SOFAR [25-50]KTLX-G3:
SOFAR 25KTLX-G3, SOFAR 30KTLX-G3, SOFAR 33KTLX-G3, SOFAR 36KTLX-G3, SOFAR 40KTLX-G3, SOFAR 45KTLX-G3, SOFAR 50KTLX-G3

Certification Report Network Code Requirements for a PGU of Type A-B-C-D - Poland

Shenzhen SOFARSOLAR Co., Ltd.

Report No.: CR-GCC-DNV-SE-0124-08777-A072-1
Date: 2023-06-12

Project name:	SOFAR [25-50]KTLX-G3: SOFAR 25KTLX-G3, SOFAR 30KTLX-G3, SOFAR 33KTLX-G3, SOFAR 36KTLX-G3, SOFAR 40KTLX-G3, SOFAR 45KTLX-G3, SOFAR 50KTLX-G3	DNV Energy Systems Renewables Certification DNV Renewables Certification GmhH Brooktorkai 18 20457 Hamburg Germany Tel.: +49 40 36149-0
Report title:	Certification Report Network Code Requirements for a PGU of Type A-B-C-D - Poland	
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Objective: Verification of network code compliance of the SOFARSOLAR solar inverter SOFAR 25KTLX-G3, SOFAR 30KTLX-G3, SOFAR 33KTLX-G3, SOFAR 36KTLX-G3, SOFAR 40KTLX-G3, SOFAR 45KTLX-G3, SOFAR 50KTLX-G3

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1 EXECUTIVE SUMMARY

The purpose of this certification report is the documentation of the network code compliance assessment of the generating units: SOFAR 25KTLX-G3, SOFAR 30KTLX-G3, SOFAR 33KTLX-G3, SOFAR 36KTLX-G3, SOFAR 40KTLX-G3, SOFAR 45KTLX-G3, SOFAR 50KTLX-G3 , which are part of the SOFAR [25-50]KTLX-G3 inverter family of SOFARSOLAR, as listed in section 4.2 of this certification report.

The assessment is made based on the following provided measurement reports and statements:

- Test report: 10325019-SHA-TR-02-B, ISO17025 accredited /1/
- Manufacturer information provided by SOFARSOLAR /6/

Tests were performed on the SOFAR 50KTLX-G3 unit. The test report /1/ and the corresponding manufacturer information /6/ were assessed according to the assessment criteria of the guidelines in section 2. A transferability assessment has been made, presented in section 6, to assess how the test result for the SOFAR 50KTLX-G3 unit can be accepted for the whole SOFAR [25-50]KTLX-G3 family.

The 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 is based on the following, with the scope as specified in Section 3.

/A/ Service Specification DNV-SE-0124: Certification of Grid Code Compliance, DNV, March 2016, amended October 2021

/B/ Conditions and procedures for using certificates in the process of connecting power generating modules to power networks, Warunki i procedury wykorzystania certyfikatów w procesie przyłączenia modułów wytwarzania energii do sieci elektroenergetycznych, version 1.2, PTPiREE, dated 2021-04-28, (in the following: PTPiREE 2021-04)

/C/ Requirements of general application resulting from Commission Regulation (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators (NC RfG) – as approved by the decision of the President of the Energy Regulatory Office DRE.WOSE.7128.550.2.2018.ZJ dated January 2nd 2019, Wymogi ogólnego stosowania wynikające z Rozporządzenia Komisji (UE) 2016/631 z dnia 14 kwietnia 2016 r. ustanawiającego kodeks sieci dotyczący wymogów w zakresie przyłączenia jednostek wytwórczych do sieci (NC RfG), PSE S.A., dated 2018-12-18 zatwierdzone Decyzją Prezesa Urzędu Regulacji Energetyki DRE.WOSE.7128.550.2.2018.ZJ z dnia 2 stycznia 2019 r, (in the following: PSE 2018-12)

/D/ Commission Regulation (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators, published in the Official Journal of the European Union L112/1, THE EUROPEAN COMMISION, 27/04/2016. (in the following: NC RfG)

3 SCOPE OF ASSESSMENT

3.1 General

The assessment covers requirements applicable to Types A/B/C/D Power Park Modules (PPMs) for which Equipment Certificates are requested in the Polish certification guideline PTPIREE 2021-04 /B/, as further detailed in Section 3.2. The assessment covers both exhaustive requirements, fully defined by the NC RfG /D/, and non-exhaustive requirements, for which complementary requirement details have been collected from the national specification for Poland in PSE 2018-12 /C/.

The scope of assessment covers the following:

- The completeness of documents and measurements
- The plausibility of the documents received
- The compliance of the test conditions of the documents with those listed in section 2
- The assessment of the measurement results concerning the requirements of the documents listed in section 2

3.2 Paragraphs of NC RfG /D/ within scope

Table 3-1 Scope of assessment and results

Capability	NC RfG /D/	PSE 2018-12 /C/	Type A	Type B	Type C	Type D	Assessment result (**)
Frequency range	13.1(a)	13.1 (a)(i)	x	x	x	x	Compliant
Rate of Change of Frequency (RoCoF) withstand capability, df/dt	13.1 (b)	13.1 (b)	x	x	x	x	Compliant
Remote cessation of active power	13.6	13.6	x	x			Compliant
Remote control of active power	14.2	14.2 (b)		x			Compliant
Limited Frequency Sensitive Mode – over frequency (LFSM-O)	13.2 (*)	13.2 (a), (b), (f)	x	x	x	x	Compliant
Limited Frequency Sensitive Mode – under frequency (LFSM-U)	15.2 (c)	15.2 (c) (i)			x	x	Compliant
Capability to withstand voltage dips (FRT) for connection below 110 kV	14.3	14.3 (a) (i), (b)		x	x	x	Compliant
Capability to withstand voltage dips (FRT) for connection above 110 kV	16.3	16.3 (a) (i), (c)				x	Compliant
Fast fault current injection, symmetric and asymmetric faults	20.2 (b), (c), 21.3 (e)	20.2 (b), (c), 21.3 (e)		x	x	x	Compliant
Active power recovery after fault clearance	20.3	20.3 (a)		x	x	x	Compliant

(*) Article 13.2(b) only applicable for type A PPMs according to NC RfG.
(**) Please note also the corresponding conditions for compliance, as stated in section 7.

4 GENERAL INFORMATION

4.1 Schematic description of the generating unit

The SOFARSOLAR solar inverter family SOFAR [25-50]KTLX-G3, consisting of: SOFAR 25KTLX-G3, SOFAR 30KTLX-G3, SOFAR 33KTLX-G3, SOFAR 36KTLX-G3, SOFAR 40KTLX-G3, SOFAR 45KTLX-G3, SOFAR 50KTLX-G3 convert electrical energy generated by photovoltaic modules (DC) to three-phase alternating current (AC).

They run at 400 rated output voltage with a rated active power output of 25 kW to 50 kW (corresponding Max. AC power from 28 kVA to 55 kVA). All variants share the same hardware and software, except minor rating differences of some components and number of strings on the input side of the inverter. These will have no influence on the electrical behaviour tested and certified, as confirmed by the manufacturer's information /6/. The different power variants are realized via adapting the rated power in the software control. There is no further difference in the hardware or software used.

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

4.2 Technical data of main components

Technical data of the main components of the SOFAR [25-50]KTLX-G3 is given below, as provided in Manufacturer's Information /6/.

Table 4-1 General Specifications

Generating Unit	SOFAR 25KTLX-G3	SOFAR 30KTLX-G3	SOFAR 33KTLX-G3
No. of phases	3	3	3
Max. AC power	28000 VA	34000 VA	37000 VA
Rated active power	25000 W	30000 W	33000 W
Rated AC-voltage (phase to phase)	400 V	400 V	400 V
Rated frequency	50 Hz	50 Hz	50 Hz
Generating Unit	**SOFAR 36KTLX-G3**	**SOFAR 40KTLX-G3**	**SOFAR 45KTLX-G3**
No. of phases	3	3	3
Max. AC power	40000 VA	44000 VA	50000 VA
Rated active power	36000 W	40000 W	45000 W
Rated AC-voltage (phase to phase)	400 V	400 V	400 V
Rated frequency	50 Hz	50 Hz	50 Hz
Generating Unit	**SOFAR 50KTLX-G3**		
No. of phases	3		
Max. AC power	55000 VA		
Rated active power	50000 W		
Rated AC-voltage (phase to phase)	400 V		
Rated frequency	50 Hz		

Table 4-2 DC Input

Generating Unit	SOFAR 25KTLX-G3, SOFAR 30KTLX-G3, SOFAR 33KTLX-G3, SOFAR 36KTLX-G3	SOFAR 40KTLX-G3, SOFAR 45KTLX-G3, SOFAR 50KTLX-G3,
Min. MPPT voltage	180 V	180 V
Max. MPPT voltage	1000 V	1000 V
Max. DC input voltage	1100 V	1100 V
Max. DC input current	3 x 40 A	4 x 40 A

Table 4-3 Software version

Software version	V000001
Firmware version	V040511/L040001/I040022

Unit Transformer

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

Grid protection

The grid protection is not part of certification scope.

Control settings

The control interface allows for the selection of different parameter sets, via the "*Country code*" field, which provide default settings based on specific grid codes and national requirements. For this assessment the parameters set called "12" at the display interface, was assessed for the functionalities within scope of this certification. The settings are by default set to and match type D requirements, which will make them compliant also to the requirements of type A, B and C.

It should be noted that compliance can be achieved also with other parameter sets and control settings, but that changes to control settings will affect the inverter control behaviour which can thus affect compliance. It should be noted the final settings must be agreed on project level in agreement with relevant system operator.

Protection settings has not been part of the assessment. Since these could intervene with and affect the compliance of the assessed functionalities, this must be further assessed at project level.

4.3 Performed tests, test setup

The tests used for this assessment, presented in the test report /1/ were performed between 2022-03-30 and 2023-05-25 in the SOFARSOLAR lab in Shenzhen (P.R. China). The tests were initially performed according to a tailor-made test plan /2/ for type A. Afterwards, all other testing items of type A-D were performed referring test plan /11/. Both test plans were issued by DNV Renewable Certification, since there is no standard test guideline for Polish requirements. The test plan was based on the Polish Network Code requirements as presented in Section 3.

All tests were performed under ISO-17025 accreditation and they were performed on the SOFAR 50KTLX-G3 unit.

Table 4-4 Performed tests, as documented in test report /1/

Test	Test report
Frequency range	Section 3.1 of /1/
Rate of Change of Frequency (RoCoF) withstand capability, df/dt	Section 3.2 of /1/
Remote cessation of active power	Section 3.3 of /1/
Remote control of active power	Section 3.4 of /1/
Limited Frequency Sensitive Mode – over frequency (LFSM-O)	Section 3.5 of /1/
Limited Frequency Sensitive Mode – under frequency (LFSM-U)	Section 3.6 of /1/
Fault Ride Through (FRT)	Section 4 of /1/
Fast fault current injection, symmetric and asymmetric faults	Section 4 of /1/
Active power recovery after fault clearance	Section 4 of /1/

The tests were performed using a DC Power supply as a simulation of the PV module and a grid simulator as a simulation of the power grid and the transmission network. A simplified diagram of the test setup is given in Figure 4-1. The measurement data were measured at MP3 at LV level.

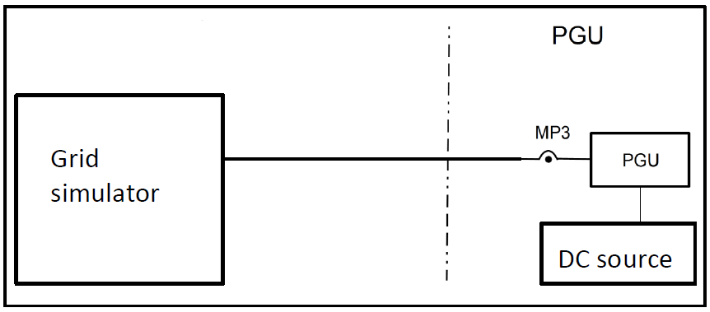

Figure 4-1 Single line diagram of the test setup

5 VERIFICATION OF NETWORK CODE COMPLIANCE

5.1 Frequency Range

5.1.1 Introduction

The frequency range requirements, as specified for Continental Europe in Article 13 item 1 (a) (i) in NC RfG /D/ and the national specification for Poland PSE 2018-12 /C/, are summarized in in Table 5-1. The same table also presents the time duration tested as specified in the test report.

5.1.2 Test setup and description

The tests were performed using a DC Power supply as a simulation of the PV module and a grid simulator as a simulation of the power grid and the transmission network.

The tests presented in the chapter 3.1 of assessed test report /1/ were performed according to a tailor made test plan /2/ basing on EN 50549-10:2021 (Draft), section 5.2.1.

The aim of this test was to confirm that the tested equipment is capable of remaining connected to the network and operate within the specified frequency ranges. The operating frequency setpoint was set to defined values, and operation was observed for at least the time specified in Table 5-1.

5.1.3 Assessment summary

Table 5-1 presents the time duration tested as specified in the test report /1/. The inverter tested did not disconnect of show signs of instability during this time.

Table 5-1 Frequency range tests: requirements and tests

Frequency range	Required time for operation	Tests performed /1/
47.5 Hz-48.5 Hz	30 min	>30 min at 47.5 Hz
48.5 Hz-49.0 Hz	30 min	
49.0 Hz-51.0 Hz	Unlimited	
51.0 Hz-51.5 Hz	30 min	>30 min at 51.5 Hz

The test for 48.5-49 Hz range was not performed, since worse case was tested (47.5 Hz) and the required time for operation is the same. The test for 49-51 Hz was not performed since this is a normal operating range and all other tests were performed at this frequency range.

Based on the performed tests, it can be confirmed that the frequency range capability of the inverter is in compliance with stated requirements.

5.2 Rate of Change of Frequency (RoCoF) withstand capability

5.2.1 Introduction

Regarding RoCoF withstand capability, as specified in Article 13 item 1 (b) of NC RfG /D/, together with the national specification for Poland in PSE 2018-12 /C/, the Power Generating Unit (PGU) must have the capability of remaining connected to the network and operate at the rate of change of frequency up to:

$$\left|\frac{df_{max}}{dt}\right| = 2.0 \left|\frac{Hz}{s}\right|$$

where this value would be measured as an average value within a shiftable measurement window with a length of 500ms.

The requirement $\left|\frac{df_{max}}{dt}\right| = 2.0 \left|\frac{Hz}{s}\right|$ constitutes a minimum requirement. If the applied technology allows connection to the network and operation at a higher rate of change of frequency, limiting the operation of the PGU to the value defined above or lower is not allowed, unless it results from the arranged rate-of-change-of-frequency-type loss of mains protection.

5.2.2 Test setup and description

The tests were performed using a DC Power supply as a simulation of the PV module and a grid simulator as a simulation of the power grid and the transmission network.

The tests presented in chapter 3.2 of test report /1/ for RoCoF withstand capability were performed according to tailor made test plan /2/ basing on EN 50549-10:2021 (Draft), section 5.3.1. The tests were carried out as a series of four frequency steps as presented on Figure 5-1, each performed with at least 2 Hz/s rate of change of frequency.

5.2.3 Assessment summary

Tests of the RoCoF withstand capability, reported in test report /1/, confirm the capability to ride through frequency drift between 49 - 51 Hz, with a gradient of at least ±2 Hz/s. Figure 5-1 show the inverter riding through frequency gradients up to +2.995 / -2.992 Hz/s, while remaining in stable operation. It can be confirmed that RoCoF withstand capability of the inverter is in compliance with stated requirements.

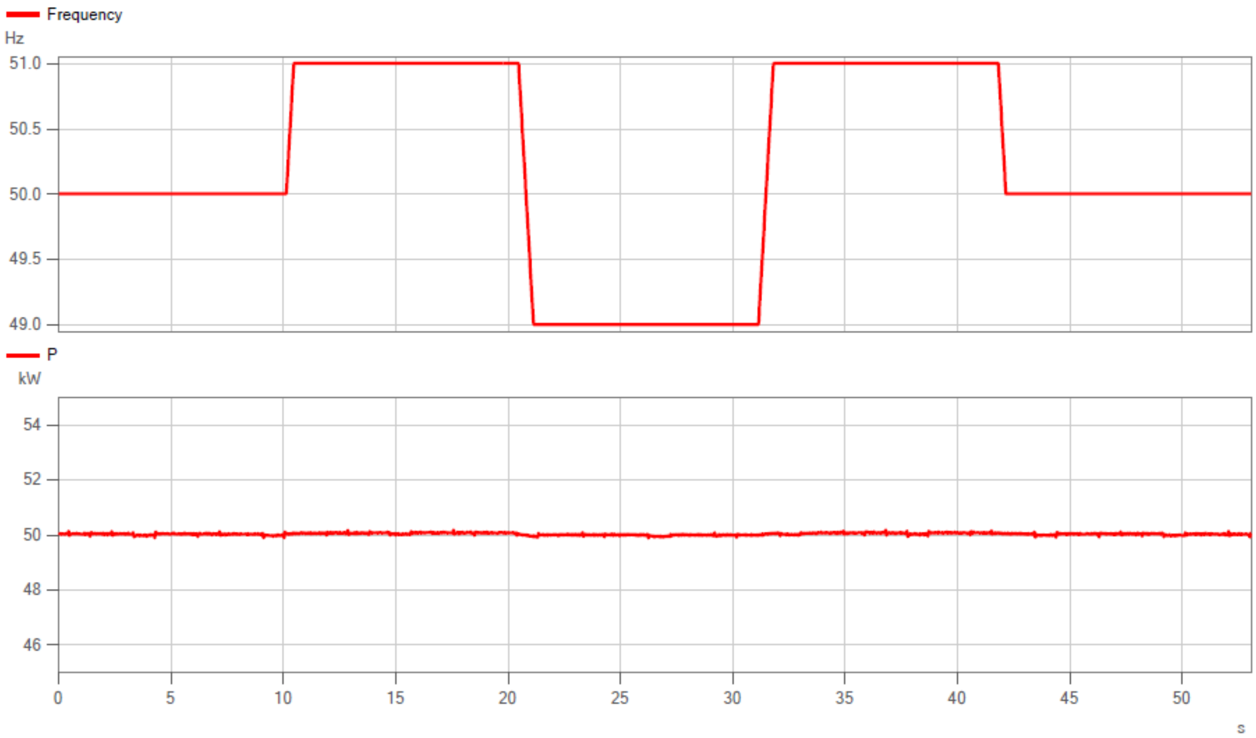

Figure 5-1 RoCoF withstand test results, showing grid frequency (upper plot) and output power (lower plot) /1/

5.3 Cessation of Active Power

5.3.1 Introduction

General requirements relating to Cessation of Active Power are defined by Article 13 item 6 of NC RfG /D/. Further specification for Poland is added by Article 13 item 6 of PSE 2018-12 /C/. The unit shall be equipped with a logic interface (input port) in order to cease active power output within five seconds following an instruction being received at the input port.

It is required that PGU is adapted to remote control of the facility by a relevant system operator. Telecommunication standards shall be determined by a relevant system operator. The relevant system operator shall also have the right to specify requirements for equipment to make this facility operable remotely.

As no specific communication standards have been stated in the assessment criteria used for this certification, listed in section 13 (6) of the PSE 2018-12 /C/, the compliance to any telecommunication standards must be further assessed at project level.

5.3.2 Test setup and description

The tests were performed using a DC Power supply as a simulation of the PV module and a grid simulator as a simulation of the power grid and the transmission network.

The tests presented in chapter 3.3 of test report /1/ for cessation of active power were performed according to tailor made test plan /2/. Inverter was operated remotely to validate its capability to cease active power within 5 seconds. To achieve remote control, a RS485 (Modbus) input of the inverter was used. The signal for cessation of active power was then given via PC. The time period was measured following the cessation command being received till the active power was reduced to zero.

5.3.3 Assessment summary

The test result, further presented in test report /1/, show that the inverter is capable of reducing the active power within 1.063 s after reception of remote shutdown signal to cease active power.

During testing, the external signal was created using a dedicated software, and it was transferred remotely to the inverter using a RS485 (Modbus) input. As confirmed by the manufacturer /6/, there is additional possibility to use digital IO to achieve a remote cessation of active power.

The function and delay time must finally be ensured at project level, considering both local communication standards and the full communication line between central control and inverter. Please see corresponding condition in section 7. As far as can be assessed at unit level based on the specifications made in PSE 2018-12, the performed tests prove that the inverter can comply with the requirements.

5.4 Remote Control of Active Power

5.4.1 Introduction

General requirements relating to remote control of active power are defined by Article 14 item 2 b) of NC RfG /D/. Further specification for Poland is added by Article 14 item 2 of PSE 2018-12 /C/. The unit shall be equipped with a logic interface (input port) in order to control active power output following an instruction being received at the input port.

It is required that PGU has the capability of remote control by a relevant system operator. The reduction requirement remains active also where the primary source of energy is insufficient to achieve the set limit value. In order to allow remote operation of generated active power by means of additional devices, telecommunication standards determined and published by a relevant system operator must be met.

As no specific communication standards have been stated in the assessment criteria used for this certification, listed in section 13 (6) of the PSE 2018-12 /C/, the compliance to any telecommunication standards must be further assessed at project level.

While there is no specific accuracy stated in Article 14 item 2 b), it can be noted that he accuracy requirement stated for type C and D PPMs in Article 15 item 2(a) of PSE 21018-12, is ≤2% of P_{SET}.

5.4.2 Test setup and description

The tests presented in section 3.4 in test report /1/ for remote control of active power were performed referring to test plan /11/ basing on FGW TG3, Rev. 25, chapter 4.1.2. To achieve remote control, a RS485 (Modbus) input of the inverter was used.

5.4.3 Assessment summary

The test result, further presented in section 3.4 of test report /1/, show that the inverter is capable to follow remote active power set-points ranging from 100 % to 0 %, as seen in Figure 5-2. The maximum measured deviation from setpoint were 1.6 % of P_{set} (at P_{set} = 10%) above the defined set-point and -0.04 % of P_{set} (at P_{set} = 90%) below the defined set-point.

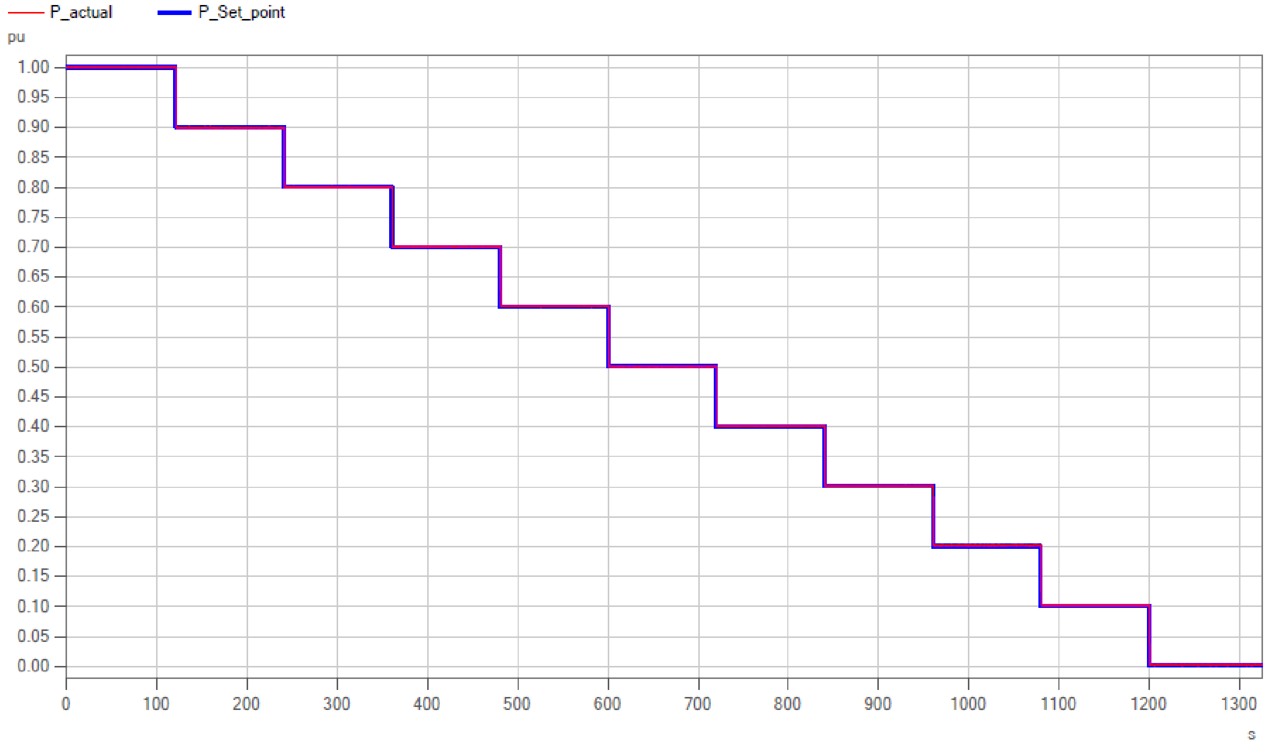

Figure 5-2 Remote control of active power, test results from test report /1/

The active power setpoint was software controlled and given into the inverter controller through RS485 (Modbus). The value of the setpoint has been controlled visually in the inverter controller and recorded as screenshot files.

The function and accuracy must finally be ensured at project level, considering both communication standards requested by relevant system operator and the full communication network of the facility. As far as can be assessed at unit level based on the specifications made in PSE 2018-12, the performed tests prove that the inverter can comply with the requirements. Please see corresponding condition in section 7.

5.5 Limited Frequency Sensitive Mode - Overfrequency (LFSM-O)

5.5.1 Introduction

The requirements for LFSM-O capabilities power-generating modules are defined by Article 13 item 2 of NC RfG /D/. Further national specification is added by corresponding article in PSE 2018-12 /C/.

The PGU shall be capable of providing active power frequency response according to the Figure 5-3 with selectable frequency threshold in the range: 50.2 Hz-50.5 Hz, with default value of, 50.2 Hz and a selectable droop settings in the range: 2-12%, with default value of 5%. A response time for activation longer than 2 second must be motivated technically, and the unit must be able to operate stably in LFSM-O mode when active power decreases down to its minimum regulating level. As further specified for Poland, the maximum capacity power (rather than the actual power before LFSM-O activation) shall be used as reference value P_{REF} to calculate the droop. Furthermore, it must be possible for the System Operator (SO) to intervene to change the setpoint value and block the LFSM-O mode.

There is a specific request in Article 13 item 2(g) of NC RfG /D/ that when LFSM-O is active, the "LFSM-O setpoint will prevail over any other active power setpoints". This is not further addressed in PSE 2018-12 /C/, but the authors PTPiREE has stated that implementations where the active power setpoint can be further decreased, but never increased, is to be accepted /9/.

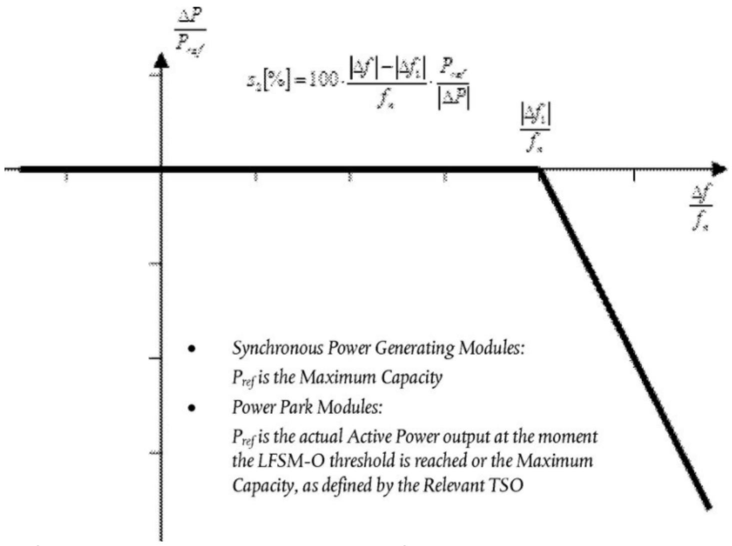

Figure 5-3 Active power frequency response capability of power-generating modules in LFSM-O. NC RfG /D/

5.5.2 Test setup and description

The tests were performed using a DC Power supply as a simulation of the PV module and a grid simulator as a simulation of the power grid and the transmission network.

The tests presented in the chapter 3.5 of assessed test report /1/ were performed as follows: for LFSM-O were performed according to tailor made test plan /2/ basing on FGW TG3 Rev. 25 /7/ For these tests the operating frequency was increased by the grid simulator causing the PGU to realise an increment in frequency, which then caused a decrement in output power due to LFSM-O functionality.

The tests were carried out for 3 different parameter sets to confirm ability for parameter changes and proper behaviour with those settings.

Table 5-2 Settings for LFSM-O tests

	Setting 1	Setting 2	Setting 3
Activation threshold	50.2 Hz	50.2 Hz	50.5 Hz
Droop	5 %	12 %	2 %

The frequency steps performed were as follows:

Table 5-3 Frequency steps for LFSM-O tests

Frequency step	Simulated grid frequency setting 1 and setting 2	Simulated grid frequency setting 3
1	50 Hz ± 0.05 Hz	50 Hz ± 0.05 Hz
2	50.1 Hz ± 0.05 Hz	50.4 Hz ± 0.05 Hz
3	50.3 Hz ± 0.05 Hz	50.6 Hz ± 0.05 Hz
4	50.9 Hz ± 0.05 Hz	50.9 Hz ± 0.05 Hz
5	51.4 Hz ± 0.05 Hz	51.4 Hz ± 0.05 Hz
6	50.3 Hz ± 0.05 Hz	50.6 Hz ± 0.05 Hz
7	50 Hz ± 0.05 Hz	50 Hz ± 0.05 Hz

5.5.3 Assessment summary

A selection of the LFSM-O test results, as provided in test report /1/, is presented in Figure 5-4 and Figure 5-6. It shows how the output power (upper plot) responds to frequency steps (lower plot) in the range of 50.0 and 51.4 Hz. As can be seen in the test result (in Figure 5-4 and Figure 5-6), the tested unit activates frequency response well within the allowable time delay of 2 seconds and it shows stable operation during the test, also at minimum regulating level (near zero active power).

As presented on Figure 5-5, the results match the defined droop characteristics within defined tolerance bands (±5% P_n as defined in FGW TG3 /7/). It was also confirmed that the inverter uses $P_{max,}$ which is the Mmaximum AC power for the variants as specified in chapter 4.2., as a reference value to calculate appropriate LFSM-O response.

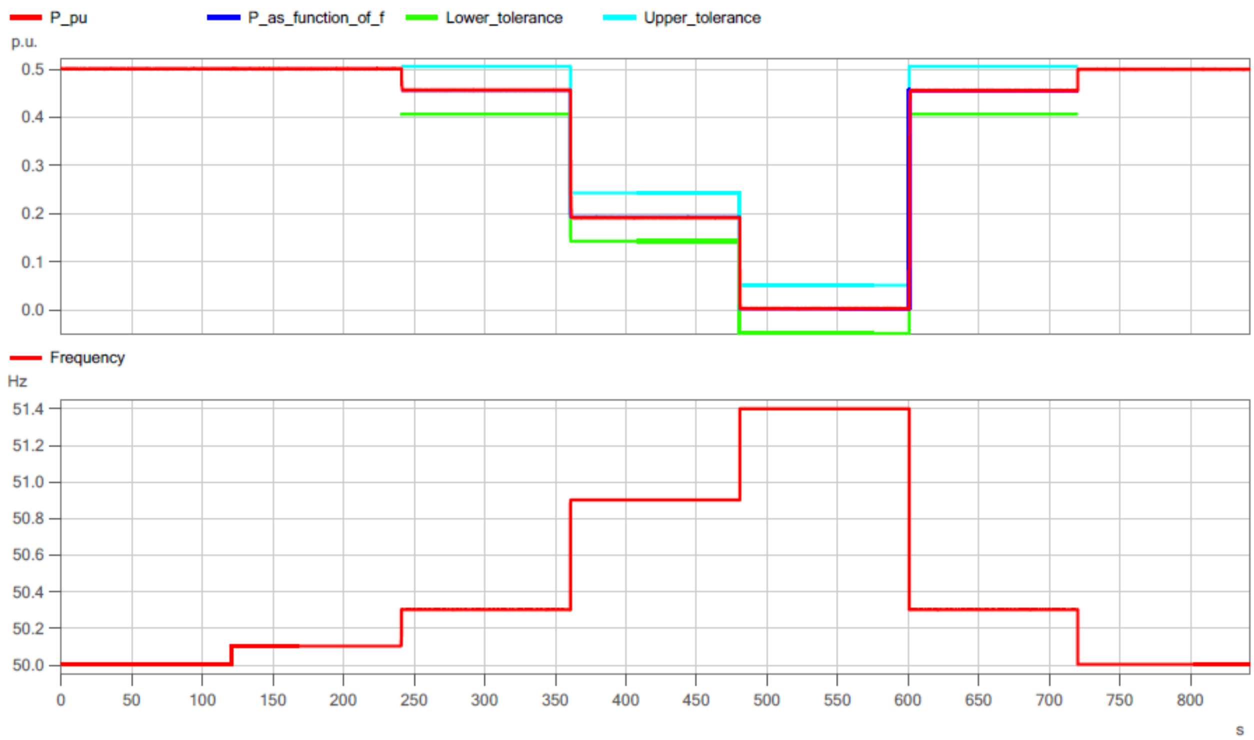

Figure 5-4 LFSM-O test results, showing input frequency steps (lower plot) and the response in active power output (upper plot), droop:5%, activation threshold: 50.2 Hz /1/

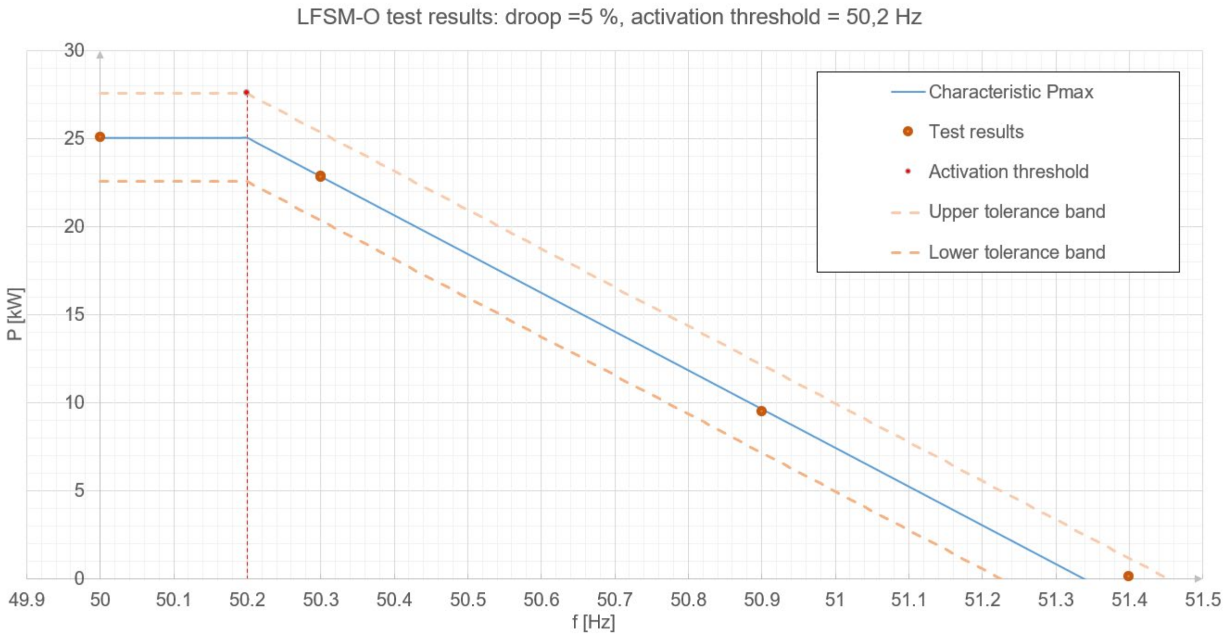

Figure 5-5 LFSM-O test result, showing test results (orange dots) compared to required droop characteristic (blue line). droop:5%, activation threshold: 50.2 Hz. Based on data from /1/

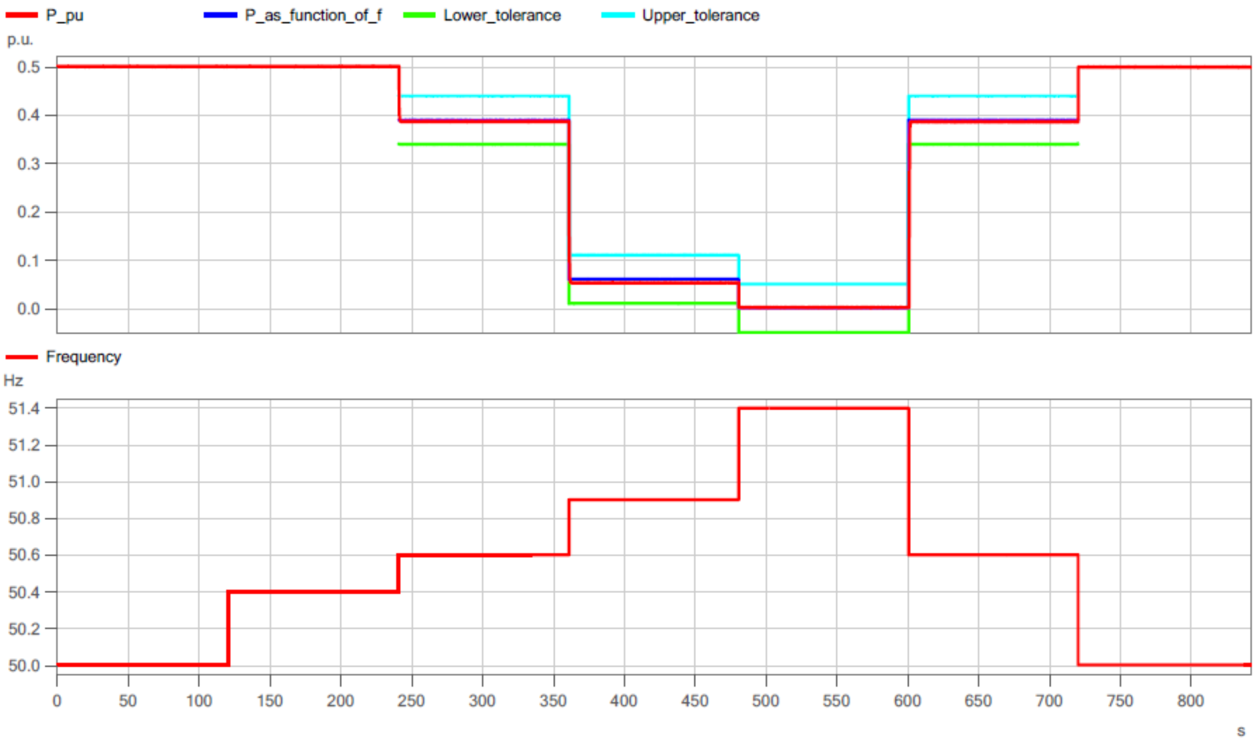

Figure 5-6 LFSM-O test results, showing input frequency steps (lower plot) and the response in active power output (upper plot), droop:2%, activation threshold: 50.5 Hz /1/

Three sets of parameters were used during the testing campaign, which confirmed possibility to set the parameters within required ranges. It should be noted that LFSM-O function is activated by setting the parameter “Over frequency discharge load register” enable, and the droop is controlled via “OverfrequencySlope” which is the percentage Pn/Hz. Below Table 5-4 shows relationship between “Droop” and “OverfrequencySlope”. Additionally, parameter “OverfrequencyStart” acts as a setting for activation threshold.

Table 5-4 Droop settings

OverfrequencySlope (1-300% Pn/Hz)	Related Power Gradient	Droops
40	40	5%
17	17	12%
100	100	2%

Furthermore, it is confirmed that the LFSM-O control has priority when active, according to manufacturer’s information /6/. Other active power control set-points can further reduce the active power output, but the value of output power cannot exceed the LFSM-O characteristic curve. This implementation is not fully in agreement with the corresponding NC RfG /D/ requirements, but is an acceptable implementation for Poland, as confirmed by PTPiREE via mail /9/.

Regarding the possibilities for remote blocking and intervention operation, as requested in Article 13 item 2(a) of PSE 2018-12, SOFARSOLAR declares via manufacturer information /6/ that it is possible to disable the function remotely via the app or RS485 port interface, which has been deemed sufficient. The local setup for remote access and communication protocols must be agreed at project level.

Based on the performed tests and provided information, compliance with stated requirements can be confirmed.

5.6 Limited Frequency Sensitive Mode - Underfrequency (LFSM-U)

5.6.1 Introduction

The requirements for LFSM-U capabilities are defined by Article 15 item 2 of NC RfG /D/. Further national specification is added by corresponding article in PSE 2018-12 /C/.

The PGU shall be capable of providing active power frequency response according to the Figure 5-7 with selectable frequency threshold in the range: 49.5 Hz-49.8 Hz, with default value of 49.8 Hz and a selectable droop setting in the range: 2-12%, with default value of 5%. A response time for activation longer than 2 second must be motivated technically, and the unit must be able to operate stably in LFSM-U mode up to its maximum capacity. As further specified for Poland, the maximum capacity power (rather than the actual power before LFSM-U activation) shall be used as reference value P_{REF} to calculate the droop. Furthermore, it must be possible for the System Operator (SO) to intervene and block the LFSM-U mode.

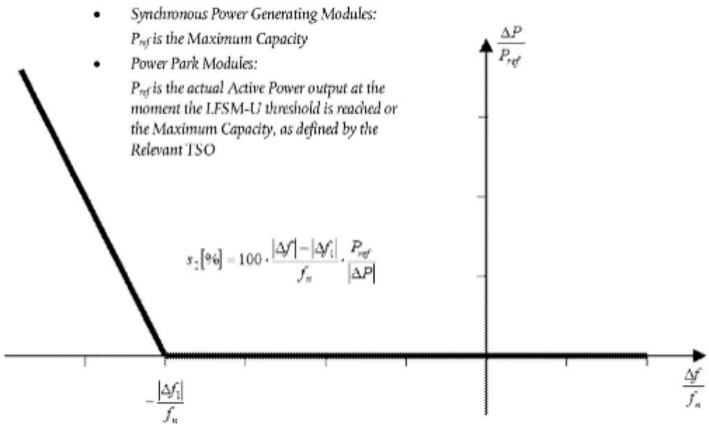

Figure 5-7 Active power frequency response capability of power-generating modules in LFSM-U. NC RfG /D/

5.6.2 Test setup and description

The tests were performed using a DC Power supply as a simulation of the PV module and a grid simulator as a simulation of the power grid and the transmission network.

The tests presented in the chapter 3.6 of assessed test report /1/ were performed as follows: for LFSM-U were performed referring to test plan /11/ basing on FGW TG3 Rev. 25 /7/. For these tests the operating frequency was decreased by the grid simulator causing the PGU to realise a decrement in frequency, which then caused an increment in output power due to LFSM-U functionality.

The tests were carried out for 3 different parameter sets to confirm ability for parameter changes and proper behaviour with those settings.

Table 5-5 Settings for LFSM-U tests

	Setting 1	Setting 2	Setting 3
Activation threshold	49.8	49.8	49.5
Droop	5 %	12 %	2 %

The frequency steps performed were as follows:

Table 5-6 Frequency steps for LFSM-U tests

Frequency step	Simulated grid frequency setting 1 and setting 2	Simulated grid frequency setting 3
1	50 Hz ± 0.05 Hz	50 Hz ± 0.05 Hz
2	49.9 Hz ± 0.05 Hz	49.6 Hz ± 0.05 Hz
3	49.7 Hz ± 0.05 Hz	49.4 Hz ± 0.05 Hz
4	47.6 Hz ± 0.05 Hz	47.6 Hz ± 0.05 Hz
5	48.7 Hz ± 0.05 Hz	48.7 Hz ± 0.05 Hz
6	50 Hz ± 0.05 Hz	50 Hz ± 0.05 Hz

5.6.3 Assessment summary

A selection of the LFSM-U test results, as provided in test report /1/, is presented in Figure 5-8. It shows how the output power (upper plot) responds to frequency steps (lower plot) in the range of 50.0 and 47.6 Hz. As can be seen, the tested unit activates frequency response well within the allowable time delay of 2 seconds and it shows stable operation during the test, also at maximum regulating level (near maximum active power)

As presented on Figure 5-9, the results match the defined droop characteristics within defined tolerance bands (±5% P_n as defined in FGW TG3 /7/). It was also confirmed that the inverter uses P_{max} as a reference value to calculate appropriate LFSM-U response. Maximum active power capacity of the variants is summarized in chapter 4.2.

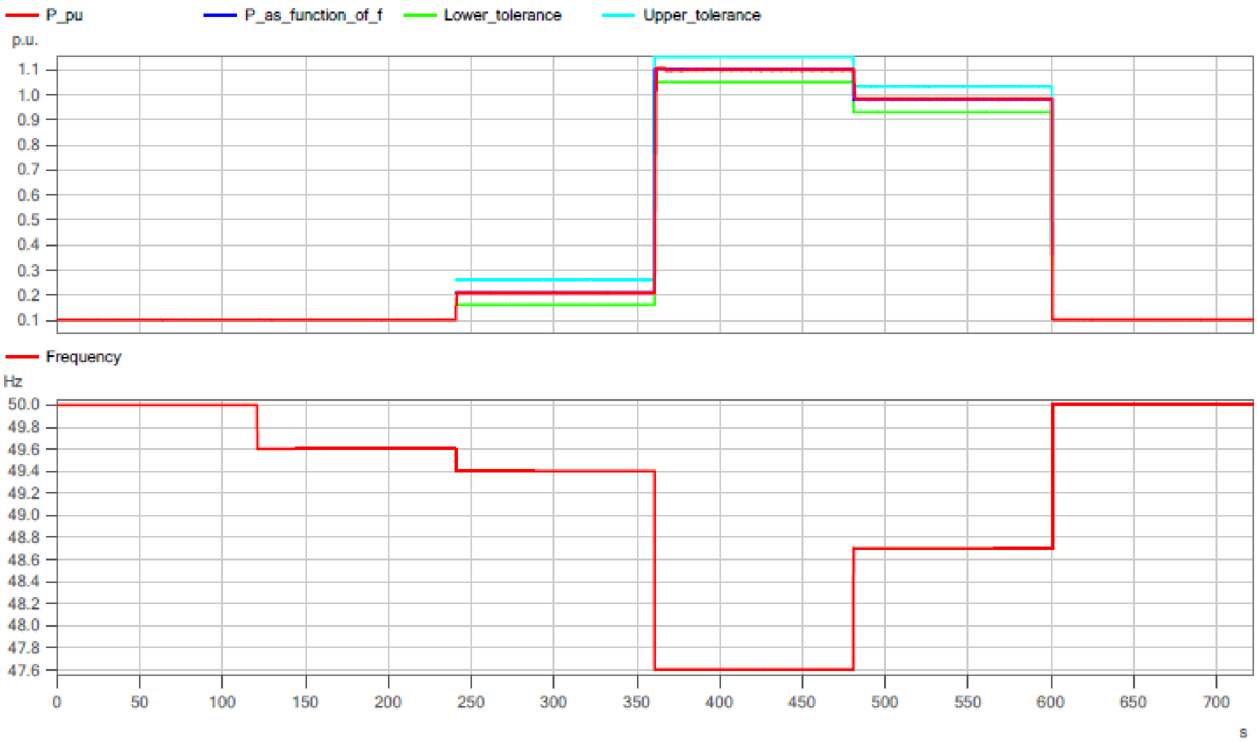

Figure 5-8 LFSM-U test results, showing input frequency steps (lower plot) and the response in active power output (upper plot), droop: 2%, activation threshold: 49.5 Hz /1/

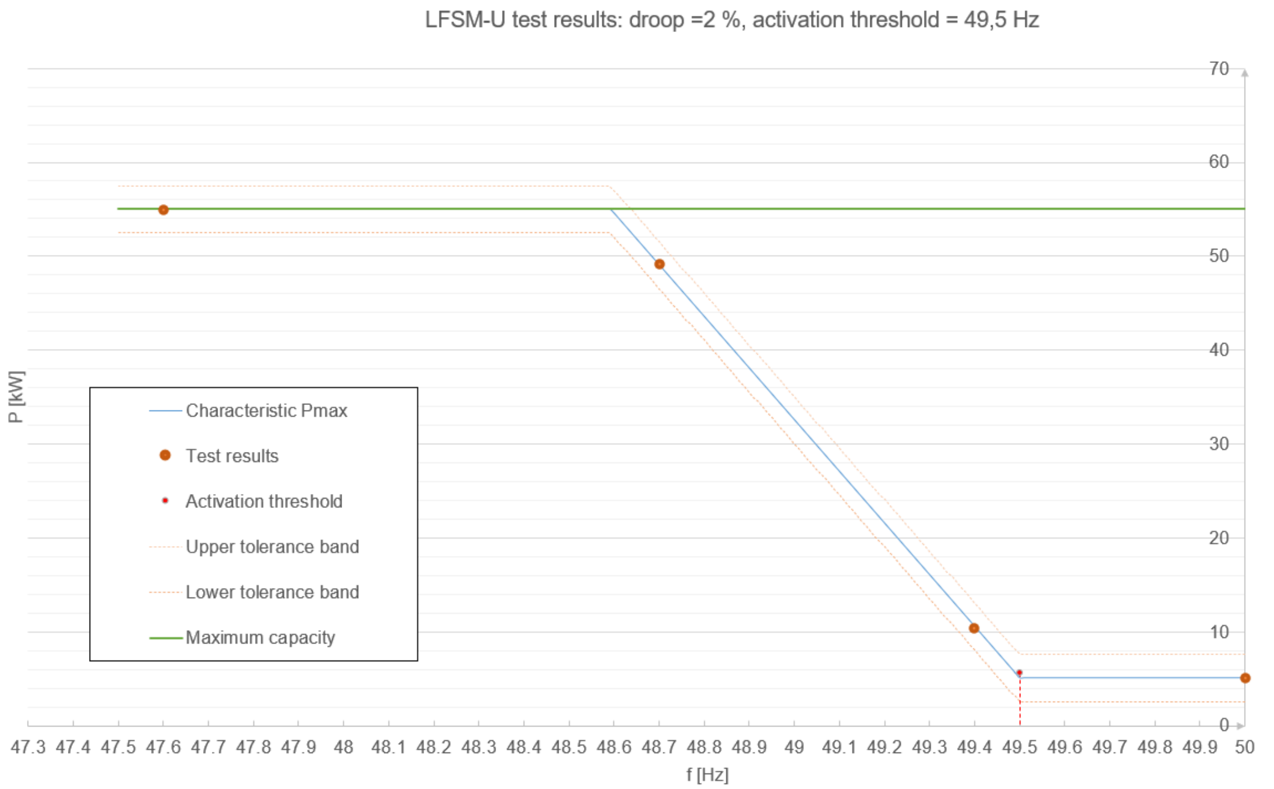

Figure 5-9 LFSM-U test result, showing test results (orange dots) compared to required droop characteristic (blue line). droop:2%, activation threshold: 49.5 Hz. Based on data from /1/

Three sets of parameters were used during the testing campaign, which confirmed possibility to set the parameters within required ranges. It should be noted that LFSM-U function is activated by setting the parameter “Under frequency charging load register” enable, and the droop is controlled via “UnderfrequencySlope” which is the percentage Pn/Hz. Below Table 5-7 shows relationship between “Droop” and “UnderfrequencySlope”. Additionally, parameter “UnderfrequencyStart” acts as a setting for activation threshold.

Table 5-7 Droop settings

UnderfrequencySlope (1-300%)	Related Power Gradient	Droops
40	40	5%
17	17	12%
100	100	2%

Furthermore, it is confirmed that the LFSM-U control has priority when active, other active power control set-points can’t influence the output, according to manufacturer information /6/.

Regarding the possibilities for remote blocking operation, as requested in Article 15 item 2(c)(i) of PSE 2018-12, SOFARSOLAR declares via manufacturer information /6/ that it is possible to disable the function remotely via the app or RS485 port interface, which has been deemed sufficient. The local setup for remote access and communication protocols must be agreed at project level.

Based on the performed tests and provided information, compliance with stated requirements can be confirmed.

5.7 Fault Ride Through

5.7.1 Introduction

The general requirements relating to Fault Ride Through (FRT) capabilities for type D PGUs are defined by Article 16.3 in NC RfG /D/. Further specifications for Poland are provided by Article 16 item 3(a) (i) and (c) of PSE 2018-12 /C/, including specification of the FRT curve provided in Figure 5-10. Separate and less stringent requirements are provided for type B PGUs in Article 14.3 of /D/ and Article 14 item 3(a) (i) and (b) in /C/, as also seen in Figure 5-10.

It is required that the PGU stays connected and stable for the area defined above the stated FRT curve to ensure stable recovery of the power system during faults.

5.7.2 Test setup and description

Tests were performed following a test plan provided by DNV /11/, which in turn follows the standards DNV-ST-0125 and IEC 61400-21-1:2019. The tests are summarized in Table 5-8.

The tests were performed using a DC Power supply as a simulation of the PV module and a grid simulator as a simulation of the power grid. The test methodology follows FGW TG3 Rev. 25 /7/.

Table 5-8 Performed FRT tests /1/

Test no.	Repeat test no.	Fault Type (3/2 phase)	Remaining voltage in %	Duration in ms	Active power output in p.u.	K-factor	Special settings	Active current recovery (≤5s)
55	56	3	3	340	>0.9	2	-	0.067
19	20	3	3	340	0.1 – 0.3	0	-	0.056
21	22	2	3	340	>0.9	2	-	0.066
23	24	2	3	340	0.1 – 0.3	2	-	0.462
57	58	3	20	900	>0.9	2	-	0.067
27	28	3	20	900	0.1 – 0.3	0	max.cap. *)	0.055
29	30	2	20	900	>0.9	2	-	0.067
31	32	2	20	900	0.1 – 0.3	2	-	0.462
33	34	3	50	1760	>0.9	2	-	0.068
35	36	3	50	1760	0.1 – 0.3	3	max.ind.*)	0.464
37	38	2	50	1760	>0.9	3	fault phase shift to AC**)	0.786
39	40	2	50	1760	0.1 – 0.3	2	-	0.051
41	42	2	50	3017***)	>0.5	2	until cut off***)	N/A
43	44	3	70	2280	>0.9	2	-	0.066
45	46	3	70	2280	0.1 – 0.3	2	max.cap. *)	0.461
47	48	3	70	2280	>0.1	4	max.ind. *)	0.463
49	50	2	70	2280	>0.9	2	max.cap. *)	0.069
51	52	2	70	2280	>0.1	4	-	0.051
53	54	3	87	10000	>0.9	2	-	0.066

**) These tests were carried out at maximum capacitive and inductive pre-fault reactive power, leading to a limitation on the active power for the full load cases.*
***) Different phase order instead of a short circuit between default phase B and C, between A and C was tested here.*
****) The value lists here is cut off time instead of fault duration time.*

5.7.3 Assessment

Figure 5-10 below provides an overview of the tests performed as documented in sections 4 in test report /1/ together with the FRT curve required in Poland.

As further detailed in Table 5-8, tests were performed for 3-phase and 2-phase faults at both full and partial power. The inverter managed to ride through all faults without disconnecting or showing unstable behavior. The inverter was also tested at 50 % voltage until cut-off (at 3.017 s). Tests were also performed to ensure a correct fault trigger on different phases. As proven by testing, the inverter can ride through both symmetrical and asymmetrical faults without disconnection for longer durations than what is required, as can be seen in the figure below.

The default settings of the LVRT-characteristic match the required characteristic for type D (and thus all types).

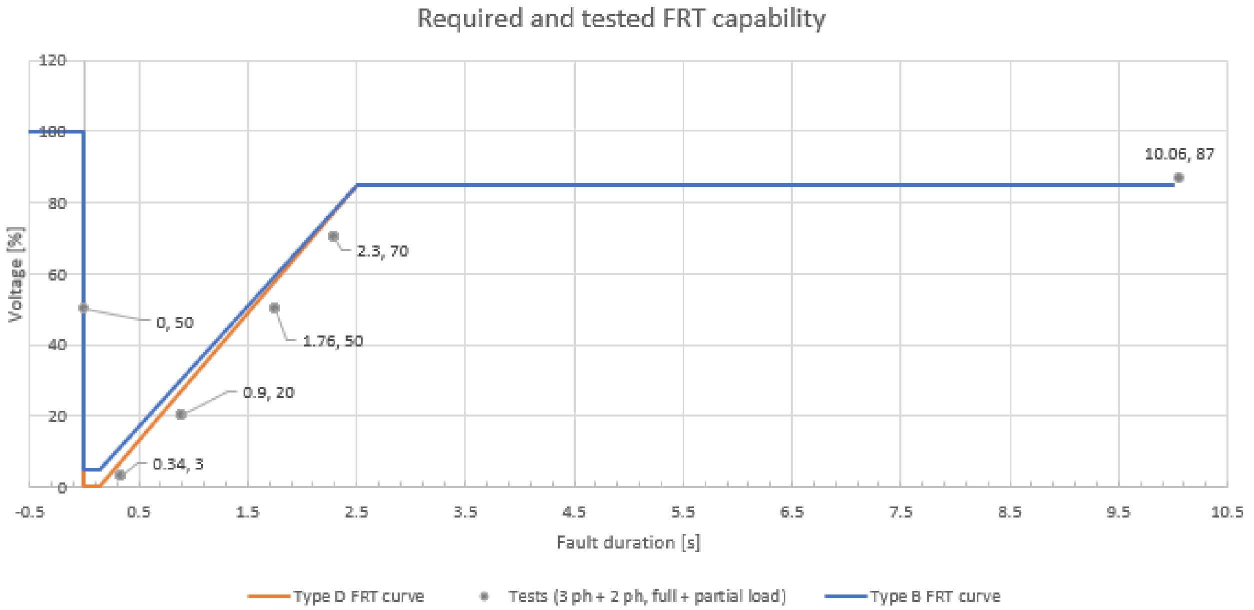

Figure 5-10 Overview of the FRT tests performed (grey dots), together with Polish LVRT requirements (blue and red line).

Based on the performed tests and provided information, compliance with requirements for Polish national network can be confirmed.

5.8 Fast fault current injection

5.8.1 Introduction

As specified in 20.2 (b) of NC RfG /D/ and further specified for Poland in corresponding articles in PSE 2018-12 /C/, the PGU should be capable of generating additional fast fault current in accordance with the static characteristics seen in Figure 5-11 during symmetrical faults, with a settable k-factor value in the range between 2 and 10. Furthermore

- 90% of additional reactive current shall be provided within 60 ms (rise time) and
- the target value should be reached with an accuracy of -10%/+20% within 100 ms (settling time).
- For faults resulting in voltage dips below 20% additional reactive current is not mandatory.

A fast fault current injection is also required during asymmetrical faults, as specified in 20.2 (c) of NC RfG /D/ and PSE 2018-12 /C/. It is stated that this should be done "while meeting the requirements with regard to static and dynamic parameters as well as symmetrical faults and taking account of limitations resulting from a non-symmetrical load". From this, following interpretation is made:

- A fast fault current shall be fed into the affected phases. An additional regulation of negative sequence reactive current is preferred even if this is not explicitly requested.
- The fast fault current shall fulfil the same requirements as for the symmetrical faults regarding the "static" characteristic (k-factor) and dynamic characteristic (rise and settling time).
- A reduction of fast fault currents is allowed in order not to cause overload due to the non-symmetrical load (e.g. exceedance of the limits of the phase current).

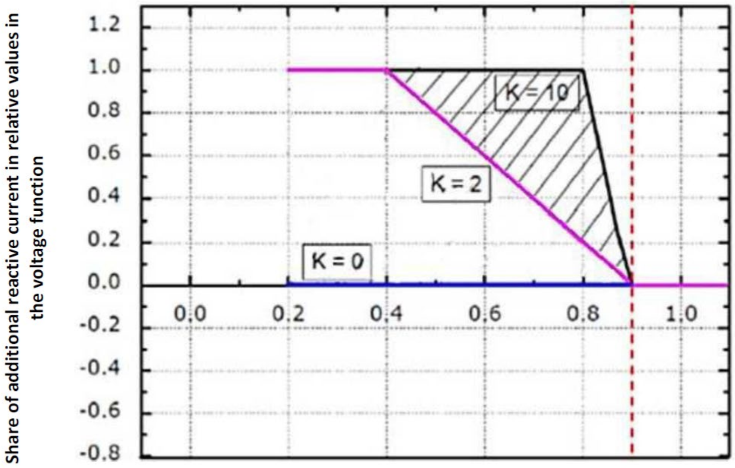

Figure 5-11: Required Reactive Current Supply during Grid Faults /C/

Furthermore, in Article 21 item 3 (e) of both NC RfG /D/ and PSE 2018-12 /C/ it is specified that reactive power contribution should have priority over active power during faults.

5.8.2 Test setup and description

See section 5.7.2.

5.8.3 Assessment

Implemented control

Regarding Figure 5-11 the reactive current response of the PGU, as documented in the Manufacture's Information /6/ is defined by the following:

The expected positive and negative sequence reactive current, $I_{q,set}^{+}$ and $I_{q,set}^{-}$, during the fault can be expressed as

(1) $$I_{q,set}^{+} = I_{q,prefault}^{+} + k(0.9 - U_{fault}^{+})$$

(2) $$I_{q,set}^{-} = I_{q,prefault}^{-} - kU_{fault}^{-}$$

In case where the sum of the positive and negative sequence reactive current reaches the current limitation I_{n}, they are scaled down proportionally to not exceed the rated current according to the following formula:

(3) $$if(\,|I_{q,set}^{+}| + |I_{q,set}^{-}| > I_n)$$

(4) $$I_{q,set,new}^{+} = \frac{I_{q,set}^{+}}{|I_{q,set}^{+}|+|I_{q,set}^{-}|}$$

(5) $$I_{q,set,new}^{-} = \frac{I_{q,set}^{-}}{|I_{q,set}^{+}|+|I_{q,set}^{-}|}$$

Where:

$I_{q,set}^{+}$ - positive sequence reactive current setpoint during fault [p.u.]

$I_{q,set}^{-}$, - negative sequence reactive current setpoint during fault [p.u.]

$I_{q,prefault}^{+}$, - positive sequence reactive current prior to fault [p.u.]

$I_{q,prefault}^{-}$ - negative sequence reactive current prior to fault [p.u.]

k - k factor, control parameter [-]

U_{fault}^{+} - positive sequence voltage during fault [p.u.]

U_{fault}^{-} - negative sequence voltage during fault [p.u.]

The k factor was set to 0, 2, 3 and 4 for the tests described in the test report /1/, as specified in the test plan /11/. The k factors for the positive and negative sequence reactive current response can be set independently of each other and have the setting range 0-10, which is confirmed by the manufacturer /6/. This range complies with the requirements of the Polish grid code. Zero-Current Mode, with no fast fault current injection, is by default disabled.

Performed tests

All the tests listed in Table 5-8 were performed twice, without disconnecting or showing unstable behaviour during or after the fault. A selection of test results can be found in the following figures. As seen in test result, fast fault current is provided well within the required 60 ms rise time and 100 ms settling time for both symmetrical and asymmetrical faults and continues for the duration of the fault. Tests were also performed to confirm that the correct behaviour regardless of which phases are faulted.

In accordance with Eq. (1) and Eq. (2), the additional reactive current is proportional to the k factor and the positive and negative sequence voltage deviation respectively. As can be seen in Figure 5-12, the provided reactive current is proportional to the voltage deviation from 0.9 Un, thus considering a 10 % dead band in positive sequence.

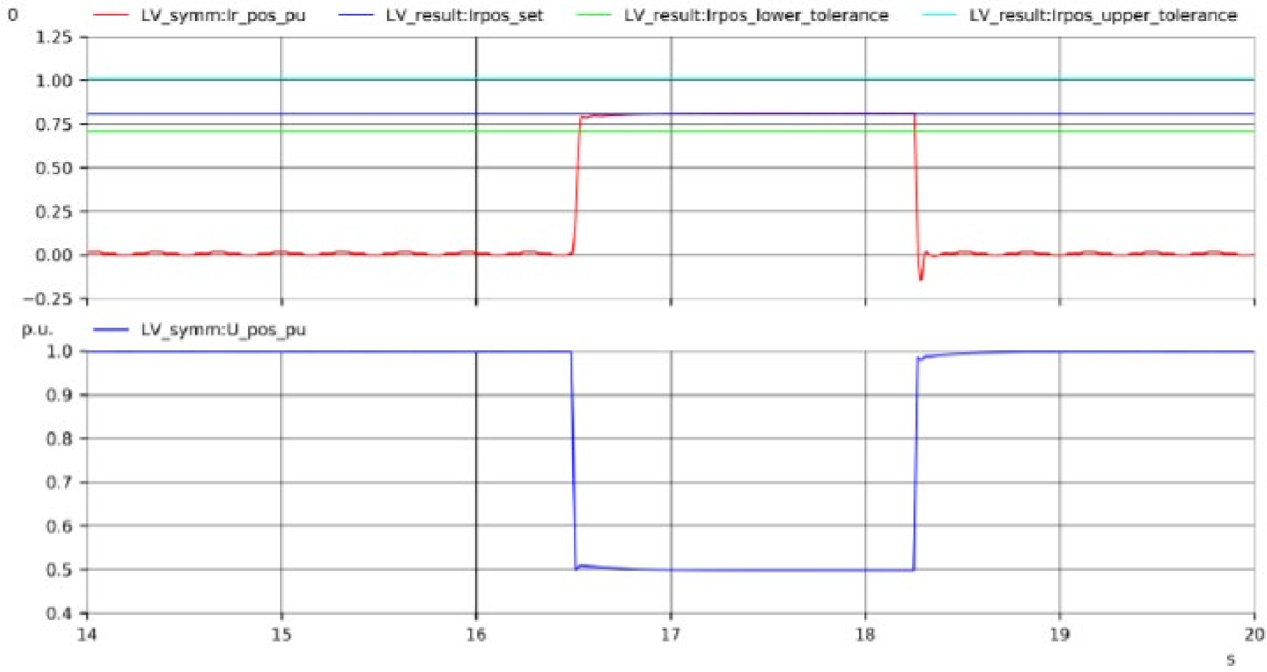

Figure 5-12 Test no. 33 (3-phase, full-load, fault voltage 50 % of Un, k=2) showing positive sequence response to a symmetrical fault. /1/

Tests performed with a pre-fault reactive power offset confirm that such an offset is correctly taken into consideration for the calculation of the additional reactive current during the faults, as can be seen in Figure 5-13 with a positive pre-fault offset. Figure 5-14 shows the negative sequence response to the same asymmetrical fault.

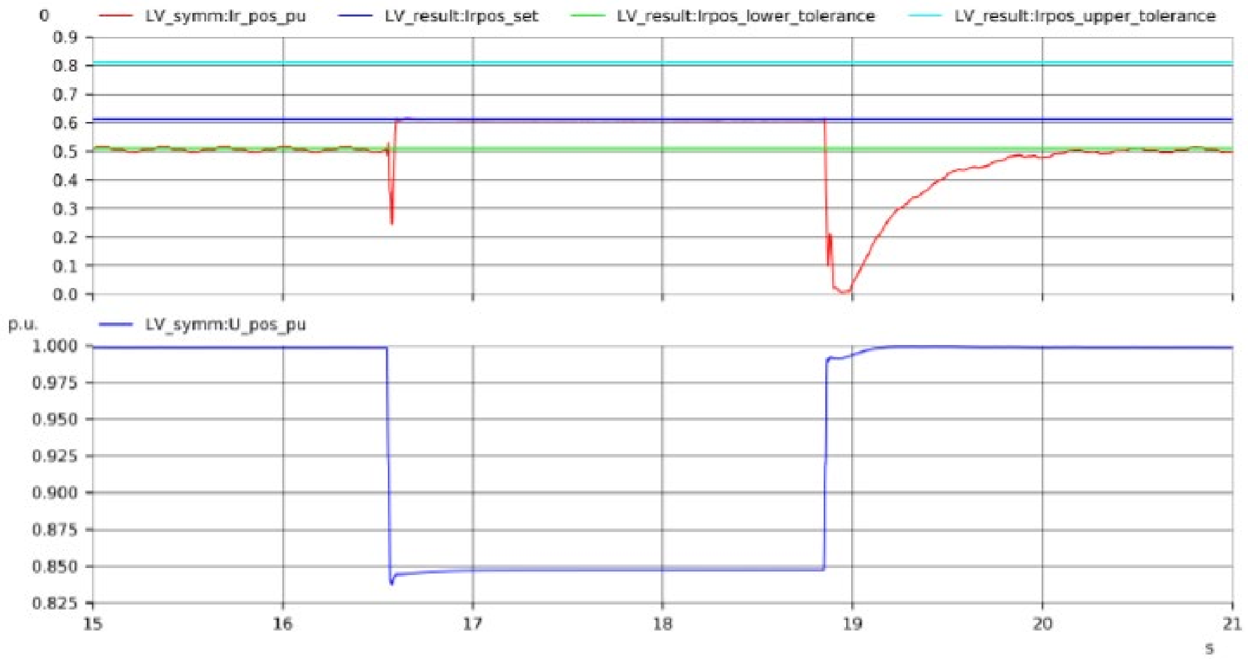

Figure 5-13 Test no. 49 (2-phase, full-load, fault voltage 70 % of Un, k=2) showing positive sequence response to an asymmetrical fault with a positive pre-fault offset in reactive current. /1/

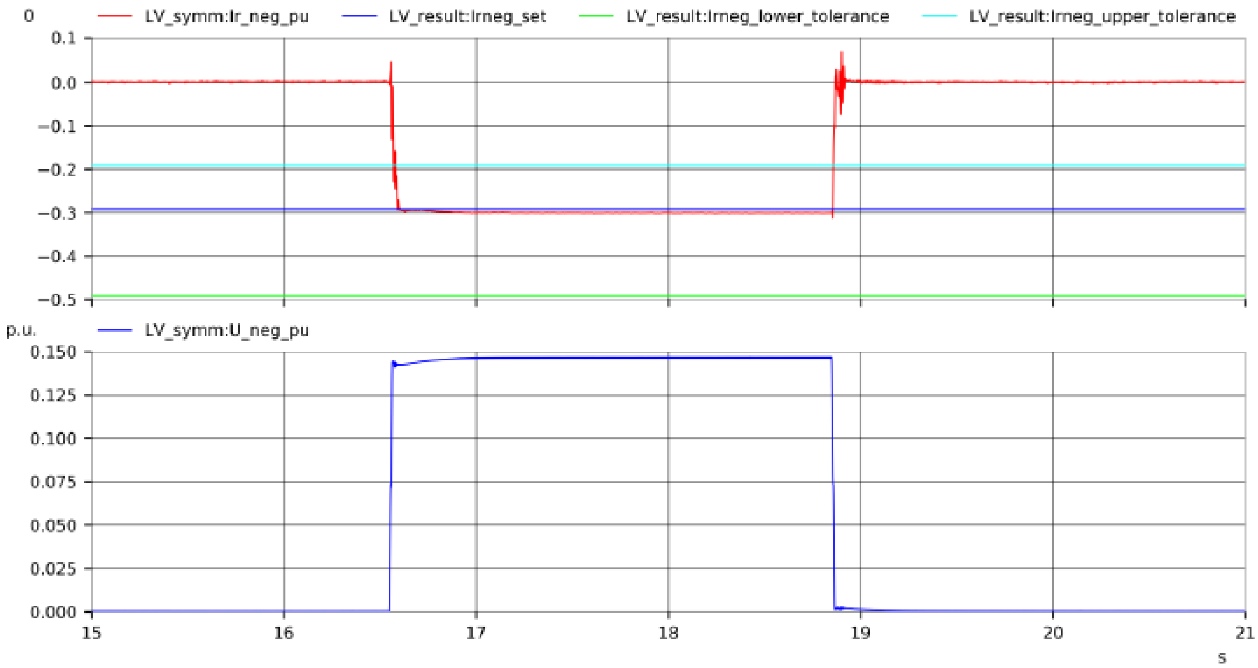

Figure 5-14 Test no. 49 (2-phase, full-load, fault voltage 70 % of Un, k=2) showing negative sequence response to an asymmetrical fault. /1/

As can be seen in Figure 5-15 and Figure 5-16 the injected power in positive and negative sequence will be scaled proportionally to limit the total amount of reactive power to 100% of I_n. Without the limitation, the positive reactive current seen in Figure 5-15 would have been 76% and negative sequence reactive current seen in Figure 5-16 would have been -95%. Instead, they are now limited to 46.4% and -54.1% respectively.

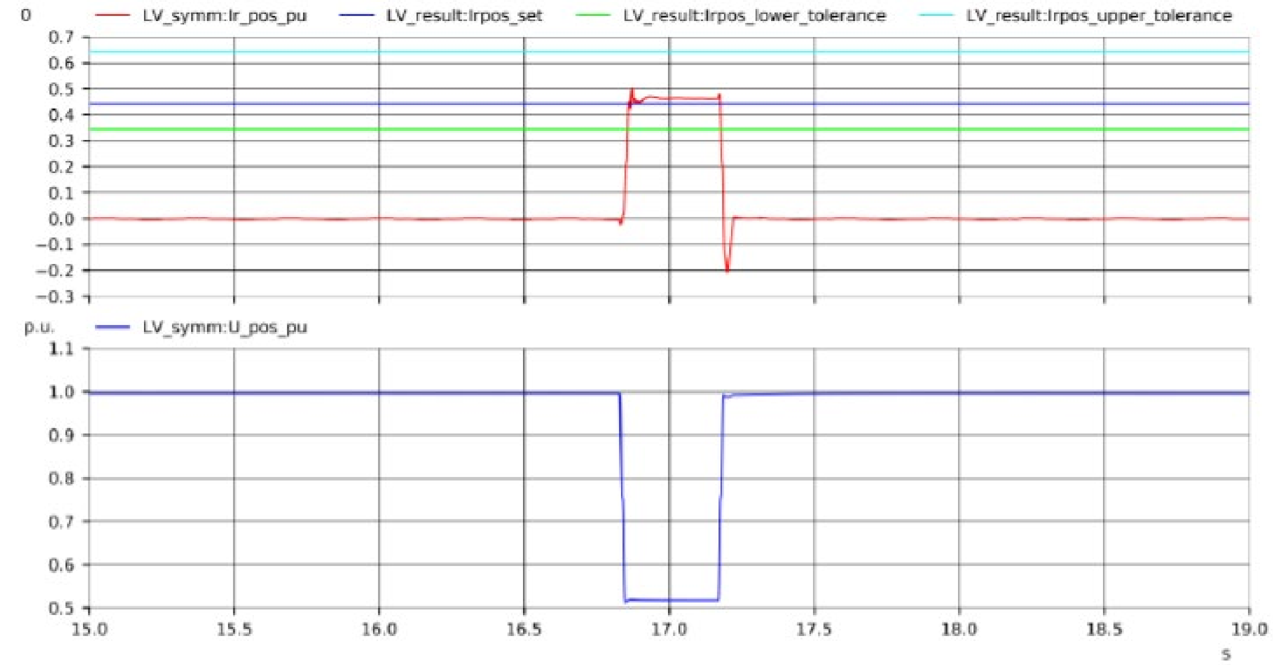

Figure 5-15 Test no. 23 (2-phase, partial-load, fault voltage 3 % of Un, k=2) showing positive sequence response to fault including current limitation. /1/

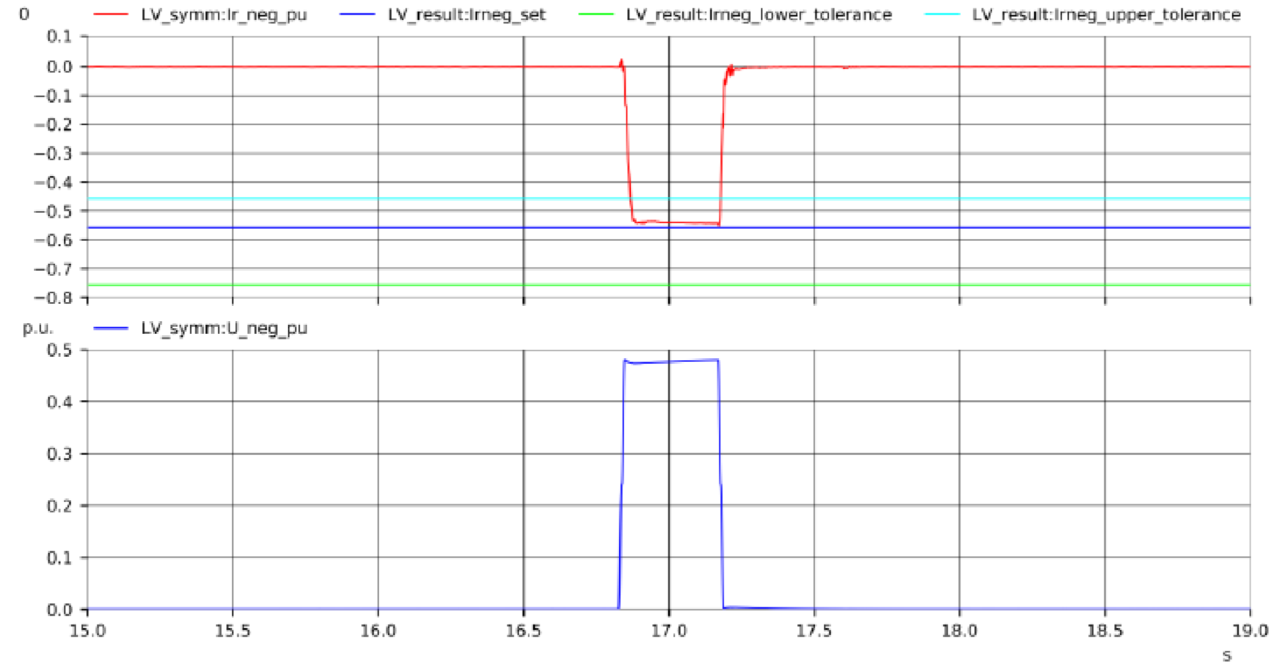

Figure 5-16 Test no. 23 (2-phase, partial-load, fault voltage 3 % of Un, k=2) showing negative sequence response to fault including current limitation. /1/

Assessment summary

Based on the performed tests and provided information, compliance with requirements for Polish national network requirements can be confirmed, provided the condition in section 7.

5.9 Active power restoration following a fault

5.9.1 Introduction

As specified in Article 20 item 3 of NC RfG /D/ and the specific requirements for Poland in Article 20 item 3 (a) in PSE 2018-12 /C/, the PGU must be able to restore the active power after fault, as counted from the removal of fault until reaching 90 % of pre-fault power, within 5 s. Undamped oscillations after the active power restoration are not allowed.

5.9.2 Test setup

See section 5.7.2.

5.9.3 Assessment

In all the assessed tests, the inverter managed to recover 90 % of active power well within 5s without showing any undamped oscillation. The test result is summarized in Table 5-8, this has been deemed compliant.

Based on the performed tests and provided information, compliance with requirements for Polish national network requirements can be confirmed.

6 TRANSFERABILITY

In order to use test result from the SOFAR 50KTLX-G3 for certification of all variants in the SOFAR [25-50]KTLX-G3 family, as listed in section 4.2, a transferability assessment has been made. The DNV service specification DNV-SE-0124 /A/ and standard DNV-ST-0125 /3/ allow for transfer of measurements based on technical equivalence, meaning that there should be no differences between the variants that could influence the measured and assessed electrical behaviour in a negative way. Regarding the allowable range for transfer of test result, the closest applicable instruction is found in German certification guideline FGW TG8 rev 9 /3/ and grid code VDE-AR N 4110 /5/, which states that result from the tested unit may be transferred to apparent power range:

$$S_{MIN} = \frac{1}{\sqrt{10}} S_{TEST} \leq S_{TEST} \leq 2 \cdot S_{TEST} = S_{MAX}$$

For the assessed family, which includes units in a range from 25 kW to 50 kW, manufacturer has submitted documentation /6/ with descriptions of the relevant similarities and differences between the variants, as further described in 4.1, and how these could influence the certified capabilities. From this, it can be confirmed that the generating units can be considered technically equivalent and that any differences between them would have no influence on the capabilities assessed.

It was accepted to test the largest variant within the family, the SOFAR 50KTLX-G3. The test result, which are presented in percentages of nominal power in the test report, would not differ between the variants within the family.

7 CONDITIONS

- Changes of the system design, hardware or the software of the certified PV inverter are to be approved by DNV
- Inverter settings must finally be agreed and checked at project level to ensure grid code compliance, based on the requirements of relevant System Operator (SO). For the functionalities within scope of this certification, more information about the settings assessed is found in *Control Settings* in section 4.2 as well as the corresponding assessment sections 5.1 - 5.9
- The capability of remote control has been shown on unit level but must finally be ensured at project level, considering any further requirements of relevant System Operator (SO) and the full communication network. For the functionalities within scope of this certification, these concerns:
  - Remote cessation of active power (see section 5.3)
  - Remote set-point control of active power (see section 5.4)
  - Remote blocking and control of LFSM-O (see section 5.5)
  - Remote blocking of LFSM-U (see section 5.6)

8 CONCLUSION

The SOFARSOLAR solar inverter family SOFAR [25-50]KTLX-G3, including SOFAR 25KTLX-G3, SOFAR 30KTLX-G3, SOFAR 33KTLX-G3, SOFAR 36KTLX-G3, SOFAR 40KTLX-G3, SOFAR 45KTLX-G3, SOFAR 50KTLX-G3, as described in section 4.2 has been assessed for compliance regarding the evaluation criteria as detailed in section 2 with the scope detailed in section 3. Under consideration of the conditions given in section 7 there is no objection against assuming the inverter SOFAR [25-50]KTLX-G3 complies with those assessment criteria listed in section 2.

9 REFERENCES

/1/ Measurement of power control characteristics and FRT capability of a PV inverter of the type SOFAR 50KTLX-G3 according to FGW TG3 Rev. 25, Report No: 10325019-SHA-TR-02-B	207 pages	Dated 2023-05-29
/2/ Test plan: Grid Code Compliance testing in Poland Family 25-50 kW KTLX-G3 - Issued by DNV	39 pages	Dated 2022-03-31
/3/ 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, Systems and storage Systems as well as their Components on the grid, FGW, Revision 9	325 pages	Dated 2019-02-01
/3/ Standard: DNV-ST-0125: Grid code compliance, DNV, March 2016, amended November 2021	76 pages	Dated 2021-11
/5/ Standard: VDE-AR-N 4110: Technical requirements for the connection and operation of customer installations to the medium voltage network, VDE, 2018-11	260 pages	Dated 2018-11
/6/ Manufacturers_information_Cert_ABCD_SOFAR 25-50 KTLX-G320230602.pdf Doc. No.: DNV-25-50-0601	7 pages	Dated 2023-05-31
/7/ Technical Guidelines for Power Generating Units and Systems, Part 3: Determination of electrical characteristics of Power Generating Units and Systems, Storage Systems as well for their Components in Medium-, High- and Extra-High Voltage Grids, FGW, Revision 25	327 pages	Dated 2018-09-01
/8/ Email from PTPiREE: “Kilka pytań” (Clarification for negative sequence)	5 pages	Received 2020-12-02
/9/ Email from PTPiREE: “RE: LFSM-O - setpoint” (Clarification for LFSM-O control priority)	3 pages	Received 2021-02-26
/10/ EN 50549-10 Draft edition, Requirements for generating plants to be connected in parallel with distribution networks — Part 10: Tests demonstrating compliance of units.	166 pages	Dated 2020-12
/11/ Test plan: Grid Code Compliance testing in Poland Family SOFAR 60-80KTLX-G3 - Issued by DNV	39 pages	Dated 2022-08-23

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