BNT[030-060]KTL:
BNT030KTL, BNT036KTL, BNT040KTL, BNT050KTL, BNT060KTL

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

Afore New Energy Technology (Shanghai) Co., Ltd.

Report No.: CR-GCC-DNV-SE-0124-08504-A072-0
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DNV

Project name:	BNT[030-060]KTL BNT030KTL, BNT036KTL, BNT040KTL, BNT050KTL, BNT060KTL
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Applicable contract(s) governing the provision of this Report: (218133-SFA-20210720)

Objective: Verification of network code compliance of the AFORE solar inverter family BNT[030-060]KTL including BNT030KTL, BNT036KTL, BNT040KTL, BNT050KTL, BNT060KTL

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0	2022-12-19	First issue	Aleksandra Voss	Artur Zbroński

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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: BNT030KTL, BNT036KTL, BNT040KTL, BNT050KTL, BNT060KTL, which are part of the BNT[030-060]KTL inverter family of AFORE, 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: 10305969-SHA-TR-01-A, ISO17025 accredited /1/
- Manufacturer information provided by AFORE /6/

Tests were performed on the AFORE BNT060KTL 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 AFORE BNT060KTL unit can be accepted for the whole BNT[030-060]KTL inverter 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 Type A-B Power Park Modules (PPM)s 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	Assessment result(**)
Frequency range	13.1(a)	13.1(a)(i)	x	x	Compliant
Rate of Change of Frequency (RoCoF) withstand capability, df/dt	13.1(b)	13.1(b)	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	Compliant
Capability to withstand voltage dips for connection below 110 kV	14.3	14.3(a)(i), (b)		x	Compliant
Fast fault current injection, symmetric and asymmetric faults	20.2(b), (c)	20.2(b), (c)		x	Compliant
Active power recovery after fault clearance	20.3	20.3(a)		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 6.

4 GENERAL INFORMATION

4.1 Schematic description of the generating unit

The AFORE solar inverter family BNT[030-060]KTL, consisting of: BNT030KTL, BNT036KTL, BNT040KTL, BNT050KTL, BNT060KTL convert electrical energy generated by photovoltaic modules (DC) to three-phase alternating current (AC).

They run at 400 V rated output voltage with a rated active power output of 30 kW to 60 kW. The different output power variants are achieved through derating via software. Model BNT030KTL has 5 PV input strings, models BNT036KTL , BNT040KTL have 6 PV input strings, model BNT050KTL has 7 PV input strings and model BNT060KTL has 8 PV input strings. There are no further differences in the hardware or firmware used, as stated by the manufacturer /6/.

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

4.2 Technical data of main components

Main technical data of the main components of the BNT[030-060]KTL is given below, as provided in Manufacturer Information /6/.

Table 4-1 General Specifications

Generating Unit	BNT030KTL	BNT036KTL	BNT040KTL	BNT050KTL	BNT060KTL
No. of phases	3	3	3	3	3
Rated apparent power	30 kVA	36 kVA	40 kVA	50 kVA	60 kVA
Rated active power	30 kW	36 kW	40 kW	50 kW	60 kW
Rated AC-voltage (phase to phase)	400 Vac	400 Vac	400 Vac	400 Vac	400 Vac
Rated frequency	50 Hz	50 Hz	50 Hz	50 Hz	50 Hz

Table 4-2 DC Input

Generating Unit	BNT030KTL	BNT036KTL	BNT040KTL	BNT050KTL	BNT060KTL
Min. MPPT voltage	200 V	200 V	200 V	200 V	200 V
Max. MPPT voltage	1000 V	1000 V	1000 V	1000 V	1000 V
Max. DC input voltage	1100 V	1100 V	1100 V	1100 V	1100 V
Max. DC input current	38 x 2 A	38 x 3 A	38 x 3 A	40 x 3 A	38 x 4 A

Table 4-3 Software version

Generating Unit	BNT030KTL, BNT036KTL, BNT040KTL, BNT050KTL, BNT060KTL
Firmware version	1.01
Software version	1.26

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 "*Safety*" field, which provide default settings based on specific grid codes and national requirements. For this certification report the parameter set called "Poland" in the display interface, was assessed for the functionalities within scope of this certification.

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 2022-09-26 and 2022-11-07 in the Afore lab, Shanghai in P.R. China. The tests were performed according to a tailor made test plan /2/ issued by DNV Renewables 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 AFORE BNT060KTL unit.

Table 4-4 Performed tests, as documented in test reports /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/
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.

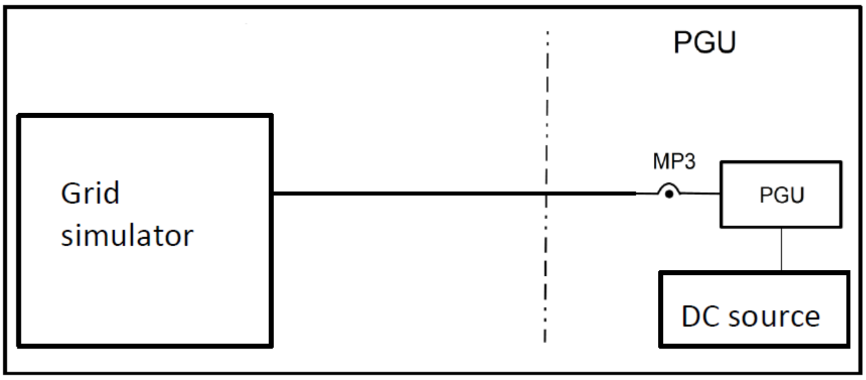

Figure 4-1 Single line diagram of the test setup

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 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: requirements and tests

Frequency range	Required time for operation	Tests performed /1/
47.5 Hz-48.5 Hz	30 min	31 min at 47.5 Hz
48.5 Hz-49.0 Hz	30 min	31 min at 47.5 Hz
49.0 Hz-51.0 Hz	Unlimited	31 min at 51.5 Hz
51.0 Hz-51.5 Hz	30 min	31 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 both tested inverters 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 500 ms.

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 made test plan /2/ basing on EN 50549-10:2021 (Draft), section 5.3.1.

The tests were carried out as a series of three frequency steps as presented on the upper plot of 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 tested inverter riding through frequency gradients above 2 Hz/s, while remaining in stable operation. It can be confirmed that RoCoF withstand capability of the inverter is in compliance with stated requirements.

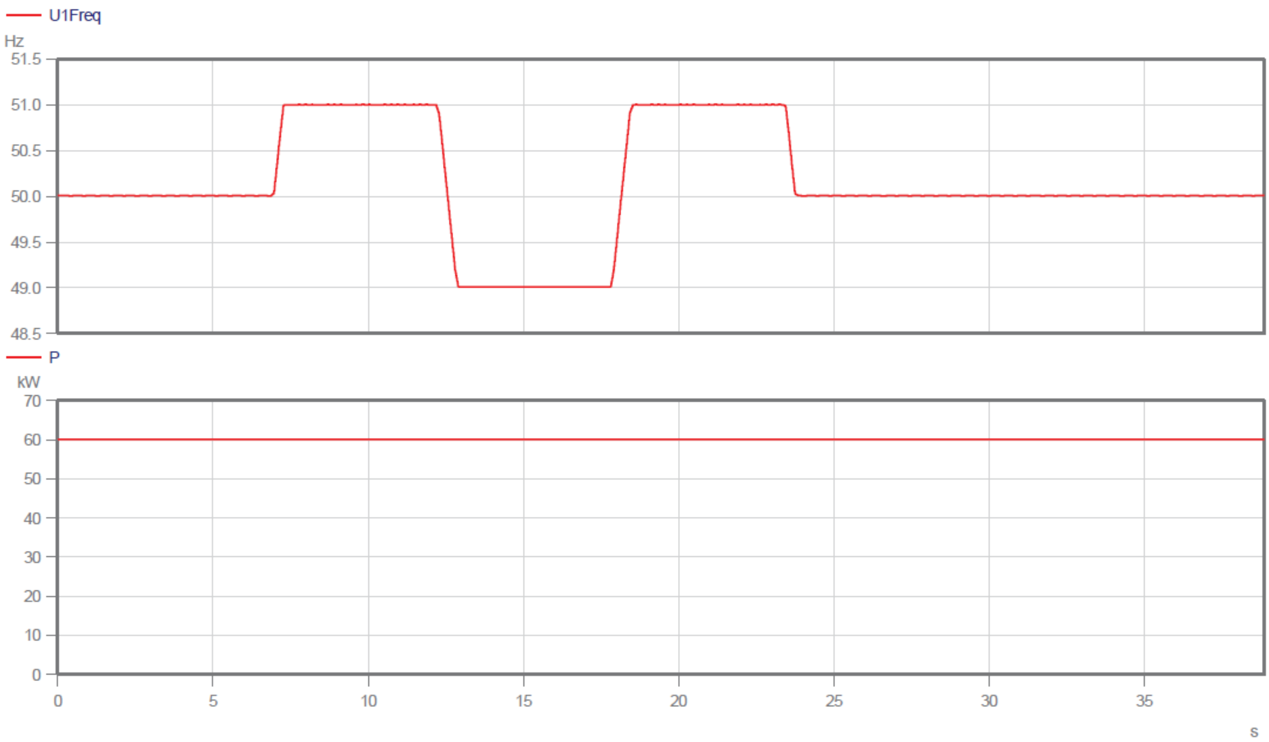

Figure 5-1 RoCoF withstand test results, showing grid frequency (upper plot) and output power (lower plot) /1/

5.3 Cessation of Active Power

5.3.1 Introduction

General requirements relating to Cessation of Active Power for Types A PGUs 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 SO. Telecommunication standards shall be determined by a relevant SO. The relevant SO 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, 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 tailore 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 input of the inverter was used, and a pulse signal of RS485 pin was measured when the cessation command was executed. The time period was measured following the cessation command being sent 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 2.40 s after reception of remote shutdown signal to cease 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 of the facility 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.

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 according to made test plan /2/ 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.

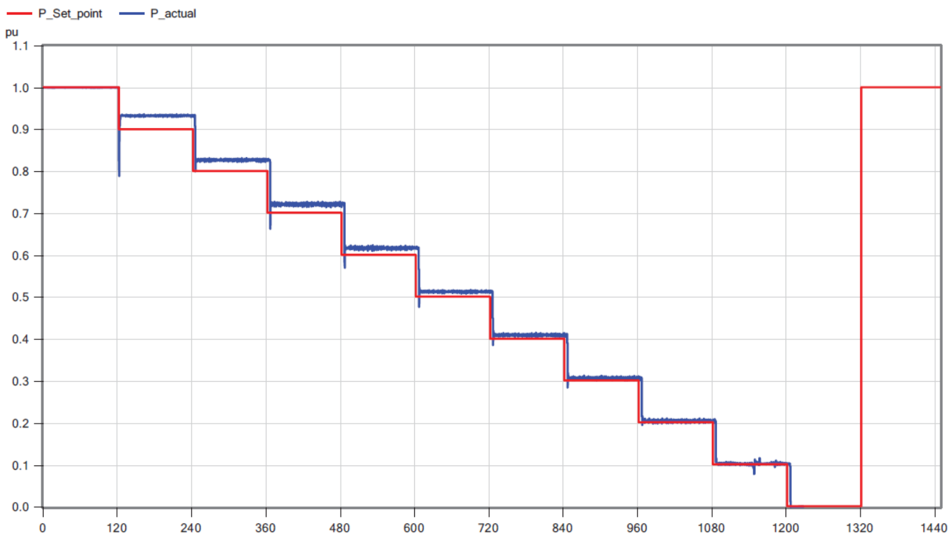

Figure 5-2 Remote control of active power, test results from test report /1/

To achieve remote control, a RS485 (Modbus) input of the inverter was used. The signal for remote control of active power was then given via PC.

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 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”.

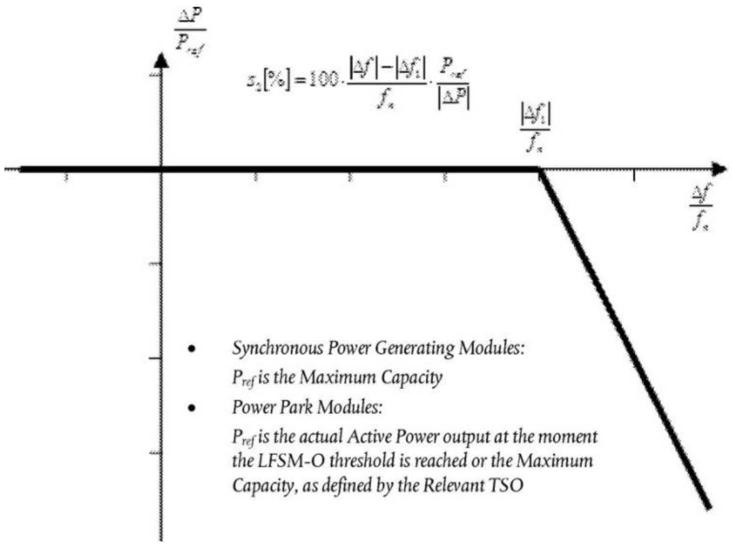

Figure 5-3 Active power frequency response capability of power-generating modules in LFSM-O. NC RfG /D/

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
1b*	50.1 Hz ± 0.05 Hz (*)	50.4 Hz ± 0.05 Hz (*)
2	50.3 Hz ± 0.05 Hz	50.6 Hz ± 0.05 Hz
2b*	50.9 Hz ± 0.05 Hz (*)	50.9 Hz ± 0.05 Hz (*)
3	51.4 Hz ± 0.05 Hz	51.4 Hz ± 0.05 Hz
4	50.3 Hz ± 0.05 Hz	50.6 Hz ± 0.05 Hz
5	50 Hz ± 0.05 Hz	50 Hz ± 0.05 Hz

(*) added compared to FGW TG3. Notation 1b, instead of 2, is only to avoid confusion in reference to the corresponding instructions of FGW TG3.

5.5.3 Assessment summary

A selection of the LFSM-O test results, as provided in test report /1/, are presented in Figure 5-4 and Figure 5-6. They show 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 test result (in Figure 5-4 and Figure 5-6), the inverter shows stable operation during LFSM-O, also at minimum regulating level, and it complies with the maximum delay time of activating frequency response below 2 s.

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 maximum active power, specified as Rated apparent power for each variant in Table 4-1, as a reference value to calculate appropriate LFSM-O response.

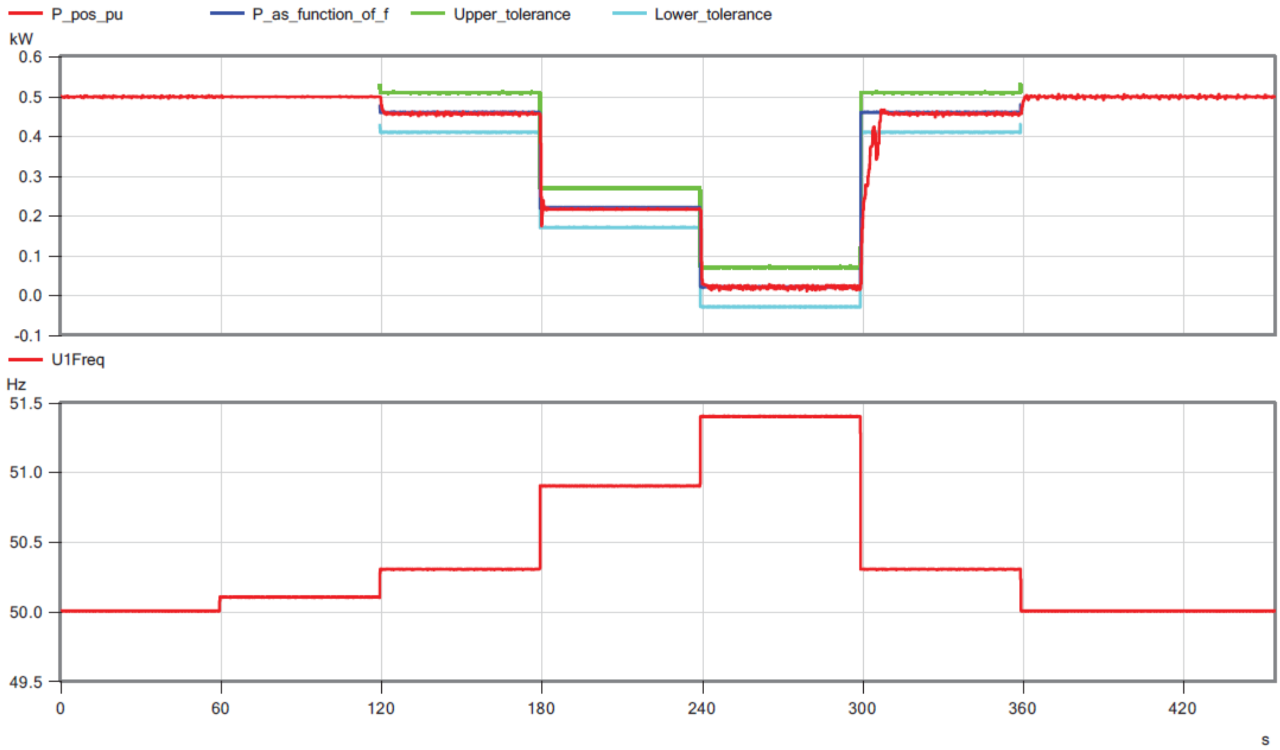

Figure 5-4 LFSM-O test results, showing input frequency steps (lower plot) and the response in active power output (upper plot), droop: 5 %, activation threshold: 50.2 Hz /1/

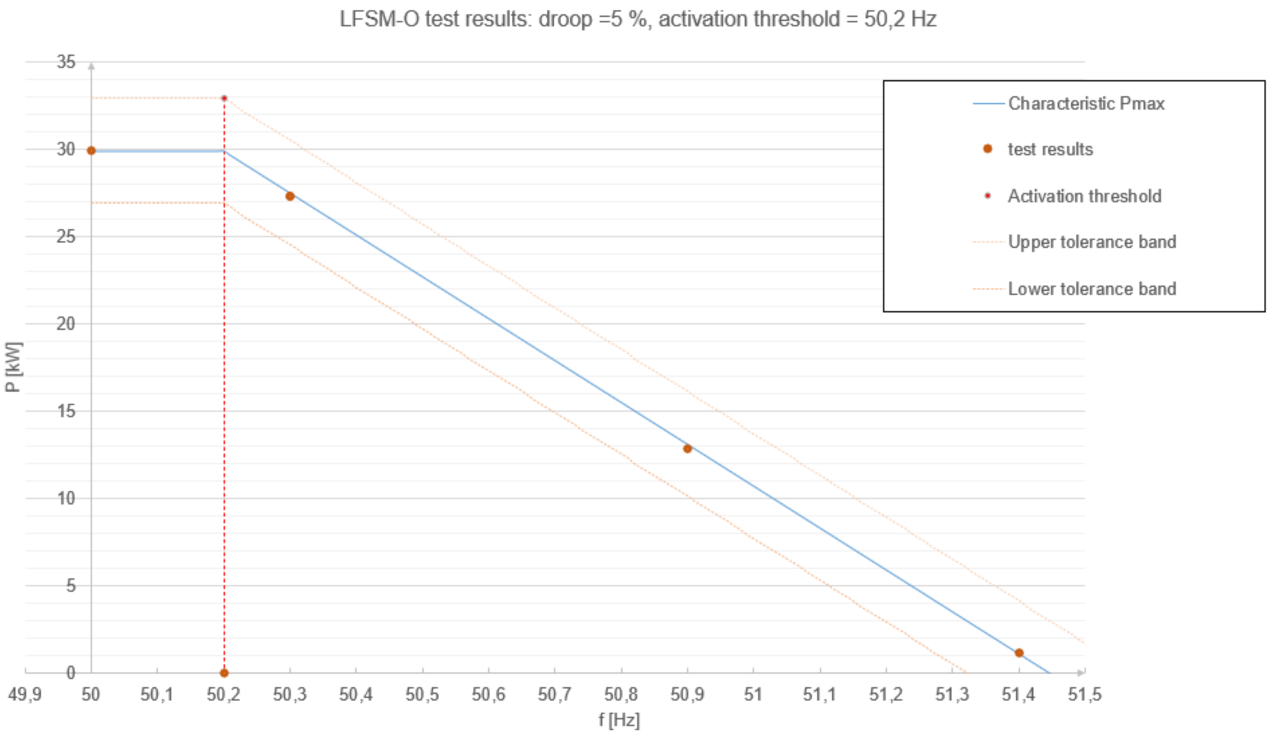

Figure 5-5 LFSM-O test result, showing test results (orange dots) compared to required droop characteristic (blue line). droop: 5 %, activation threshold: 50.2 Hz, Based on data from /1/

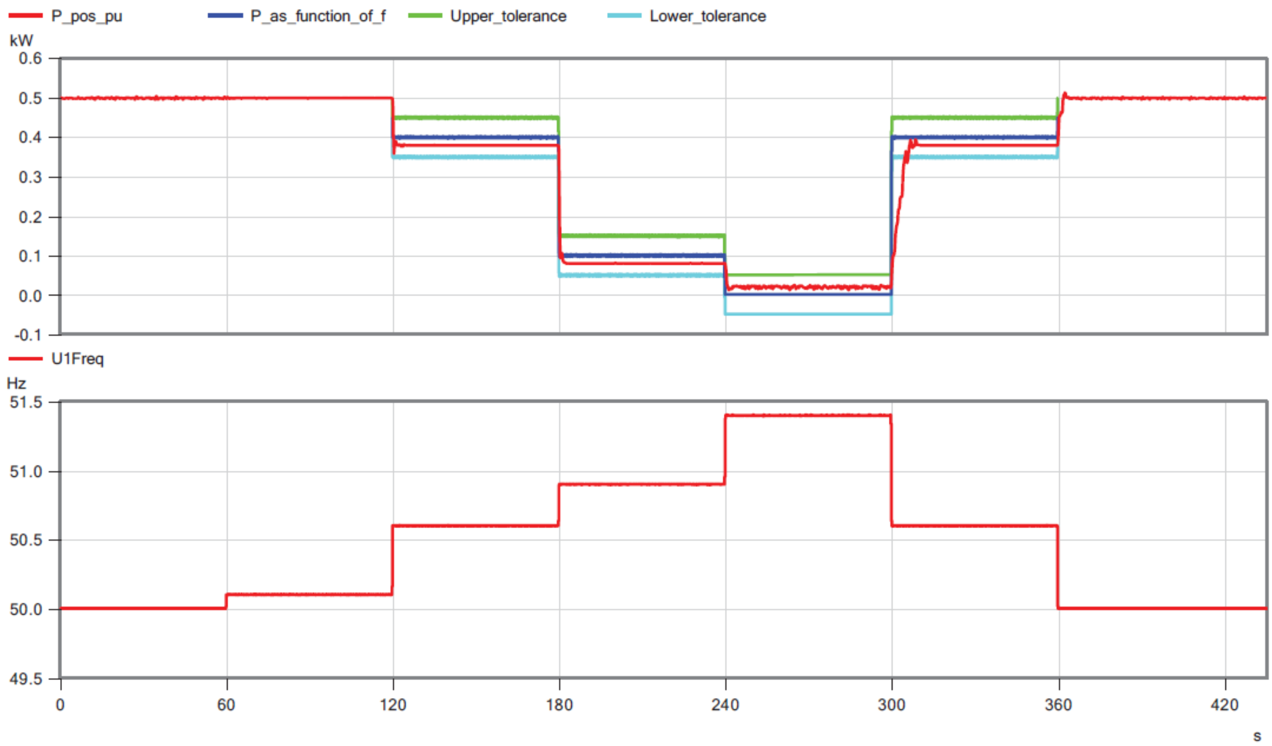

Figure 5-6 LFSM-O test results, showing input frequency steps (lower plot) and the response in active power output (upper plot) droop: 2 %, activation threshold: 50.5 Hz, deactivation threshold off /1/

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 the droop is controlled via “OverFRatio” parameter. Additionally, parameter “OverFDeadBand” acts as a setting for activation threshold.

Furthermore, it is confirmed that the LFSM-O control has priority when active, according to manufacturer information /6/.

Regarding the possibilities for remote blocking and intervention operation, as requested in Article 13 item 1(a) of PSE 2018-12, AFORE declares via manufacturer information /6/ that it is possible to disable the function remotely via 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 Fault Ride Through

5.6.1 Introduction

The general requirements relating to Fault Ride Through (FRT) capabilities for type B PGUs are defined Article 14.3 in NC RfG /D/. Further specifications for Poland are provided by Article 14 item 3(a)(i) and (b) of PSE 2018-12 /C/, including specification of the FRT curve provided in Figure 5-7.

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.

5.6.2 Test setup and description

Tests were performed following a test plan provided by DNV /2/, which in turn follows the standards DNV-ST-0125 and IEC 61400-21-1:2019. The tests are summarized in Table 5-4.

The test was 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 5-4 Performed FRT tests /1/

Test no.	Fault Type (3/2 phase)	Ref no. Test Plan	Remained Voltage in %	Duration in ms	Active Power Output in p.u.	K factor	Special Settings
94	3	5-1	5	403	>0.9	2	
96	3	5-2	5	404	0.1 – 0.3	0	
98	2	5-3	5	400	>0.9	2	
100	2	5-4	5	400	0.1 – 0.3	2	
102	3	20-1	20	842	>0.9	2	
132	3	20-2	20	830	0.1 – 0.3	0	
106	2	20-3	20	840	>0.9	2	
109	2	20-4	20	840	0.1 – 0.3	2	
110	3	6	50	1716	>0.9	2	
112	3	7	50	1712	0.1 – 0.3	3	max.ind. *)
114	2	8	50	1720	>0.9	3	fault phase shift to AC**)
142	2	9	50	1720	0.1 – 0.3	2	
118	2	10	50	12070	0.6	2	until cut-off
120	3	11	70	2308	>0.9	2	
122	3	12	70	2307	0.1 – 0.3	2	max.cap. *)
124	3	13	70	2309	>0.1	4	max.ind. *)
137	2	14	70	2305	>0.9	2	max.cap. *)
138	2	15	70	2307	>0.1	4	
130	3	16	87	9996	>0.9	2	full load

**) These tests were carried out at maximum capacitive or 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.*

5.6.3 Assessment

Figure 5-7 below provides an overview of the tests performed as documented in section 4 in test report /1/ together with the FRT curve required in Poland.

As further detailed in Table 5-4, tests were performed for 3-phase and 2-phase faults at both full and partial power. The inverter was also tested at 50 % voltage until cut-off (at 12007 ms). 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 5-7.

It should be noted that the data points marked in grey correspond to the measured voltage. The corresponding time for which the unit should remain connected is longer than tested. Following the FGW TG3 /7/, the durations required are dependent on the reached voltage level as measured during the no-load test.

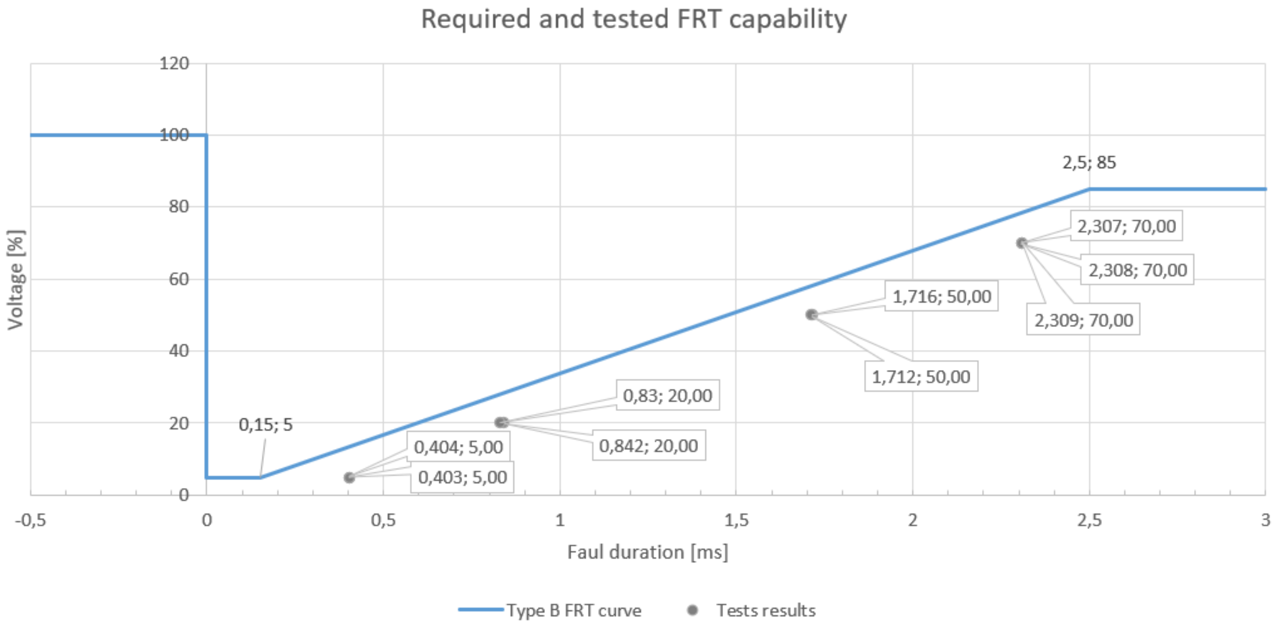

Figure 5-7 Overview of the FRT tests performed (grey dots), together with Polish LVRT requirements for B-type units (blue line).

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

5.7 Fast fault current injection

5.7.1 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 5-8 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).

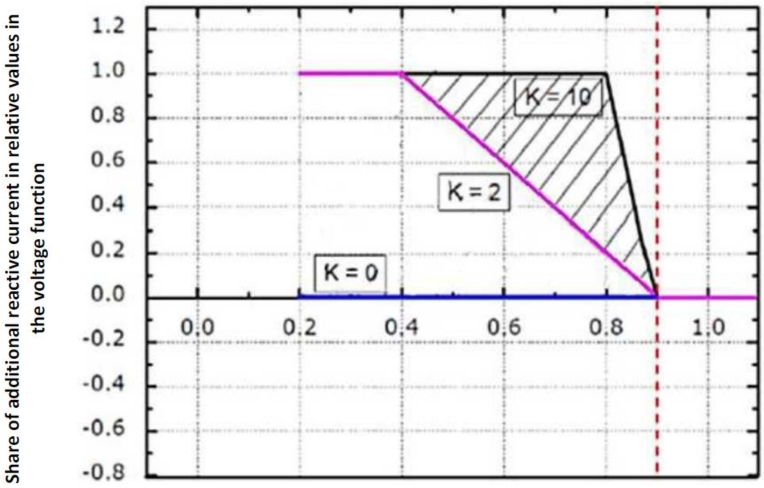

Figure 5-8: Required Reactive Current Supply during Grid Faults /C/

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.

5.7.2 Test setup and description

See section 5.6.2.

5.7.3 Assessment

Implemented control

Regarding Figure 5-8 the reactive current response of the PGU, as documented in the Manufacturer'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:

$$(1) \qquad I^{+}_{q,set} = I^{+}_{q,prefault} + k(0.9 - U^{+}_{fault})$$

Equations (2)-(5) were not provided by the manufacturer, instead they were derived from test results and therefore only exemplify the behavior of the inverters:

$$(2) \qquad I^{-}_{q,set} = I^{-}_{q,prefault} - kU^{-}_{fault}$$

In case where the sum of the positive and negative sequence reactive current reaches the current limitation I_n the former is limited according to the following formula:

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

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

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

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.]

Regarding settings, the k-factor can be set in the range 0-10, as specified by the manufacturer /6/, and was tested for k factor of 0, 2, 3 and 4. Fast fault current injection functionality enabled by default.

Performed tests

All the tests listed in Table 5-4 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 5-9, the provided reactive current is proportional to the voltage deviation from 0.9 Un, thus considering a 10% dead band in positive sequence.

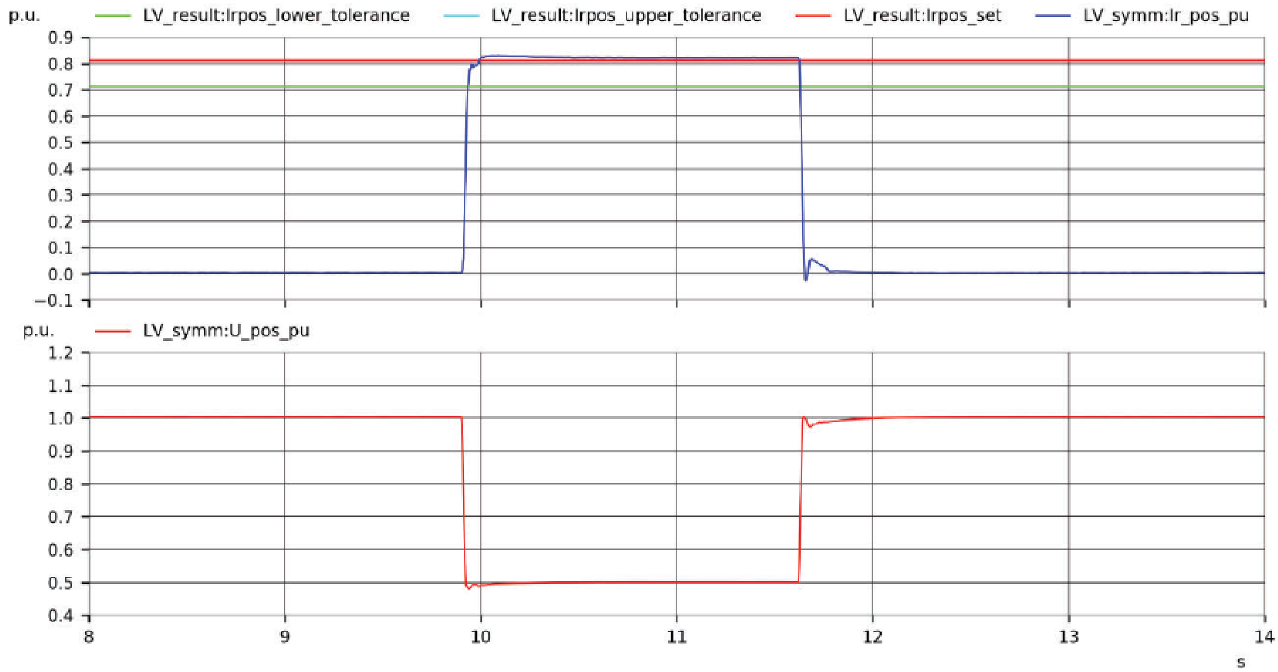

Figure 5-9 Test no. 110 (3-phase, full-load, fault voltage 0.5 p.u. of Un, k=2), showing positive sequence response /1/

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 5-10 with a positive pre-fault offset. Figure 5-11 shows the negative sequence response to the same symmetrical fault.

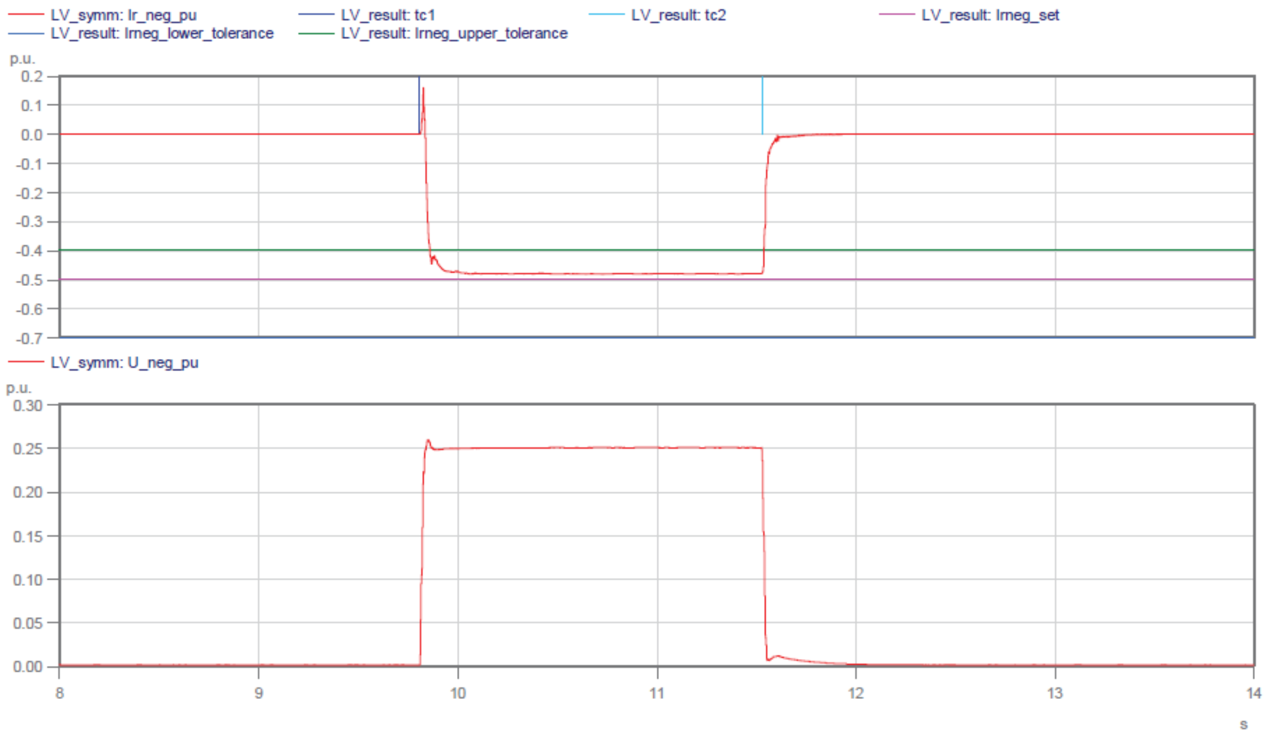

Figure 5-10 Test no. 142 (2-phase, full-load, fault voltage 0.5 p.u. of Un, k=2) showing positive sequence response to asymmetrical fault /1/

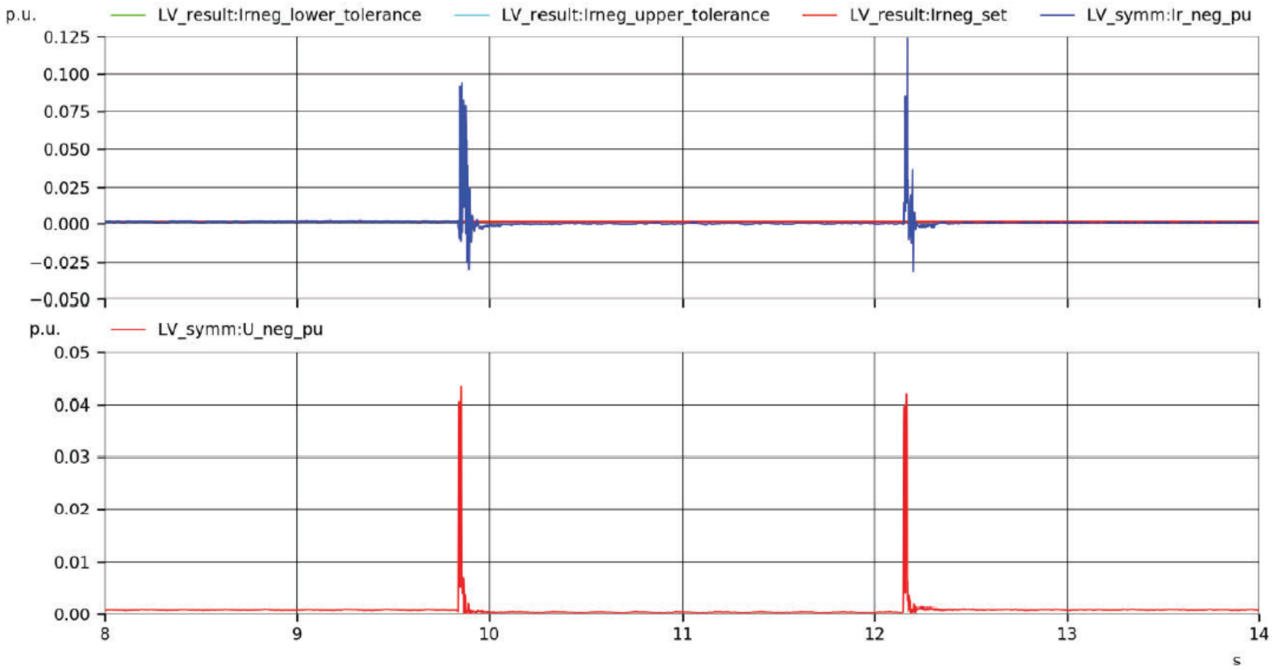

Figure 5-11 Test no. 142 (2-phase, full-load, fault voltage 0.5 p.u. of Un, k=2) showing negative sequence response to asymmetrical fault t /1/

As can be seen in Figure 5-12 and Figure 5-13 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 5-12 would have been 60 % and negative sequence reactive current seen in Figure 5-13 would have been -80 %. Instead, they are now limited to 45 % and -57 % respectively.

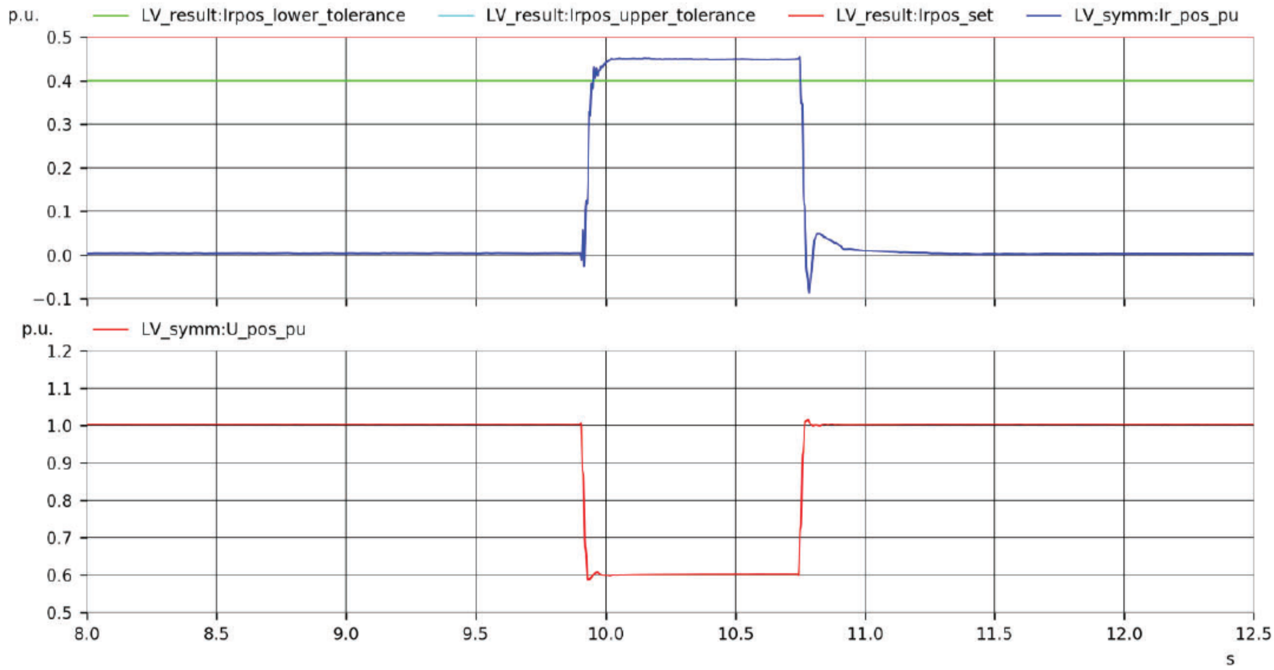

Figure 5-12 Test no. 106 (2-phase, partial-load, fault voltage 0.20 p.u. of Un, k=2) showing positive sequence response to fault including current limitation /1/

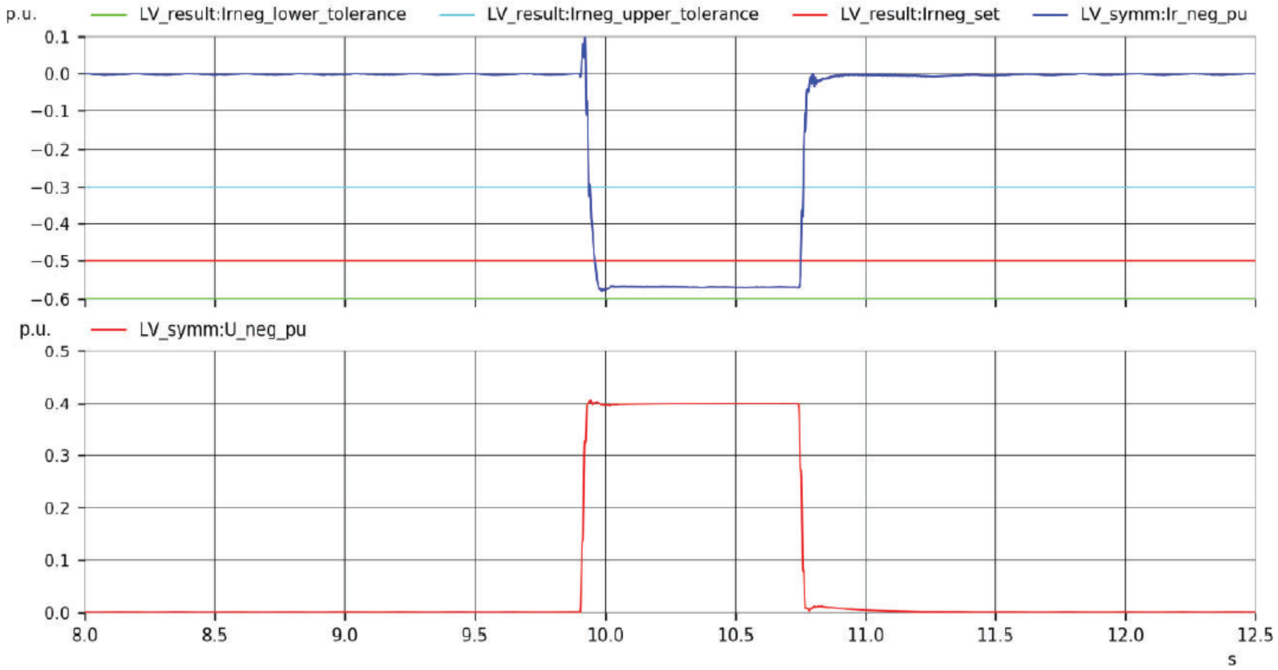

Figure 5-13 Test no. 106 (2-phase, partial-load, fault voltage 0.20 p.u. of Un, k=2) showing negative sequence response to fault including current limitation /1/

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.

5.8 Active power restoration following a fault

5.8.1 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.

5.8.2 Test setup

See section 5.6.2.

5.8.3 Assessment

In all the assessed tests, the inverter managed to recover 90 % of active power well within 5 s without showing any undamped oscillation. Since 90 % of active power is always resumed within 5 s, 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 AFORE BNT060KTL for certification of all variants in the BNT[030-060]KTL 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 /4/ 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 PV inverters, there is a specific allowance to extend this range, if justified in agreement with the certifier. This is stated in 2.12.2 of the corresponding certification guideline FGW TG8 rev 9 /3/. Within the transferable range, it is required that the variant expected to show the least favourable test result should be tested, which should be motivated by AFORE.

For the assessed family, which includes units in a range from 30 kW to 60 kW (and correspondingly 30 to 60 kVA), it has been accepted to test the largest variant within the family. AFORE 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.

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 inverters 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 -5.8.
- 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, this 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).

8 CONCLUSION

The AFORE solar inverter family BNT[030-060]KTL, including BNT030KTL, BNT036KTL, BNT040KTL, BNT050KTL, BNT060KTL, 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 family BNT[030-060]KTL 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 BNT060KTL according to FGW TG3 Rev. 25 and Polish Grid Code, Report No: 10305969-SHA-TR-01-A	193 pages	Dated 2022-11-22
/2/ Test plan: Grid Code Compliance testing in Poland Family BNT[030-060]KTL - Issued by DNV	35 pages	Dated 2021-07-27
/3/ Technical guideline: FGW TG8: Technical Guideline Part 8 – Certification of the electrical characteristics of power generating units, systems and storage as well as for their components connected to the grid, FGW, Revision 9/	325 pages	Dated 2019-02-01
/4/ Standard: DNV-ST-0125: Grid code compliance, DNV, November 2021	61 pages	Dated 2021-10
/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/ Manufacturer's information Doc. No. AF2021-09005	5 pages	Dated 2022-11-07
/7/ Technical Guidelines for Power Generating Units and Systems, Part 3: Determination of electrical characteristics of power generating units and systems connected to MV, HW and EHV grids, published by Fördergesellschaft Windenergie und andere Erneuerbare Energien e.V. (FGW) Revision 25	327 pages	Dated 01/09/2018

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