradient meets the specifications.	Compliant, gradient adjustable over parameter no. 20 (Power recovery gradient of overfrequency derating)

No.	Evaluation Criteria	Acceptance Criteria	Assessment result
C1	On the characteristic curve according to Figure 25, the points 1., 2., 3.1, 4.1., 5. and 6. in the **underfrequency** range were achieved in the indicated sequence.	True. The initial active power feed-in is a maximum of 10% P_{rE}. The steps are held for at least 30 s.	Compliant, see chapter 4.1.2.2 in measurement report
C2	At each of the steps, a pause took place for at least the time required to demonstrate that no undamped power oscillations took place.	True, if decaying resonance behaviour evident.	Compliant, see chapter 4.1.2.2 in measurement report
C3	Rise and settling times have been determined for the steps from 2 to 3.1 and 3.1 to 4.1. They meet the specifications.	The rise and settling times determined meet the specifications.	Compliant, see chapter 4.1.2.2 in measurement report
C4	The active power gradient has been determined for the step from 5. to 6. This meets the specifications.	The determined active power gradient meets the specifications.	Compliant, gradient adjustable over parameter no. 26 (Power recovery gradient of underfrequency rise power)
D	An operating capability above 51.5 Hz has been shown, if present.	Shown in manufacturer's declaration.	Compliant, the PGU can remain in operation at the grid frequency above 51.5 Hz if not interfered by the grid protection setting

For Type 2 PGUs the following applies:

No.	Evaluation Criteria	Acceptance Criteria	Assessment result
1.1.1	PGU and controllable consumer units of Type 2 comply with the requirements for rise and settling times according to Table 9 of VDE-AR-N 4110 /A/ for the active power **increase** in the ranges 49.8 Hz to 47.5 Hz as well as 51.5 Hz to 50.2 Hz. (Limitations due to technical restrictions need to be observed)	$T_{an90\%} \leq 10$ s for $\Delta P \leq 50$ % $P_{b,Inst}$;$T_{ein} \leq 30$ s	Compliant

1.1.2	PGU and controllable consumer units of Type 2 comply with the requirements for rise and settling times according to Table 9 of VDE-AR-N 4110 /A/ for the active power **reduction** in the ranges 49.8 Hz to 47.5 Hz as well as 51.5 Hz to 50.2 Hz. (Limitations due to technical restrictions need to be observed)	$T_{an90\%}$ ≤ 2 s for ΔP ≤ 50 % $P_{b,Inst}$; T_{ein} ≤ 20 s	Compliant
1.1.3	Storage systems of Type 2 comply with the requirements for rise and settling times according to Table 5 for the active power increase in the ranges 49.8 Hz to 47.5 Hz as well as 51.5 Hz to 50.2 Hz.	$T_{an90\%}$ ≤ 1 s for $\Delta P \leq$ 100 % $P_{b,Inst}$ $Tein \leq 10$ s	Not relevant for PV inverter
1.1.4	Storage systems of Type 2 comply with the requirements for rise and settling times according to Table 5 for the active power reduction in the ranges 49.8 Hz to 47.5 Hz as well as 51.5 Hz to 50.2 Hz.	$T_{an90\%} \leq$ 1 s for $\Delta P \leq$ 100 % $Pb,Inst$; $Tein \leq 10\ s$	Not relevant for PV inverter
1.1.5	Wind turbines comply with the requirements for rise times for the active power increase in the range 49.8 Hz to 47.5 Hz as well as 51.5 Hz to 50.2 Hz. (Limitations due to technical restrictions need to be observed)	$T_{an90}\% \leq 5$ s for $\Delta P \leq 20$ % $P_{b,Inst}$ From P=50 % $Pb,Inst$:	Not relevant for PV inverter
1.3	The standard value of the static behaviour is 2% for Type 2 storage systems.	$s_{Standard}$=2% (=100% Pref/Hz)	Not relevant for PV inverter
6	Feed-in operation at 10% P_{rE} is possible.	True	Compliant, see chapter 4.1.2.2 in measurement report
7	The specifications for frequency-dependent active power are met (Figure 17).	True	Compliant, by manufacturer declaration

5.4.2 Assessment

5.4.2.1 General information and grid safety management

Maximum active power output was measured, the ramp rate results and step point accuracy are found in measurement report /2/. The PGU stayed connected throughout all tests.

Table 5-17 presents the measurement results of maximum active power output, averaged over 200 ms, 1 minute and 10 minutes.

Table 5-17 Maximum values of active power /2/

	600-s-Average	**60-s-Average**	**0.2-s-Average**
Active power maxima [kW]	P_{600} = 36.12	P_{60} = 36.13	$P_{0.2}$ = 36.17
Relative active power maxima p = P / P_N [p.u.]	P_{600} = 1.00	p_{60} = 1.00	$p_{0.2}$ = 1.00

The active power of the unit is limited by different reference quantities and values, which has inherent limitation at higher temperatures. The active power will be de-rated if the value(s) shown in /1/ Annex 4 are exceeded.

The accuracy of the set-point control, presented in /2/, was measured for 10 % steps from 100 % to the minimum capacity 0 % of rated power, using 1-minute average values, showing a maximum deviation of 0.46 % of rated power, which is well within the requirements of /A/.

The maximum and minimum active power ramp rate of the PGU has been tested in accordance with FGW TG3 /B/, with the resulting gradients and settling times as presented in Table 5-18 which complies with the active power range requested by /A/.

Table 5-18 Result for slow and fast ramp measurements /2/

Active power step	**Gradient [%/s]**	**Rise and settling time [s]**
Slow:		
P_0 = 70 % → P_{min} = 50 %	0.33	46.65
P_{min} = 50 % → P_0 = 70 %	0.33	44.73
Fast:		
P_0 = 90 % → P_{min} = 10 %	0.67	114.14
P_{min} = 10 % → P_0 = 90 %	0.66	113.34

5.4.2.2 Active power output as a function of grid frequency

As specified by the manufacturer /1/, the units RoCoF ride-though function complies with the requirements set out by /A/.

The LFSM-O tests were performed in steps as seen in Table 5-19. The mean active gradient was measured to 40.07 % P_{ref}/Hz for a gradient setting of 40 % P_{ref}/Hz, following the same gradient both for increase and decrease of frequency. The maximum and mean active power gradient when returning below 50.2 Hz was measured to 10.07 and 10.05 % P_{ref}/min respectively, for a defined gradient of 10.0 % P_{ref}/min. The settling time is specified in Table 5-20, showing compliance with the requested active power gradient for PGU units of type 2 /A/.

Table 5-19 LFSM- O tests /2/

Step reference	Frequency [Hz]	Power set-point P_{set} [p.u.]	Power measured P_{set} [p.u.]	Power gradient [% P_M/Hz]
1	50.00	0.500	0.503	-
2	50.30	0.481	0.483	-
3	51.40	0.260	0.262	-40.08
4	50.30	0.482	0.483	-40.06
5	50.00	0.500	0.504	-

Table 5-20 Rise and settling times for LFSM-O tests /2/

Frequency step	Rise time [s]	Settling time [s]
2 → 3	157.49.	159.40
3 → 4	153.59	153.59

The tests for LFSM-U was performed in a corresponding manner as the LFSM-O tests. The mean active gradient was measured to 39.67 % P_{ref}/Hz for a gradient setting of 40 % P_{ref}/Hz, following the same gradient both for increase and decrease of frequency. The maximum and mean active power gradient when returning below 49.8 Hz was measured to 9.64 and 9.58 % P_{ref}/min respectively, for a defined gradient of 10.0 % P_{ref}/min. The settling time is specified in Table 5-22 and compliant with the requested active power gradient for PGU units of type 2 /A/.

Table 5-21 LFSM- U tests /2/

Step reference	Frequency [Hz]	Power set-point P_{set} [p.u.]	Power measured P_{set} [p.u.]	Power gradient [% P_M/Hz]
1	50	0.100	0.103	-
2	49.70	0.107	0.107	-
3	47.60	0.193	0.193	-39.83
4	48.70	0.148	0.148	-39.52
5	49.70	0.107	0.107	-
6	50.00	0.100	0.103	-

Table 5-22 Rise and settling times for LFSM-U tests /2/

Frequency step	Rise time [s]	Settling time [s]
2 → 3	0.00	0.00
3 → 4	0.00	0.00

The active power provision of the Huawei SUN2000-33KTL-A and the SUN2000-36KTL with rated voltage of 480 V where not tested separately. The parameters defining the gradients and response times are equal for all PGU units, the set values refer to the respective rated power(s) of the PGU. Due to the technical equality the requirements for set-point control are regarded as fulfilled for this as well.

The functionality of chapter 8.1 of VDE-AR-N 4110 /A/ is implemented by Huawei as explained in the following. The active power set point change is prioritized over the active power change caused by the LFSM-U and LFSM-O functions. For LFSM-U, only an increase of the active power set point will be considered and prioritized during the underfrequency event (see Figure 5-8). For LFSM-O, only a decrease of the active power set point will be considered and prioritized during the overfrequency event (Figure 5-9).

In Figure 5-8 and Figure 5-9 set point changes occurring during underfrequency and overfrequency events are shown. These are simulation results using the validated simulation model. The signal "Pref" is the external active power set int and "id_dem" is the active current which is equal to the power as the voltage is constant at 1 p.u..

As stated above all requirements in conjunction with "Active power output as a function of grid frequency" stated in the FGW TG8 /C/ and Chapter 11.2.8 of VDE-AR-N 4110 /A/ are fulfilled by the inverter. For this reason, this function can be considered as compliant. Should this functionality not be desired on project level, the operator also has the possibility to disable "Active power output as a function of grid frequency" altogether. In this case however, a plant controller is needed which takes over this functionality instead of the inverter.

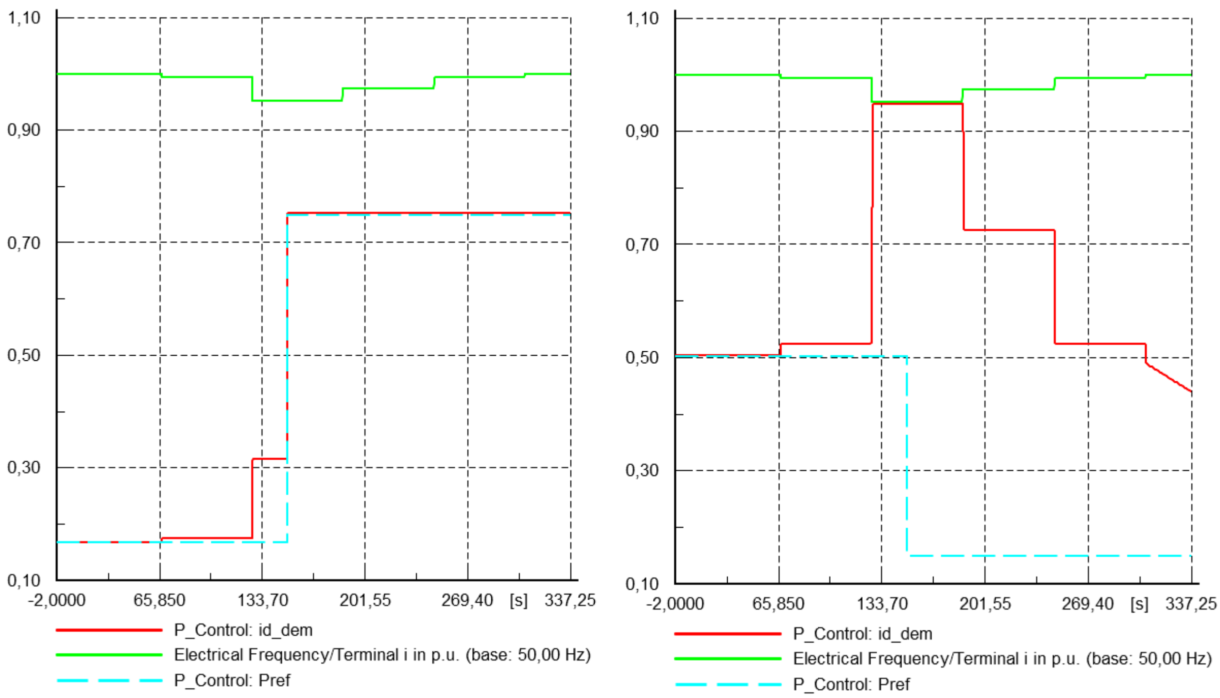

Figure 5-8 LFSM-U function with an increasing set point change (left) and decreasing set point change (right)

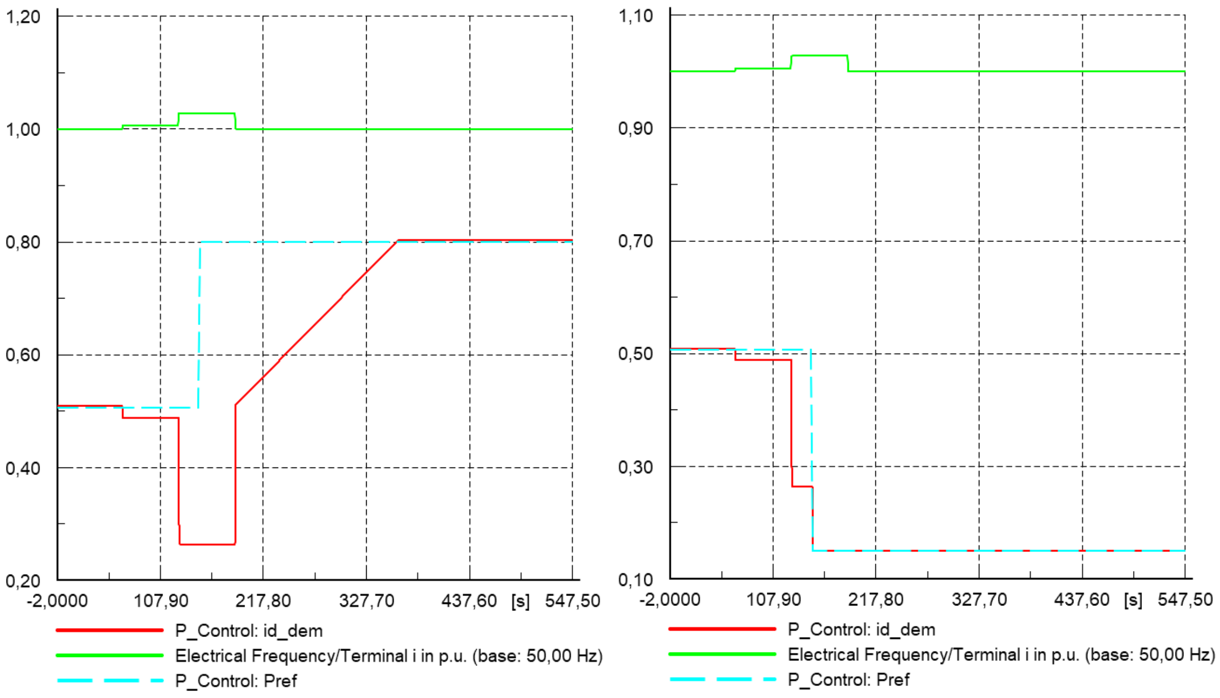

Figure 5-9 LFSM-O function with an increasing set point change (left) and decreasing set point change (right)

5.5 Connection

5.5.1 Switching-in conditions

The following generally applies:

No.	Evaluation Criteria	Acceptance Criteria	Assessment result
1	In the voltage-frequency range to be shown (47.5 Hz ± 0.1 Hz and at 50.2 Hz ± 0.1 Hz as well as at 90% U_n ± 2% Un and 110% ± 2% U_n) a connection of the PGU to the medium-voltage grid is technically possible	True	Compliant, by measurement report chapter 4.5 and by manufacturer declaration
2	Automatic connection of the PGU after disconnection from the grid by triggering a grid protection device is only possible in given voltage and frequency ranges.	$U \geq 95\% U_n$ $49.9 \text{ Hz} \leq f \leq 50.1 \text{ Hz}$	Compliant, as by measurement report chapter 4.5
3	Automatic reconnection only takes place after grid stabilisation time which can be adjusted.	Stabilisation time can be adjusted from 0 to 30 min.	Compliant, time until reconnection adjustable in the range of 0 to 120 min, see parameter list /7/
3.1	The evidence was provided based on a delay time of 5 min and the possible setting range was stated.	True	Compliant, confirmed by measurement institute
4	The gradient of active power was shown. a) By means of manufacturer's declaration: Setpoint specifications (connection without protection being triggered previously) and b) By means of measurement: Reconnection after voltage loss (connection after grid protection was triggered)	True	Compliant a) The soft start time the active power from 0 to power rated after fault, default value is 600 s /7/ b) see measurement report /2/, section 4.1.3
4.1	The gradients determined under 4 are always larger than 0.33% P_{rE}/s.	True	Compliant, see 5.5.2. Can be adjusted in the required range through parameter 27 /7/

4.2	The gradients determined under 4 are always smaller than 0.66% P_{rE}/s.	True	Compliant, see 5.5.2. Can be adjusted in the required range through parameter 27 /7/

Further evidence

No.	Evaluation Criteria	Acceptance Criteria	Assessment result
A	The gradient was measured after a power outage of at least one minute up to an active power of at least 50% P_{rE}.	True	Compliant, see measurement report /2/, section 4.1.3

For Type 2 PGU the following applies:

No.	Evaluation Criteria	Acceptance Criteria	Assessment result
1*	Asynchronous generators with drive unit are connected within the indicated speed range.	Connection within speed range 95% ns ≤ n ≤ 105% ns.	Not relevant for PV inverter
1.1*	The connection of the asynchronous generators with drive unit takes place on a current-limited basis.	True. Information provided in the manufacturer declaration regarding the current-limiting measures.	Not relevant for PV inverter
2	Asynchronous generators which cannot be connected when de-energised (e.g. DFIG) comply with the general connection conditions.	True. Shown in manufacturer's declaration.	Not relevant for PV inverter

5.5.2 Assessment

The results of the verification of the reconnection condition, found in /2/ are showing that reconnection without previous protection triggering only takes place at voltages between 90 % and 110 % and at frequencies between 47.5 Hz and 50.2 Hz, as requested by the VDE-AR-N 4110 /A/. For connection after protection triggering, it has been demonstrated that reconnection is possible in for a voltage of at least 95 % and at in the frequency range of 49.9 Hz to 50.1 Hz. Since the setting for the voltage and frequency range can be adjusted according to the parameter list /7/, the requirements are regarded as fulfilled, which would be easily achievable by changing the corresponding setting.

The limit values for voltage and frequency can be monitored continuously prior to reconnection, with a parametrizable time window of 0-120 minutes. This was verified during testing with a time delay of 5 minutes, as required by /A/.

After reconnection, the active power will be resumed with a limited active power increase, as shown in corresponding tests presented in section 4.1.3 of /2/, which were done according the FGW TG3 Rev. 25 /B/. The average gradient was measured to be 10.04 %P_n/min. However, the test procedure described in /B/ is not correct according to the requirements of /A/. Upon reconnection after decoupling the PGU from the grid, the active power gradient shall be adjustable in the range >0.33 %P_n/s and <0.66 %P_n/s. The manufacturer has provided details to confirm that the gradient after reconnection is parametrizable between 0.125 %P_n/s and 5 %P_n/s, thereby complying with the required range defined in VDE-AR-N-4110.

The PGU units Huawei SUN2000-33KTL-A and SUN2000-36-KTL with rated voltage of 480 V where not tested separately. However, the results are equal in all units, and since the adjustable parameters defining the reconnection gradient is linked to the rated power of each PGU, the connection requirements are regarded as fulfilled for these as well.

5.6 Protection

5.6.1 Readability of the protection setting

The following generally applies:

No.	Evaluation Criteria	Acceptance Criteria	Assessment result
1	The protection devices on the power generating units have been designed in such a way that the settings can be easily read without additional equipment or if additional equipment is required, the authenticity and identification of the data read out is ensured.	True	Not compliant, the integrated grid monitoring/ protection parameters can be checked per remote via WebUI or via SUN2000 app using a mobile phone

5.6.2 Test terminal

The following generally applies:

No.	Evaluation Criteria	Acceptance Criteria	Assessment result
1	Protection test is possible without disconnecting wires.	True	Not compliant, see section 6 below
1.1	The manufacturer's declaration includes a technical description of the test terminal demanded in requirement 1, as per Chapter 6.3.3.5 of the application rule.	True	Not compliant, the PGU does not provide test terminals for on-site testing. For necessary on-site testing, an external monitoring relay with corresponding test terminals must be installed and the PGU's monitoring parameters must be set accordingly

5.6.3 Operating range

The following generally applies:

No.	Evaluation Criteria	Acceptance Criteria	Assessment result
1	A type test is available for the protection devices integrated in the PGU for the setting ranges required according to Table 11 or 13 according to FGW-TG3-Rev. 24 or later.	True	Compliant, see /2/ chapter 4.4.4 and 4.4.5
2	Additional protection devices which are present in the PGU are shown with their setting value range.	True	Compliant Self-protection: parameter 81 for overvoltage protection (1.3 Un for 150 ms) /7/ Undervoltage default value is 60 V (L-N) /14/ Overcurrent protection, 1.5 Imax. Trigger after <1 ms /11/

5.6.4 Accuracy

The following generally applies:

No.	Evaluation Criteria	Acceptance Criteria	Assessment result
1	The required measurement accuracies for the protection devices of the PGU (voltage: ±1% U_n; frequency: ±0.1 Hz: see FNN-Recommendation Annex B) are met. Regarding the frequency support equipment, FGW TG3 is currently being revised. Until the next revision from a measurement perspective an accuracy of 0.1 Hz must be demonstrated.	True	Compliant, see /2/ chapter 4.4.4 and 4.4.5
2	The reset ratio of the voltage protection devices is complied with.	≥ 0.98 (overvoltage protection) ≤ 1.02 (undervoltage protection)	Compliant, see /2/ chapter 4.4.3

5.6.5 Independence of the protection functions

The following generally applies:

No.	Evaluation Criteria	Acceptance Criteria	Assessment result
1	The integrated protection in the PGU - if present - works independently of the control functions.	True	Compliant, see manufacturer declaration /1/
2	Function presentation to show that protection and control functions operate in different software blocks.	Details provided	Compliant, see schematic in /10/

5.6.6 Own and auxiliary power supply

The following generally applies:

No.	Evaluation Criteria	Acceptance Criteria	Assessment result
1	Grid-independent auxiliary power supply is available and maintains protection functions for at least 5 s.	True	Compliant, the grid monitoring functions can be maintained for at least 5 s during grid voltage loss /1/
1a	Functionality of the protection functions within the operating ranges shown in Figure 4 proven.	True	Compliant, see manufacturer declaration /1/
2	A failure of the auxiliary power supply of the protection devices leads to immediate switch-off of the PGU.	True	Compliant, see manufacturer declaration /1/
3	The protective functions are functional prior to the start of power input by the power generating unit.	True	Compliant, see manufacturer declaration /1/

Further evidence

No.	Evaluation Criteria	Acceptance Criteria	Assessment result
A	A failure of the auxiliary power supply of the protection devices and/or system control leads to immediate triggering of the PGU’s main switch.	True	Compliant, see manufacturer declaration /1/
Note: this evidence is optional			

5.6.7 Coupling switch

The following generally applies:

No.	Evaluation Criteria	Acceptance Criteria	Assessment result
1	The coupling switch ensures three-pole galvanic separation.	True	Compliant, see manufacturer declaration /1/ and measurement report
2	The coupling switch is designed as specified by the manufacturer. The switching capacity of the coupling switch is stated.	True	Compliant, see manufacturer declaration /1/
3	The coupling switch is able to be triggered without delay taking into account the protection equipment required according to 10.3.	True	Compliant, see manufacturer declaration /1/
4	The sum of time elements of the protection and switching equipment does not exceed 100 ms.	True	Compliant, see manufacturer declaration /1/ and measurement report

5.6.8 Assessment

Several tests were performed for the SUN2000-36KTL running at 400 V rated output voltage for the verification of the disconnection of the generating unit from the grid during over-voltage and under-voltage, as well as during over-frequency and under-frequency events. In order to determine the release times of the protection system, the voltage and frequency was changed in steps, using a grid simulator. The tests were performed in accordance with FGW TG3 /B/ and comply with the requirements of FGW TR8 /C/. The minimum possible settable delay time for the protection was 50 ms and minimum value for undervoltage protection was 0.15 U_n.

The main-protection implemented in the software meets the requirements of the stated guidelines with regard to trigger accuracy, release ratio and triggering time.

The operation time of the circuit breaker was not tested separately for the SUN2000-36KTL. However, according to /2/, all over-/undervoltage and over-/underfrequency protection tests include the reaction time of the main breaker. Using these results, the operating time of the circuit breaker has been demonstrated to be within 50 ms. The maximum time was measured to be 45 ms including the main breaker switch-off (at <f). Failure of auxiliary power supply was not tested separately, however the expected behaviour was confirmed by the manufacturer.

The maximum under-voltage capability and over-voltage capability of the SUN2000-36KTL and SUN2000-33KTL-A is shown in Figure 5-10.

The changed rated output voltage of the SUN2000-36KTL (to 480 V) does not have any impact on the maximum under-voltage and over-voltage capability.

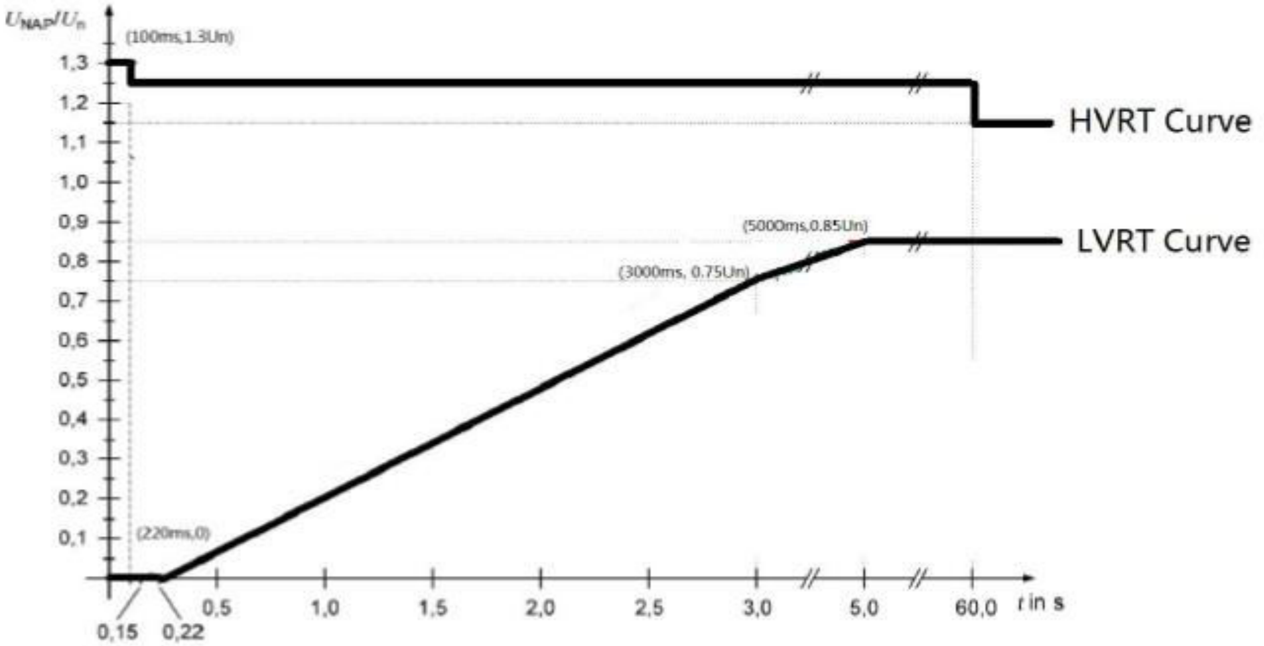

Figure 5-10 Maximum under- and overvoltage capability of the SUN2000-36KTL and SUN2000-33KTL-A.

The maximum and minimum operating range in terms of frequency is 50-57.5 Hz and 42.5-50 Hz respectively, in which the inverter can operate up to max. 2 hours /7/, /10/.

Huawei Technologies Co., Ltd. provided corresponding manufacturer documentation /1/ regarding the requirements for the protection function of the medium-voltage guideline /A/. The protective device operates independently of the inverter control (using a separate software module). It has a sufficient CPU resource and the auxiliary power supply can be maintained for at least 5 s. If the auxiliary power supply fails, the generating unit is immediately disconnected. Furthermore, a power-outage in the protection device will lead to an instantaneous tripping of the circuit breaker. Overall, the inverters fulfil the requirements with two exceptions: the inverters have no display to check the protection settings and the required test terminals are not available.

To check the protection settings, a corresponding Huawei application (app) for smartphones or tablets is available. Since the operator of the PV-plant is responsible to provide a proper method for assessing the correct settings, it might be necessary for them to either provide such a device (tablet or smartphone), with corresponding application, on demand or to keep such a device permanently on site, if requested by the grid operator.

Regarding the missing test terminals, the consequences need to be investigated on project level. Depending on the requirements of the corresponding grid operator, an additional "intermediate" protective disconnection device on the low-voltage side of the transformer might be necessary.

Due to the technical equality and the same disconnection device, these requirements are regarded as fulfilled also for the SUN2000-33KTL-A and the SUN2000-36KTL running at 480 V rated output voltage.

5.7 Transferability

According to the manufacturer, the unit series SUN2000-33KTL-A and SUN2000-36KTL (400 V / 480 V) have an identical hardware platform. The implemented control and firmware is identical in all units. There is no difference regarding AC behavior between the PGU types apart from the power rating deviation and current limitation of each unit. Both parameter names and numbers are the same for all PGU units, with gradients and different characteristic curve supporting points referring to the rated values of power or voltage for each PGU. In addition, the grid protection devices are identical for the different PGU types.

From DNV GL's point of view, technical equivalence in the sense of FGW TG8 /C/ is therefore present and the measurement results of the operation and control behavior as well as the network perturbations can be transferred to the PGU units of type SUN2000-33KTL-A with a rated voltage of 400 V and SUN2000-36KTL with a rated voltage at 480 V according to the specifications in the respective chapters of this certification report.

6 CONDITIONS

- The components listed in section 5.2 shall be used. Changes to the system design, software or the manufacturer's quality system are to be approved by DNV GL.
- In case PT1-behaviour for reactive power set point changes is requested on project level, this needs to be implemented by a plant controller providing the corresponding set-points to the generating unit.
- The PGU has one interface to handle active power set points. Consequently, prioritization of control input signals from different actors (such as grid operators and direct sellers) is not possible. To have this feature implemented a plant controller is needed in order to comply with A.1.2.5.1.1 No. 3 in FGW TG8 /C/ on project level.
- The display to check the protection settings is missing, as well as the test terminals used to enable protection tests without disconnecting any wires. This is not in agreement with the requirements of the VDE-AR-N 4110 /A/. Therefore, the following shall be taken into account:
    - With regard to the missing display, the operator of the PV-plant is responsible to provide a proper solution for checking the settings of the generating unit. If requested by the grid operator, it might therefore be necessary to provide such device (e.g. tablet or smartphone) with a corresponding application, which is either to be stored on site or need to be provided on demand.
    - With regard to the missing test terminals, the consequences need to be investigated on project level. Depending on the requirements of the corresponding grid operator, an additional "intermediate" protective disconnection device on the low-voltage side of the transformer might be necessary.
- In general, it needs to be investigated on project level whether a permanent reduction of the rated active power is necessary to meet the reactive power requirement at the grid connection point. This applies especially to the inverter SUN2000-36KTL when running in PQ-Mode 1.
- The parameters of the generation unit are summarised in the parameter list provided by the manufacturer /7/. The specified "default values" do not automatically meet the requirements according to the guidelines mentioned in in section 2. If necessary, the settings must be adjusted and checked on a project level.
- If a reactive power provision by the functionality "Q(U) control" or by "Q with voltage limiting function" is required on project level the use of a plant control having these functions implemented is mandatory.
- The P(f) function prioritizes some external active power setpoint inputs higher than the active power calculated based on the P(f) characteristic (for more details see section 5.4.2.2). If this is not desired on project level in the way it is implemented, the use of a plant control having these functions implemented is mandatory.

7 CONCLUSIONS

The following tests and measurements were performed, according to the requirements of the FGW TG3 /B/:

- Active power peaks
- Active power control by means of set-point control
- Active power reduction at increased grid frequency (LFSM-O)
- Active power increase at reduced grid frequency (LFSM-U)
- Active power limitation during restart of the generating unit
- Voltage independent PQ diagram (Q capability)
- Separate operating points in the voltage dependent PQ diagram
- Reactive power control by means of fixed set-point control (Q setpoint)
- Q(P) control
- Power quality: flicker, measurement of harmonics and inter-harmonics of the currents, switching operations and current asymmetry
- Grid protection: over/under-voltage and over/under-frequency
- Reconnection conditions
- Verification of the working range

The tests received were assessed according to the criteria given in the corresponding sections of the FGW TG8 /C/. The inverters SUN2000-33KTL-A and the SUN2000-36KTL running at 480 V rated output voltage, are technically equal according to the definition of the FGW TR8 /C/.

Under consideration of the conditions given in section 5, the photovoltaic inverters SUN2000-33KTL-A and SUN2000-36KTL of Huawei Technologies Co., Ltd. fulfil the requirements on the aforementioned criteria as given in the regulations cited in section 2.

8 REFERENCES

/1/	Manufacturer's declaration for compliance to technical requirements of the VDE-AR-N 4110:2018-11, V1.4	19 pages	dated 2020-05-28
/2/	Measurement of power quality and power control characteristics of a PV inverter of the type HUAWEI SUN2000-36KTL according to FGW TG3 Rev. 25, report no. 10157045-A-3-A	108 pages	dated 2020-04-17
/3/	Extract of the measurement report "Measurement of power quality and power control characteristics of a PV inverter of the type HUAWEI SUN2000-36KTL", extract no. 10157045-S-2-A	5 pages	dated 2020-04-17
/4/	Measurement of power quality and power control characteristics of a solar inverter of the type HUAWEI SUN2000-36KTL according to FGW TG3 Rev. 23, report no. GLGH-4280 16 13964 294-A-0002-A	66 pages	dated 2016-05-25
/5/	Manufacturer's certificate of the specific data of the generating unit SUN2000-36KTL, V1.0	3 pages	dated 2020-03-18
/6/	Manufacturer's certificate of the specific data of the generating unit SUN2000-33KTL-A, V1.0	3 pages	dated 2020-03-18
/7/	Parameter list of SUN2000-36KTL & SUN2000-33KTL-A, V1.5	11 pages	dated 2020-05-28
/8/	Product declaration for transferability: SUN2000-36KTL, SUN2000-33KTL-A, V1.1	4 pages	dated 2020-05-26
/9/	User Manual SUN2000-(29.9KTL, 33KTL-A, 36KTL, 42KTL), issue 11	119 pages	dated 2019-06-08
/10/	Description of the Function Blocks of the Voltage Protection, V1.2	5 pages	dated 2020-05-22
/11/	Overview on the necessary documentation and data for the Prototype Confirmation of power generating units (PGU) in accordance to the VDE-AR-N-4110/4120 e Guideline, Version V1.1	15 pages	dated 2019-05-09
/12/	ISO 9001:2015 Certificate no. 01 100 1933213 issued to Huawei Technologies Co., Ltd. for the design, manufacture and service of inverters	5 pages	dated 2020-04-09
/13/	Declaration of conformity for ISO 9001	1 page	dated 2020-05-19
/14/	Verifying Comments Sheet (VCS) VCS-06046-0, revision 27	43 pages	dated 2020-05-29

9 ANNEX

9.1 Overview of Documents

Table 9-1 Overview of Documents

No.	Content	Filename	MD5-Checksum
1	Parameter list of SUN2000-36KTL & SUN2000-33KTL-A, Version V1.5	Huawei_SUN2000-36KTL_Parameter list_V1.5.pdf	aebd0dad4c35a183cfc1ca4894c6ed73

9.2 Extract from 10157045-A-3-A

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EXTRACT OF THE TEST REPORT "MEASUREMENT OF POWER QUALITY AND POWER CONTROL CHARACTERISTICS OF A PV INVERTER OF THE TYPE HUAWEI SUN2000-36KTL "

„Technical Guideline Part 3", Revision 25, FGW

Extract No.
10157045-S-2-A
Date of Issue
2020-04-17

Installation type	SUN2000-36KTL	Generic type of installation	PV inverter
Manufacturer	Huawei Technologies Co. Ltd.	Nominal power P_n in kW	36
Test report	10157045-A-3-A	Period of measurement	2020-02-21 – 2020-04-13

Nominal Data

Nominal apparent power S_n in kVA	36	Nominal current I_n in A	52.00
Nominal frequency f_n in Hz	50	Nominal voltage U_n in V	400

Switching operations – Cut-in at cut-in conditions

Max. number of switching operations N_{10}	20			
Max. number of switching operations N_{120}	240			
Grid impedance angle	**30°**	**50°**	**70°**	**85°**
Flicker step factor $k_f(\psi_k)$	0.01	0.01	0.02	0.02
Voltage change factor $k_u(\psi_k)$	0.09	0.07	0.06	0.06

Switching operations - Cut-in at full load conditions

Max. number of switching operations N_{10}	20			
Max. number of switching operations N_{120}	240			
Grid impedance angle	**30°**	**50°**	**70°**	**85°**
Flicker step factor $k_f(\psi_k)$	0.03	0.02	0.03	0.03
Voltage change factor $k_u(\psi_k)$	0.87	0.66	0.38	0.17

Switching operations – Cut-off at full load conditions

Max. number of switching operations N_{10}	1			
Max. number of switching operations N_{120}	12			
Grid impedance angle	**30°**	**50°**	**70°**	**85°**
Flicker step factor $k_f(\psi_k)$	0.14	0.11	0.07	0.05
Voltage change factor $k_u(\psi_k)$	0.89	0.67	0.37	0.15

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Asymmetry

Power bin in % of P_n	u_i in %	Power bin in % of P_n	u_i in %
0	5.64	60	0.57
10	1.40	70	0.54
20	0.92	80	0.52
30	0.76	90	0.51
40	0.67	100	0.51
50	0.61	-	-
Max. current asymmetry $u_{i\,max}$ for P≥ 10 % P_n in %		1.52	

Flicker

ψ_k / P_{bin} in % of P_n	30°	50°	70°	85°
0	0.19	0.19	0.19	0.19
10	0.95	0.78	0.59	0.47
20	1.56	1.22	0.79	0.51
30	1.55	1.21	0.78	0.50
40	1.54	1.21	0.79	0.51
50	1.54	1.23	0.82	0.56
60	1.53	1.22	0.81	0.52
70	1.54	1.23	0.82	0.52
80	1.53	1.23	0.82	0.53
90	1.51	1.21	0.81	0.52
100	1.50	1.22	0.82	0.54

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Harmonics

Power bin in % of P_n	0	10	20	30	40	50	60	70	80	90	100	max.
h						I_h/I_n in %						
2	0.01	0.15	0.14	0.14	0.15	0.16	0.16	0.16	0.17	0.17	0.18	0.18
3	0.02	0.16	0.15	0.14	0.14	0.14	0.14	0.16	0.18	0.20	0.22	0.22
4	0.00	0.17	0.18	0.17	0.17	0.16	0.16	0.16	0.16	0.16	0.16	0.18
5	0.02	0.24	0.19	0.09	0.13	0.17	0.21	0.24	0.27	0.29	0.29	0.29
6	0.00	0.02	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04
7	0.02	0.20	0.24	0.19	0.15	0.15	0.15	0.17	0.20	0.22	0.25	0.25
8	0.00	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
9	0.01	0.06	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06
10	0.00	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.03	0.03
11	0.01	0.31	0.26	0.35	0.46	0.50	0.51	0.52	0.53	0.54	0.53	0.54
12	0.00	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
13	0.01	0.19	0.20	0.26	0.38	0.42	0.43	0.44	0.45	0.45	0.46	0.46
14	0.00	0.02	0.01	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.03
15	0.00	0.03	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.04
16	0.00	0.03	0.02	0.02	0.03	0.02	0.03	0.02	0.02	0.02	0.02	0.03
17	0.00	0.14	0.16	0.16	0.24	0.29	0.31	0.32	0.33	0.33	0.33	0.33
18	0.00	0.03	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03
19	0.00	0.13	0.13	0.12	0.18	0.23	0.26	0.28	0.29	0.30	0.30	0.30
20	0.00	0.01	0.03	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03
21	0.01	0.01	0.04	0.01	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.04
22	0.00	0.01	0.03	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.04
23	0.00	0.04	0.08	0.10	0.11	0.16	0.20	0.22	0.23	0.24	0.24	0.24
24	0.00	0.01	0.03	0.04	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.04
25	0.00	0.04	0.05	0.08	0.09	0.13	0.16	0.19	0.20	0.21	0.23	0.23
26	0.00	0.01	0.01	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03
27	0.00	0.02	0.02	0.03	0.04	0.02	0.03	0.03	0.03	0.03	0.04	0.04
28	0.00	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
29	0.00	0.04	0.04	0.06	0.06	0.08	0.12	0.14	0.16	0.17	0.18	0.18
30	0.00	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03
31	0.00	0.02	0.03	0.04	0.05	0.07	0.10	0.12	0.14	0.16	0.17	0.17
32	0.00	0.01	0.01	0.01	0.02	0.03	0.02	0.03	0.02	0.03	0.03	0.03
33	0.00	0.01	0.01	0.01	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.03
34	0.00	0.01	0.01	0.01	0.01	0.02	0.02	0.03	0.02	0.03	0.03	0.03
35	0.00	0.01	0.02	0.02	0.03	0.05	0.07	0.09	0.11	0.12	0.14	0.14
36	0.00	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.03	0.02	0.03
37	0.00	0.02	0.01	0.02	0.03	0.04	0.05	0.08	0.09	0.11	0.12	0.12
38	0.00	0.01	0.01	0.01	0.01	0.03	0.02	0.02	0.02	0.02	0.02	0.03
39	0.00	0.01	0.01	0.01	0.01	0.02	0.04	0.02	0.02	0.02	0.02	0.04
40	0.00	0.01	0.01	0.01	0.01	0.03	0.02	0.02	0.04	0.02	0.03	0.04
41	0.00	0.02	0.02	0.01	0.01	0.02	0.05	0.05	0.08	0.09	0.11	0.11
42	0.00	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.04	0.02	0.03	0.04
43	0.00	0.02	0.01	0.01	0.01	0.02	0.04	0.04	0.06	0.08	0.09	0.09
44	0.00	0.01	0.01	0.01	0.01	0.02	0.03	0.02	0.02	0.02	0.06	0.06
45	0.00	0.01	0.01	0.01	0.01	0.01	0.03	0.02	0.02	0.04	0.06	0.06
46	0.00	0.01	0.01	0.01	0.01	0.01	0.03	0.02	0.03	0.03	0.06	0.06
47	0.00	0.02	0.02	0.01	0.02	0.02	0.03	0.03	0.05	0.07	0.10	0.10
48	0.00	0.01	0.01	0.01	0.01	0.01	0.03	0.02	0.03	0.04	0.05	0.05
49	0.00	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.05	0.06	0.08	0.08
50	0.00	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.04	0.04	0.04	0.04
THC (%)	**0.04**	**0.60**	**0.58**	**0.62**	**0.77**	**0.87**	**0.93**	**0.98**	**1.03**	**1.07**	**1.11**	

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Interharmonics

Power bin in % of P_n	0	10	20	30	40	50	60	70	80	90	100	max.
f in Hz						I_f in % of I_n						
75	0.01	0.06	0.06	0.06	0.09	0.10	0.08	0.08	0.09	0.08	0.14	0.14
125	0.01	0.04	0.04	0.04	0.06	0.06	0.05	0.05	0.05	0.05	0.08	0.08
175	0.01	0.04	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.03	0.05	0.05
225	0.00	0.03	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.04	0.04
275	0.00	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.04
325	0.00	0.03	0.03	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.04
375	0.00	0.04	0.03	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04
425	0.00	0.03	0.03	0.02	0.03	0.03	0.02	0.03	0.03	0.03	0.03	0.03
475	0.00	0.02	0.03	0.02	0.02	0.03	0.02	0.03	0.03	0.03	0.03	0.03
525	0.00	0.02	0.03	0.03	0.02	0.03	0.02	0.03	0.03	0.03	0.03	0.03
575	0.00	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03
625	0.00	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03
675	0.00	0.03	0.02	0.03	0.03	0.02	0.03	0.03	0.03	0.03	0.03	0.03
725	0.00	0.04	0.03	0.03	0.03	0.02	0.03	0.03	0.03	0.03	0.03	0.04
775	0.00	0.04	0.02	0.03	0.03	0.02	0.03	0.03	0.03	0.03	0.03	0.04
825	0.00	0.07	0.05	0.02	0.03	0.02	0.03	0.03	0.03	0.03	0.03	0.07
875	0.00	0.04	0.03	0.02	0.02	0.02	0.03	0.03	0.02	0.03	0.03	0.04
925	0.00	0.07	0.05	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.03	0.07
975	0.00	0.02	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.04
1025	0.00	0.02	0.07	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.03	0.07
1075	0.00	0.01	0.06	0.05	0.02	0.02	0.02	0.03	0.02	0.02	0.03	0.06
1125	0.00	0.02	0.07	0.05	0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.07
1175	0.00	0.02	0.06	0.06	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.06
1225	0.00	0.02	0.06	0.06	0.07	0.02	0.02	0.02	0.03	0.02	0.03	0.07
1275	0.00	0.02	0.02	0.06	0.04	0.02	0.02	0.02	0.03	0.02	0.03	0.06
1325	0.00	0.02	0.01	0.06	0.07	0.02	0.02	0.02	0.03	0.03	0.03	0.07
1375	0.00	0.01	0.02	0.02	0.04	0.03	0.02	0.02	0.03	0.03	0.03	0.04
1425	0.00	0.02	0.02	0.02	0.03	0.02	0.03	0.02	0.02	0.03	0.03	0.03
1475	0.00	0.02	0.02	0.02	0.04	0.03	0.02	0.02	0.02	0.03	0.03	0.04
1525	0.00	0.02	0.02	0.02	0.05	0.03	0.03	0.02	0.03	0.04	0.04	0.05
1575	0.00	0.02	0.02	0.02	0.04	0.07	0.03	0.03	0.03	0.04	0.04	0.07
1625	0.00	0.02	0.01	0.01	0.05	0.04	0.03	0.03	0.03	0.04	0.04	0.05
1675	0.00	0.02	0.01	0.01	0.02	0.07	0.03	0.03	0.03	0.03	0.04	0.07
1725	0.00	0.02	0.02	0.01	0.02	0.04	0.03	0.03	0.03	0.03	0.04	0.04
1775	0.00	0.02	0.01	0.01	0.02	0.04	0.04	0.03	0.03	0.04	0.03	0.04
1825	0.00	0.02	0.02	0.01	0.02	0.03	0.02	0.03	0.03	0.04	0.04	0.04
1875	0.00	0.01	0.01	0.01	0.02	0.04	0.03	0.03	0.03	0.04	0.04	0.04
1925	0.00	0.01	0.01	0.01	0.02	0.05	0.02	0.03	0.03	0.03	0.04	0.05
1975	0.00	0.01	0.01	0.01	0.02	0.04	0.05	0.02	0.04	0.03	0.04	0.01

DNV·GL

Higher frequencies components

Power bin in % of P_n	0	10	20	30	40	50	60	70	80	90	100	max.
f in kHz						I_f in % of I_n						
2.1	0.00	0.04	0.04	0.03	0.04	0.07	0.12	0.08	0.14	0.13	0.16	0.16
2.3	0.00	0.03	0.04	0.04	0.04	0.05	0.10	0.09	0.10	0.14	0.20	0.20
2.5	0.00	0.03	0.03	0.04	0.04	0.05	0.05	0.11	0.12	0.15	0.17	0.17
2.7	0.00	0.05	0.04	0.05	0.06	0.07	0.06	0.15	0.10	0.20	0.19	0.20
2.9	0.00	0.03	0.03	0.04	0.04	0.04	0.05	0.09	0.10	0.12	0.13	0.13
3.1	0.00	0.03	0.03	0.03	0.03	0.03	0.08	0.07	0.07	0.09	0.13	0.13
3.3	0.00	0.03	0.03	0.03	0.03	0.04	0.07	0.04	0.07	0.05	0.06	0.07
3.5	0.00	0.02	0.02	0.02	0.03	0.06	0.05	0.04	0.04	0.05	0.05	0.06
3.7	0.00	0.03	0.03	0.03	0.04	0.05	0.04	0.04	0.04	0.05	0.05	0.05
3.9	0.00	0.03	0.03	0.03	0.05	0.04	0.03	0.04	0.04	0.04	0.05	0.05
4.1	0.01	0.02	0.03	0.04	0.04	0.03	0.02	0.03	0.03	0.04	0.04	0.04
4.3	0.00	0.02	0.04	0.04	0.03	0.03	0.02	0.03	0.03	0.04	0.04	0.04
4.5	0.00	0.02	0.03	0.03	0.02	0.03	0.03	0.03	0.04	0.04	0.04	0.04
4.7	0.00	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03
4.9	0.00	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.03	0.03	0.03	0.03
5.1	0.00	0.01	0.02	0.02	0.01	0.02	0.02	0.03	0.03	0.03	0.04	0.04
5.3	0.00	0.01	0.01	0.02	0.01	0.01	0.02	0.02	0.02	0.03	0.03	0.03
5.5	0.00	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02
5.7	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.03	0.03
5.9	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02
6.1	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02
6.3	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02
6.5	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
6.7	0.00	0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01
6.9	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
7.1	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
7.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
7.5	0.01	0.00	0.01	0.01	0.00	0.00	0.01	0.01	0.00	0.01	0.01	0.01
7.7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7.9	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
8.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01
8.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8.7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00

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About DNV GL

Driven by our purpose of safeguarding life, property and the environment, DNV GL enables organizations to advance the safety and sustainability of their business. We provide classification and technical assurance along with software and independent expert advisory services to the maritime, oil & gas and energy industries. We also provide certification services to customers across a wide range of industries. Operating in more than 100 countries, our professionals are dedicated to helping our customers make the world safer, smarter and greener.