Recent Challenges Regarding the Verification of Photovoltaic Inverters Properties and their Compliance with Technical Requirements

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Abstract: Distributed generation by renewable energy sources, is a new phenomenon in recent years and it brings several challenges for electric power system operations. Given that, distributed generators shall be strictly in compliance with relevant standards and technical requirements, to preserve current level of quality and reliability of electric power supply. Therefore, this research is aimed at compliance verification of non-synchronous power generating modules, with any relevant requirements. At the beginning, it provides comprehensive review on this issue including historical development, the current situation in the Czech Republic and relationships between legislation and standards, currently in force. The main contribution of the paper lies in the experiments performed on photovoltaic inverters, which represent the key components of photovoltaic systems and are responsible for fulfilling the imposed operational requirements. The results provide a real-world picture of the current state, in this field. We found that none of the tested inverters fulfilled the requirements to the full extent and therefore, we recommend careful verification of the power generating modules, units or component's ability in this regard, before commissioning.

Keywords: photovoltaic; inverter; requirements; RfG; EN50549-1; compliance

1 Introduction

The growth of living standards and constant social and economic development arising the need to secure more and more energy in a sustainable way. Currently, the majority of energy (more than 70% [1]) comes from fossil sources such as oil, coal and natural gas. The global trend is a gradual transition to renewable energy sources (RES) due to several factors. First, there is a question of climate change, which an integral part of fossil fuel usage and the associated greenhouse gas formation. Also, with increasing global energy consumption, the required amount of fossil fuels increases. Non-renewable resources are limited and energy extraction is therefore not sustainable in the long term. Similarly, there is an effort of individual countries to increase their energy independence on fossil fuels imported from abroad. All these factors lead in developed countries to national and transnational policies for carbon neutrality with clearly defined milestones for individual years (for example, 2030 or 2050). This is possible only by gradually increasing the share of RES used in electricity production but also, for example, in transport. Developing countries are also following these goals. For example, China, which is the largest producer of greenhouse gases in the world, aims to be carbon neutral by 2060 [2]. Despite this, fossil fuels remain the main source for electricity generation with a share of approximately 40% from a global perspective [3].

Photovoltaic (PV) power plants are among the most widespread RES in the Czech Republic, primarily due to the favorable climatic conditions and problem-free availability of the primary source. The breakthrough years were 2009-2012, when the so-called "PV boom" caused by massive government support resulted in a strong increase of installed capacity (from 39.5 MWp in 2008 to 1959.1 MWp in 2010). The most significant part was created by PV plants with nominal power outputs ranging from ones up to tens of MW connected at the medium voltage (MV) level. Due to the unexpectedly fast progress towards the fulfillment of the European Union energy targets until 2020 [4], to which the Czech Republic committed itself, the government support was gradually reduced and finally completely suspended from 1 January 2014. After this date, legislative support gradually began to move towards to sources with low power output aiming on maximizing the consumption of the generated electricity at the place of production. For example, in 2014, a subsidy program called new green savings [5] was launched, which was intended for energy savings in family houses and apartment buildings (the next stage is currently underway, which is expanded to include other areas of energy savings). Subsequently, in 2016, the term "microsource" was introduced by decree No 16/2016 of the Energy Regulatory Office [6]. Microsource is source with a rated current of up to and including 16 A per phase and a total maximum installed power of up to and including 10 kW. Advantage is, that there is no license needed and the decree provides also the possibility of a simplified connection process of small sources falling into this category after meeting defined conditions, which include, for example, preventing the power supply to the distribution system (DS) by appropriate technical means. In practice, they are almost exclusively PV plants connected to the low voltage (LV) with some form of surpluses accumulation and outputs in the order of kWs. This led to a change in the previous trend and the expansion of the so-called hybrid systems, which can be very effective when properly designed and optimized [7]. In case of any interest in the supply of electricity to the DS, the microsource must undergo the “first parallel connection process”. Subsequently, the owner of the resource has various business models at his disposal, such as the supply of electricity to the grid at spot prices, or recently increasingly popular concept called "virtual battery".

Historical and related legislative developments in the field of RES lead to the current situation where a large number of distributed generation (DG) with low power output are gradually connected to the grid across the country. Annual increments in the number of PV installations and the total amount of installed power are shown in Figure 1. There is clear exponential trend currently fueled especially by high energy prices. In the first half of 2022, higher numbers of installations were added with an overall larger portion of installed capacity than in the entire previous year.

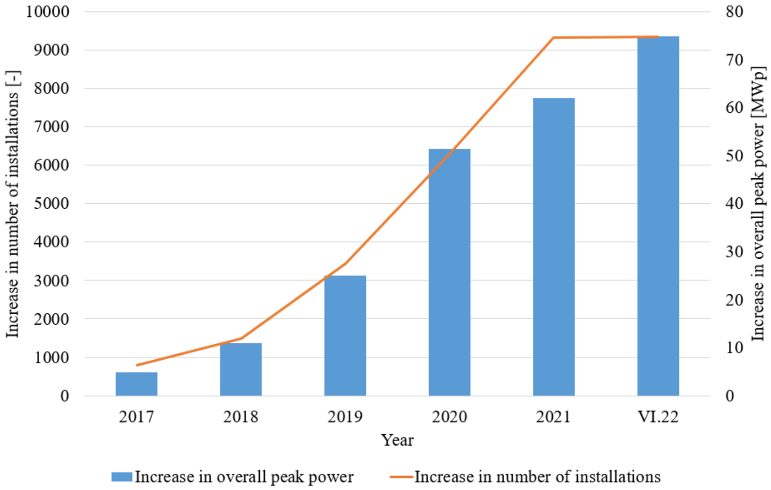

Figure 1
Increase in PV installed capacity and number of installations in the Czech Republic [8]

DG represents a change in existing approaches and brings a number of challenges in terms of managing the operation of the electric power system. In certain types of DS, there may be problems with power flow direction and voltage limits. This is mainly the case of the LV grids in rural areas. These are typical by long radial feeders with a relatively small cross-section, the consequence of which can be a high impedance at the point of common coupling (PCC). The load profile in rural areas is also significant factor, which is low during the day while PV plants power generation is high. The combination of these factors at a certain level of RES penetration can lead to a reverse power flow to the superior system and increase in voltage above the permitted limits defined in the EN 50160 [9]. Subsequently, it can cause source protections tripping, which is undesirable for both the distribution system operator (DSO) and the source owner. From the source owner point of view the electricity is not generated, and from the DSO point of view, problem is solved only for very short time. After tripping, voltage will return to the permitted limits, plant will resynchronize and problem will recur. In addition there are also another issues which can possibly occur [10], including voltage asymmetry or harmonic current distortion by power electronics, which can affect loads, protections and increase losses of distribution transformers [11] [12].

Considering the aforementioned potential problems, it was necessary to formulate clear requirements on DG in order to prevent negative phenomena and maintain the current quality and reliability of electric power supply. From the European point of view, the Network Code on Requirements for Grid Connection of Generators (RfG) [13] was established in 2016. The power generating modules (PGMs) are divided into individual categories depending on the nominal power output with different mandatory and non-mandatory requirements imposed on each category and generation technology (synchronous or non-synchronous). RfG became integral part of regional grid codes, because ENTSO-E members have been obliged (according to [13]) to implement the requirements by April 27th, 2019. EU countries have taken different approaches of implementation, but in any case, the result is that all newly connected power generation facilities (PGFs) or PGMs must meet the requirements. The RfG task is not to solve the grid specifics in individual countries, therefore the implementation of optional requirements or the specific range of required values for several mandatory requirements is left to local technical regulations.

Product standards were subsequently created in line with RfG - EN 50549-1 [14] and EN 50549-2 [15] focusing on sources connected to LV and MV, respectively. The standards are established so that the PGFs/PGMs assembled from products which conform with EN 50549-1/2 are able to achieve compliance with the RfG and its national implementation (national grid code, e.g., PPDS:P4 [16] in the Czech Republic). The specific parameters of individual RfG and EN 50549-1/2 requirements are defined at the national level, or even at the level of individual DSOs according to local specifics. The relationships between national technical regulations, standards and EU regulations are shown in Figure 2.

According to [17], the manufacturer must ensure that products which he is going to introduce on the market are designed and manufactured according established regulations and technical requirements. He submits all the information and documentation necessary to prove the conformity of the product to the competent national authority. It is also his duty to draw up and issue a product declaration of conformity with the relevant requirements, but manufacturer is in conflict of interests, because he has significant economic interest in introducing the product on the market. Therefore, the declaration of conformity may not provide a guarantee of conformity fulfillment. This can lead to the introduction of such products on the market, which do not meet the requirements partially, or even in their entirety.

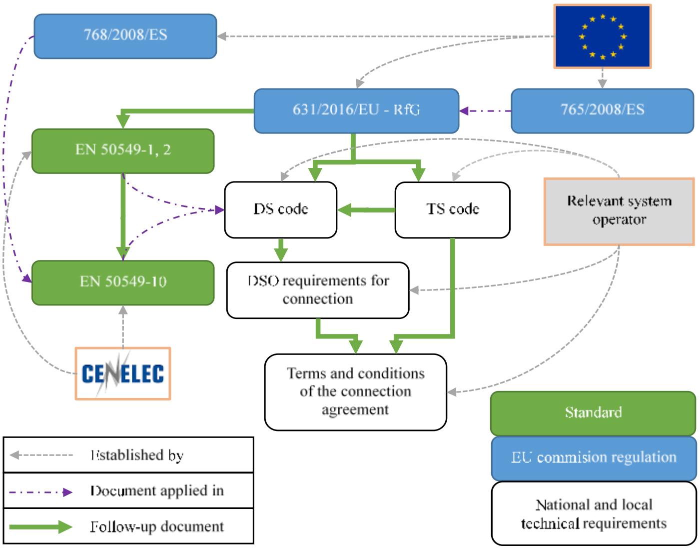

Figure 2
Relationships between relevant documents

The purpose of all legislative regulations and technical requirements related to DG, including PV plants, is to ensure their safe operation and to mitigate or completely eliminate negative impacts, such as voltage rise, etc. Therefore, it is absolutely necessary to ensure the correct and uniform application of the regulations to all products from all manufacturers placed on the common European market. This basic assumption is currently only slightly enforced in practice. For example, in the Czech Republic, the DSOs within the first parallel connection process (process of connecting such a source that is expected to supply the electricity to the grid) require proof of compliance through the "Document of generating module". However, it is only an ordinary form in which the contractor and the PGF owner guarantee the compliance with RfG and PPDS:P4 by their signature. The weight of such a document is therefore controversial and since the declaration of conformity is also not a reliable way how to prove the compliance, the only option, which is logically offered, is independent verification, for example, in certified third-party laboratories. The problem is the lack of testing workplaces and non-existing verification methodology or related standards nowadays (2022).

The aim of this contribution is to provide a comprehensive overview about the operational characteristics of DG (especially PV plants) and their verification. Currently, apart from the authors´ contributions [18]-[22], there is only a minimum of publications [23] [24] focused on this very important but at the same time often overlooked area. The requirements imposed on non-synchronous PGFs are analyzed, potential problems and risks associated with their implementation are identified, and the need for systematic compliance verification is rationalized.

The practical experiments are focused on PV systems where the key component of the system, the PV grid-tie or hybrid inverter, is responsible for the whole system operational properties. Presented verification results provide a realistic picture of the current situation in the requirements implementation by individual manufacturers of PV inverters.

2 Selected Requirements for Verification

RfG and EN 50549-1/2 contain a number of requirements regarding synchronous and non-synchronous PGMs. As this contribution deals with compliance of PV inverters, requirements for non-synchronous PGMs are relevant and those that can have a fundamental impact on DS operation have been chosen for verification. The tested PV inverters are considered as components intended for use in A category of PGMs and for connection to LV DS. Therefore, the technical standard EN 50549-1 (hereinafter as EN) and local implementation of RfG – PPDS:P4 is applied and verified. An overview of selected requirements is given in Table 1. From an overall perspective, they can be divided into requirements imposed on withstand capability to sudden change of certain quantity and requirements that require an active response as the reaction to the change in the related quantity. In the following subsections, these requirements will be explained in detail together with the relevant legislative documents as well as technical standards and the specification of individual parameters with regard to national localization through the grid code in the Czech Republic.

Table 1

List of selected requirements

Requirement	**RfG (article)**	**EN 50549- 1 (subclause)**
Rate of change of frequency (ROCOF) immunity	13.1(b)	4.5.2
Power response to over-frequency	13.2	4.6.1
Automatic connection and starting to generate electrical power	13.7	4.10
Voltage support by reactive power	17.2	4.7.2
Voltage related active power reduction	-	4.7.3

2.1 Rate of Change of Frequency (ROCOF) Immunity

In general, PGFs should contribute to overall stability by withstanding dynamic changes in magnitude and frequency of voltage, unless safety standards require disconnection. ROCOF immunity is the only one of the selected, for verification, which can be considered to meet the withstand capability requirement. Other examples, which are not subjects in this paper, are the fault-ride-through capability, defined in RfG and the Under-voltage ride through or Over-voltage ride through defined in EN.

ROCOF immunity shall be provided regardless of protection settings. It means that the PGF shall remain connected and able to operate during frequency changes at a defined rate. The PGMs within the PGF shall have ROCOF immunity greater than or equal to the value defined by the responsible party (DSO or TSO) according to EN and RfG. It is also stated in EN, that when the ROCOF immunity is not defined by the responsible party, at least 2 Hz/s must apply for non-synchronous generation technologies.

Grid code in the Czech Republic requires the same value for non-synchronous PGMs as default stated in EN – 2 Hz/s.

2.2 Power Response to Over-frequency

Power response to over-frequency is defined both in EN and RfG, while RfG uses the term “limited frequency sensitive mode – over-frequency (LFSM-O)”.

PGF shall activate active power response to over-frequency after reaching an activation frequency threshold. Active power shall decrease with predefined droop as a response to increasing frequency. Both the frequency threshold for activation (f_1) and frequency droop (s) shall be programmable in the range of at least 50.2 to 52 Hz and at least 2 to 12%, respectively, according to EN. The parameters are specified by relevant transmission system operator (TSO).

The droop reference power is P_{ref}, which is different for synchronous and non-synchronous PGMs. For non-synchronous PGFs P_{ref} is the power generated at the moment when the frequency reaches the threshold value. The value of active power calculated according to reference power P_{ref} and droop defines the maximum power limit (Figure 3). For example, when the power of the primary source decrease during activated active power response to over-frequency, lower values of delivered power are allowed.

EN also requires the possibility to set a threshold value for deactivating the function (f_{stop}), which is used in some countries. Its basic principle (graphically explained in Figure 3) is that the power to which the PGF was limited remains constant even when the frequency is decreasing until the threshold value for deactivation is reached. After deactivation, power can be increased gradually with the same rate as defined in requirements for automatic connection and starting to generate electrical power.

The frequency threshold for activation is 50.2 Hz, the frequency threshold for deactivation is 50.05 Hz a droop is 5% according to Czech grid code.

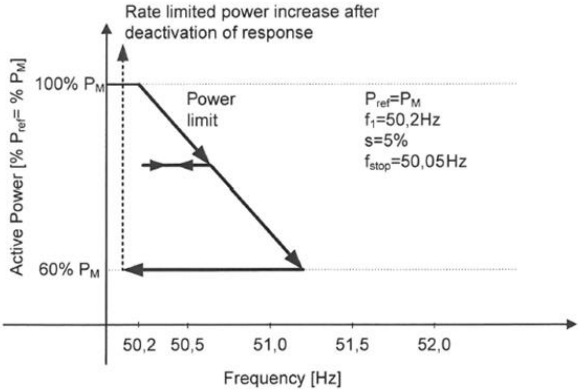

Figure 3

Power response to over-frequency - settings according to Czech grid code

2.3 Automatic Connection and Starting to Generate Electrical Power

Synchronization of PGFs with DS shall be fully automatized. Relevant TSO shall specify requirements on automatic connection and starting to generate power according to RfG. EN imposes two categories of requirements depending on whether it is automatic reconnection and starting to generate power after interface protection tripping (as a fault result) or it is standard operational start. For both situations automatic connection and starting to generate electrical power is allowed only if the voltage and frequency are within the permitted range for at least the evaluation period that is specified. Permitted ranges as well as evaluation period shall be settable within minimal ranges provided by EN, together with the default values which shall apply when no settings are specified by the DSO.

The subject of compliance testing presented in this article are requirements for automatic reconnection and starting to generate power after fault occurrence. The Czech grid code enables automatic connection and starting to generate electrical power after interface protection tripping in this situation:

- Frequency and voltage are for at least 5 min in the ranges below:
  - $U = (0.85 – 1.10)xU_n$
  - f = 47.5-50.05 Hz

Also, power output shall rise gradually up to available power with maximum rise rate (gradient) of 10% of nominal power per minute after synchronization.

2.4 Voltage Support by Reactive Power

RfG does not impose any requirements for reactive power regarding to A category PGMs. Voltage support by reactive power is defined in EN within requirements referred as power response to voltage changes. It states that the PGFs must be able to control active and reactive power if required by the relevant DSO. At the same time, PGF must not lead to exceeding the permitted voltage limits in [9] and during the normal operation conditions shall be able to contribute to maintaining the voltage within the limit. Requirements for reactive power capability are in line with EN in the Czech republic and they are shown in Figure 4.

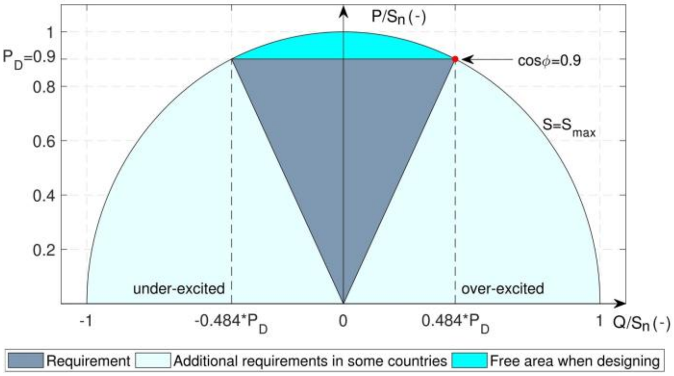

Figure 4

Requirements on reactive power of PGMs in the Czech Republic

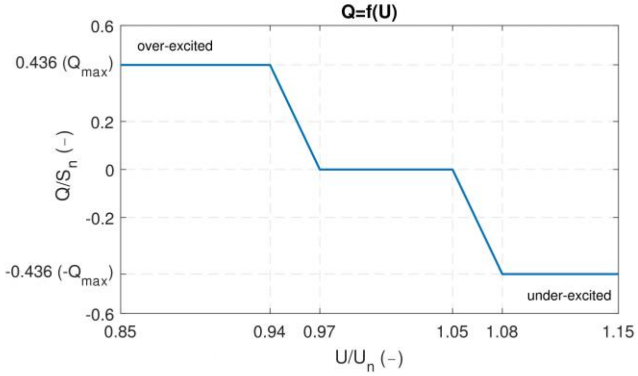

Figure 5

The most common setting of reactive power control characteristic in the Czech Republic

There are several control modes which can utilize reactive power capability defined in EN. They include simple fixed Q and cosφ setpoint control modes or more complex one, based on predefined control characteristics – reactive power dependent on voltage - Q(U) or cosφ dependent on active power - cosφ(P).

Currently, all DSOs in the Czech Republic require exclusively Q(U) control mode. This mode automatically set reactive power, which corresponds to specific voltage value based on control characteristic. The specific setting can be required individually in connection agreement, but the Czech grid code specifies the default setting shown in the Figure 5.

2.5 Voltage Related Active Power Reduction

Similar to the previous case, active power reduction is not required within the RfG. EN also does not directly define this requirement, but allows the implementation of a function that reduces the active power depending on the voltage in order to prevent the overvoltage protection tripping. Based on our long time practice in the field, control characteristic in Figure 6, which is characterized by two points - values of voltage for 100% and 0% of nominal inverter power is the most commonly implemented. The setting of control characteristics in Figure 6, is commonly required by the largest DSO in the Czech Republic. However, different settings can be required individually in connection agreements.

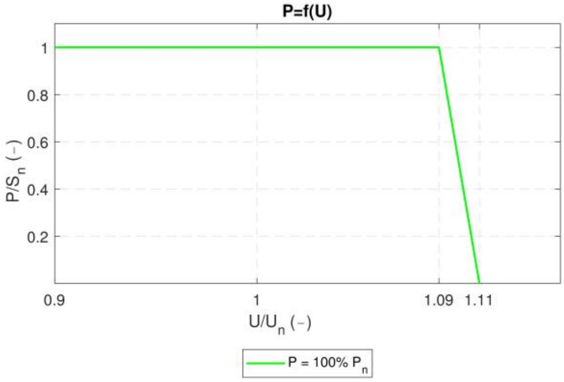

Figure 6

The most common setting of voltage related active power reduction control in the Czech Republic

3 Test Platform and Tested Inverters

A test platform with the necessary equipment for complex compliance testing of 1-phase and 3-phase PGUs and components of PGMs up to 50 kW with the requirements of EN 50549-1/2 [14] [15], RfG [13] and PPDS:P4 [16] was built at Department of Electrical Power Engineering at Brno University of Technology. Its composition allows to simulate low voltage alternating current system, enabling the simulation of selected phenomena on the output voltage, separately from the public DS, for testing the behavior and response of the inverter based PGUs or components of PGMs, but also more complex local energy management systems in cooperation with battery energy storage systems and loads. The wiring diagram with all of the equipment used for compliance verification is shown in Figure 7.

Selected laboratory equipment allows to perform repeatable tests always with the same parameters according to predefined test procedures. A DUT – in this case a tested PV inverter is supplied by programmable DC source at its DC side. DC source can be operated in PV simulator mode and is able to simulate various nonlinear voltage-current characteristics of PV module or PV array up to 10 kW. The 4-quadrant AC programmable source is powered by DS and it is used to create an artificial grid where the tested inverter is connected. Source output voltage and frequency can be changed arbitrarily and different test sequences can be programmed using the appropriate software. Selected quantities (voltage, current, power, etc.) were measured at the inverter´s input and output. Aggregated values were recorded every 50ms - the smallest sample time of the analyzer used.

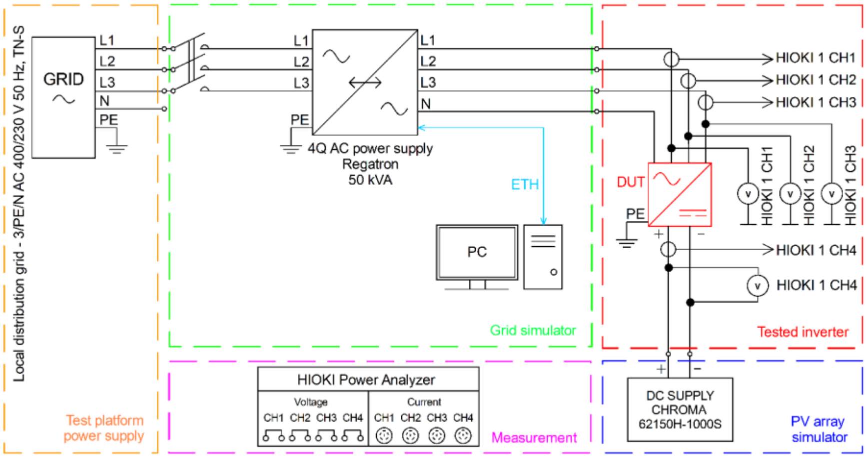

Figure 7

Test platform wiring diagram for inverters verification purposes

Overall, three photovoltaic inverters from three different manufacturers were tested. Their brief specification and marks used in the results presentation are given in Table 2. All of the tested inverters are available on the common European market and were purchased in the Czech Republic while also had a declaration of conformity with RfG and EN. Before the testing, the firmware was updated to the latest version. Then, they were configured in order to operate according to Czech grid code. This option is available in user interface of each inverter after entering the installer code and this is the most common way of parametrization by certified installers based on which they declare the compliance in "Document of generating module", which is required by DSO.

Table 2

Inverter's specifications

Mark	**Nominal power P_n [W]**	**Number of phases [-]**	**Type**
A	10000	3	hybrid
B	6000	3	hybrid
C	6000	3	hybrid

4 Results and Comments

Graphs, which are used for the results presentation and evaluation of the individual requirements described in chapter 2, contains the measured values together with the required response of the inverter according to the requirements in the Czech Republic. In order to allow easy comparison of the results, values of active and reactive power were converted into per unit system. A base unit to which measured values are referenced are nominal power outputs of each inverter. Inverters B and C were tested at output power equal to 100% of nominal, while inverter A at 80% of nominal due to laboratory equipment and MPPT input limitations.

The first of the verified requirements is automatic connection and starting to generate electric power after a fault. In this case, the 3-phase symmetrical overvoltage was simulated as the fault and the integrated interface protection of all inverters tripped. The course of the active power from the moment when the voltage returns to the nominal value is shown in Figure 8 The frequency was equal to the nominal value of 50 Hz and constant during the whole test. As can be seen, the inverter B and C fulfill the requirement on time delay before synchronizing to the grid after the voltage and frequency return to the interval between limit values, because the observation time until the inverters started to generate power was exactly 300 s. Subsequently, inverter C increased the output power with a gradient of precisely prescribed 10% P_n/min while inverter B with a slightly lower gradient, namely 9.66% P_n/min. However, a gradient lower than the prescribed one is allowed and therefore it can be concluded that the inverter B and C meets the requirements. On the contrary, Inverter A synchronized to the grid approximately 30 s after the voltage returned to the limits and began to supply all available power almost immediately. This means that it does not respect the requirements in the Czech republic and therefore, does not comply.

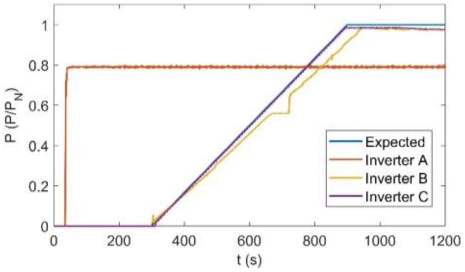

Figure 8

Active power during starting to generate electrical power after synchronization

Verification of withstand capability to fast frequency changes was performed for overall three changes, as can be seen in the right part of Figure 9. All the frequency changes were performed with ROCOF = 2 Hz/s, as this is the minimum required rate that the inverters must withstand. At the beginning of the test sequence, the voltage and frequency were kept constant until inverters synchronize. After inverters ramped up to the available power and reached a steady state, the frequency was increased by 1 Hz, followed by 2 Hz decrease and 1 Hz increase back to the nominal frequency. The decisive criterion for the ROCOF requirement compliance evaluation is that the inverter remains connected and is able to operate during fast frequency changes. As can be seen in the left part of the figure, all three tested inverters remained connected and continued to supply active power to the grid. Therefore, the requirement for ROCOF immunity can be considered fulfilled and in compliance with the requirements in the Czech Republic for all tested inverters.

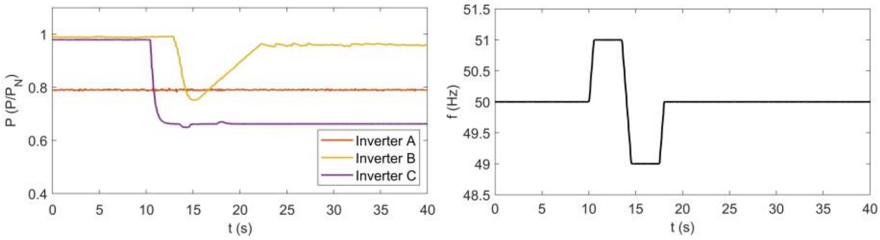

Figure 9

Active power response to rapid frequency changes

As already mentioned, the inverters have been configured to default setting for the Czech Republic without any changes, and thus active response to frequency changes (LFSM-O) should be activated. Inverter A did not respond in any way to the frequency drop, which probably indicates that it has a high response time, or this function is not active. For inverters B and C, the active power decrease occurs, probably due to LFSM-O, while it can be seen that the inverters have different response and inverter B has higher response time. In the next sequence, a test dedicated exclusively to the verification of LFSM-O will be described, where this behavior will be clarified.

At the beginning of testing sequence for verifying of LFSM-O compliance, similar to the previous case, constant frequency and voltage were applied at the inverters terminals to reach the steady state. After that, the test sequence continued by the smooth increase of the frequency from the nominal value up to 52 Hz, followed by the smooth decrease back to the nominal value with 5 mHz/s rate of change of frequency. The frequency during the testing sequence can be seen in the right part of Figure 10 and the response of the inverters in the left part. The measured values were also averaged in one second and plotted in the P-f area (Figure 11) for easy compliance assessment and evaluation of the response settings (frequency threshold for activation and deactivation of the function, reference power and droop). The results show that, as indicated by the ROCOF test, power output of inverter A does not respond to frequency changes. In addition, the integrated interface protections tripped the inverter at 51.8 Hz. This behavior does not meet the requirements for LFSM-O even for the protection settings (in the Czech Republic, the non-synchronous PGMs shall be disconnected if the frequency exceeds 52 Hz). In this respect, inverter B and C did not show any deviations and LFSM-O is active in both of them. Droop and threshold value for activation are correctly set. On the other hand, inverter B does not have set the threshold value for deactivation and therefore does not comply with the requirements. Inverter C has a correctly set threshold value for deactivation, but does not respect the prescribed power increase gradient to be applied according to EN. After reaching the threshold value for deactivation, it waits for 300s and after that, it ramps up the output power to the available power rapidly. For this reason, it can be concluded that only inverter C has LFSM-O in compliance with the requirements in the Czech Republic, but it does not conform with EN.

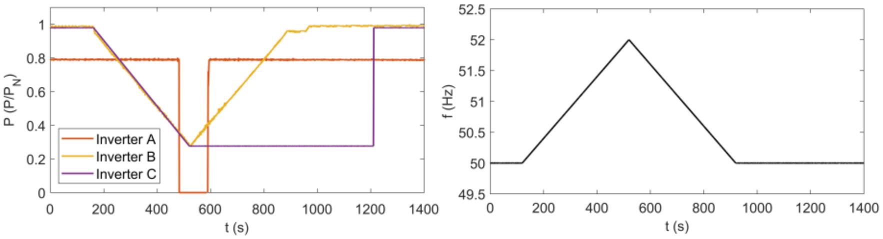

Figure 10

Active power response to over-frequency

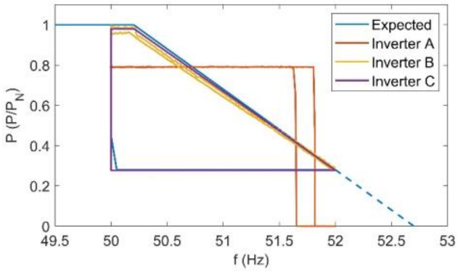

Figure 11

Active power response to over-frequency in P-f area

To verify the response of active and reactive power to voltage changes, a gradual change of voltage from a nominal value to 258 V, followed by a gradual decrease to 202 V and a return to the nominal value was used after steady state was reached. The rate of change of voltage was 50 mV/s. The test signal can be seen in the right part and the reactive and active power response in the left part of Figure 12 and Figure 13, respectively. Similar to the previous case, measured values were averaged in one second and plotted in Q-U and P-U area (Figure 13) respectively. Based on the measured data, it is clear that the inverter A was operated with a constant power factor (approximately about 0.9) and both the Q(U) and P(U) control mode were not active. In addition, it was not capable of continuous operation at a voltage lower than 215 V, when it was disconnected. Due to incorrect implementation of the requirements for automatic connection and the starting to generate electrical power, the inverter was repeatedly connected and disconnected from the grid, with the disconnection occurring after the output power has increased to the available power. This behavior can have a negative impact on the power quality, especially on the voltage fluctuations at the point of common coupling. Measured values during period of repeated connection and disconnection have been removed from P-U and P-Q area for better readability. Inverter B activated the control mode for voltage support by reactive power depending on the voltage both in the case of an increase and a decrease in voltage.

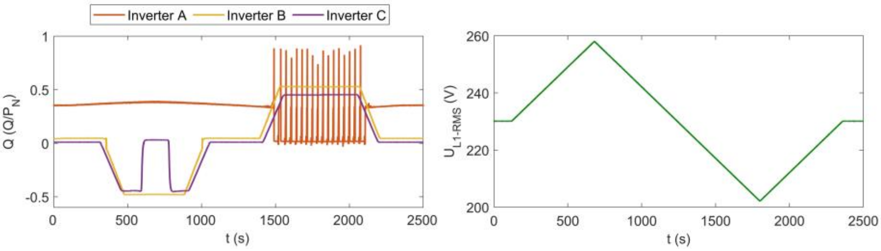

Figure 12

Reactive power response to voltage changes

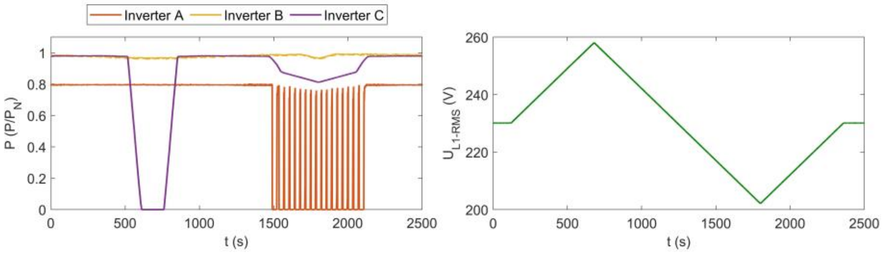

Figure 13

Active power response to voltage changes

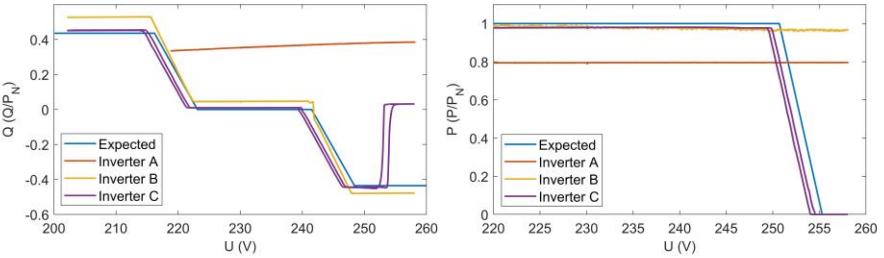

Figure 14

Reactive and Active power response to voltage changes in Q-U area and P-U area respectively

It is clear from the Figure 14 that the parameters of the Q(U) control mode are not in compliance with the requirements in the Czech Republic because inverter exceeds maximum and minimum required reactive power and therefore reaches lower power factor than 0.9 in both cases. Voltage dependent active power regulation was not activated in the entire tested voltage range. Invertor C supplies the reactive power according to required Q(U) control characteristic, but values of reactive power are a little bit shifted to the left. This could occur due to different measurement uncertainty of the inverter and power analyzer. Also, reactive power response is not exactly the same for the same voltage when voltage is increasing and decreasing respectively. Active power response to voltage is valid and according to requirements, but same the same statements are valid as in the previous case. After active power was limited to the zero, inverter was no longer able to provide reactive power support of voltage. The measured values were also processed into the P-Q area (Figure 15) together with the expected working space according to the nominal apparent power declared by the manufacturer. Inverter B and C are able to exceed the nominal current limits, while for inverter A, this could not be assessed. In view of the above facts, it is clear that none of the tested inverters is in compliance with the requirements for the reactive power supply depending on voltage, and only inverter C, is in compliance with the requirement for voltage related active power reduction.

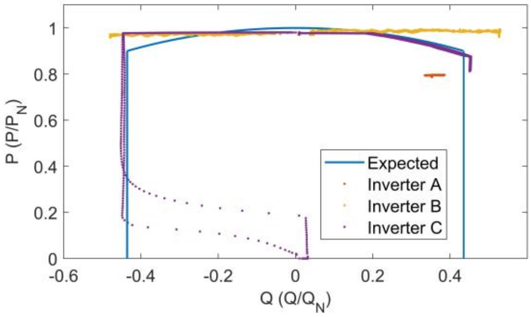

Figure 15
PQ diagram of tested inverters

Conclusions

This paper examines the requirements imposed on one of the most crucial components of non-synchronous power generating modules - photovoltaic inverters and experimental laboratory verification of their compliance with the requirements in the Czech Republic. Verification was carried out in ResLab laboratory at Brno University of Technology. The main goal is to present the actual situation in this area and to point out the serious problems, that occur in the implementation of requirements, by the inverter manufacturers.

Overall, three inverters were tested. It was found and proven by the results obtained and presented in this paper, that none of the tested inverters fulfilled the requirements according to the RfG, EN 50549-1 standard and their Czech localization, through the grid code referred here as PPDS:P4. This fact leads to the conclusion that PV inverter manufacturers are not able to correctly and consistently implement the requirements, as defined by national/international standards and regulations, as well as provide sets of settings for individual markets and local grid code requirements. If this trend continues, it may, in the future, have a fundamentally negative impact on the safety, reliability, quality, efficiency and predictability of the DS operations, as well as the operations for the entire electric power system.

Among the most significant deviations found were:

- Not respecting the grid parameters observing time before synchronizing and subsequent power rise gradient after fault
- Inactive or incorrectly set active power response at over-frequency
- Inability to operate in the entire operating range of voltage
- Inactive or incorrectly set reactive power response to voltage changes
- Inactive or incorrectly set active power response to voltage changes

Considering the above mentioned, we strongly recommend the swift establishment of standards for testing and verification of non-synchronous power generating modules, units and components. Furthermore, the introduction of certification processes and accredited laboratories, intended for the detailed examination of the compliance of all power generating modules, to be used in parallel operation with DS, at least within the type range.

Last, but not least, reliable requests and control of compliance with any imposed requirements, not only on the basis of a declaration of conformity, but on the basis of certificates issued by third parties, for example, certified laboratories that have no economic motivations, in relation to a component manufacturer.

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