Testing and Certification procedure for distributed power generating units according to the new CEA Regulation for grid connectivity in India

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Abstract—**This paper presents a testing and certification procedure for the evaluation of grid compliance of power generating units (mainly wind and inverter-based solar stations), according to the amended Regulation released by the Central Electricity Authority of India (CEA) in February 2019.**

Keywords-component; Central Electricity Authority (CEA); grid compliance; harmonics, IEC, IEEE; OVRT; UVRT

I. INTRODUCTION

During the last years, a substantial upgrade of the grid connection requirements for power generating units (PGUs) is taking place worldwide. New requirements for PGUs are introduced in most countries to ensure robustness and frequency/voltage support on the grid, such as Overvoltage Ride Through capability (OVRT) and the Frequency - Active Power response characteristics [1]-[7]. The main drivers for these changes are the evolution in the control capabilities of the units using power electronic inverters as well as the expansion of the distributed generation. In addition, the establishment of harmonized rules for grid connection of all PGUs is important for the regulatory authorities and the grid operators, in order to provide a clear legal framework, ensure power system security, facilitate the integration of renewable energy sources (RES) and allow a more efficient use of the network and resources, for the benefit of the consumers [1]. Therefore, most new grid code requirements apply to all types of PGUs, including synchronous and asynchronous generators, inverter based technologies (e.g. wind turbines (WTs) and solar inverters (PVs)) and offshore installations. In addition, the recent grid code requirements cover a wider range of nominal powers of the PGUs, starting from powers even below 1 kW).

On the other hand, with the establishment of new grid connection requirements, new challenges appear in the area of grid compliance testing and certification. Obviously, the testing procedures followed up to now need to be reviewed and updated accordingly. As an example, the IEC 61400-21, Ed.2 standard [8], which was widely used for WT testing for more than 10 years, was recently withdrawn and replaced with the new IEC 61400-21-1, Ed.1 [9]. In the same direction, several countries have already adapted their particular testing procedures for grid compliance certification to the latest changes in their grid codes or they are currently in the adaptation phase. In Germany, FGW has issued a new revision of the Technical Guideline 3 (FGW-TR3, [10]), which incorporates the requirements of the new German grid codes for connection to medium voltage (MV), high voltage (HV) and Extra High Voltage (EHV) [2]-[4]. The relevant German guidelines for the modelling and the certification of PGUs, systems and components have been also updated [11]-[12]. In UK, the Energy Networks Association (ENA) issued a particular Engineering Recommendation (EREC G99) to provide requirements for the connection of PGUs to the distribution networks in UK, where particular advice for the compliance testing is also included [13]. A test procedure according to the European Network Code [1] is currently under development by CENELEC Working Group TC8X WG03, while similar updates are taking place also in other countries such as in Spain, where the special procedure for wind and photovoltaic farms used up to now [14] is expected to be replaced.

In India, the Central Electricity Authority (CEA), after five years from the previous amended Regulations for grid connectivity requirements, where requirements for wind turbines and generating stations using inverters were included for the first time [16]-[17], has come up with an amended Regulation in February 2019, with modifications and new connection rules [18]. The experience from testing and certification according to the previous requirements has shown that the existence of a dedicated testing and certification procedure for the verification of grid compliance, as described in [19], is important for all involved parties (public authorities, manufacturers, testing and certification bodies etc.) to work more efficiently and speed-up the installations of distributed power generating stations in India. Apparently, an updated procedure has to be followed from now on, following the latest CEA amendment. The aim of this paper is to propose an updated testing procedure for assessing compliance with the new CEA Regulations (2019) [18], exploiting the experience of UL in testing and certification according to the former CEA Regulations (2013) [17].

Regarding the structure of the paper, in Section II, the amended requirements of the CEA standard for grid connectivity are presented. Section III includes proposals for the necessary tests for each particular electrical characteristic (fault ride through capability, flicker, harmonics, grid protection and control requirements). In Section IV, a brief discussion on the certification procedure for the assessment of grid compliance is included, while the conclusions of the present work are summarized in Section V.

II. CEA REQUIREMENTS FOR GRID CONNECTIVITY

The Indian regulatory framework for the connection of PGUs was introduced in the CEA Regulations (2007) [16], where the general standards for grid connectivity are prescribed. In 2013, CEA issued a first Amendment [17], where particular requirements for wind and power converter based generating stations were included. With the latest Amendment of 2019 [18], CEA expanded the range of application of the grid connectivity requirements to all PGUs and voltage levels, while further requirements for the grid support have been incorporated like the capability of the units to remain connected after overvoltage events (OVRT) and the capability to control the active power in under- and over-frequency events. A summary of the complete scope of CEA requirements in power quality, control capability and response in transient events is given below.

A. Electrical characteristics in normal operation (PQ)

The power quality parameters of interest are the harmonics, DC current injection and flicker. The CEA Regulation does not refer explicitly to any measurement guideline but incorporates the following provisions:

- With regard to harmonic current emissions, they should not violate the limits specified in the standard 519 of the Institute of Electrical and Electronics Engineers (IEEE) [19]
- The DC current injection of the PGUs at the point of connection should not be greater than 0.5% of the rated current I_n
- The flicker emissions should be kept within the limits specified in the IEC 61000, which can be related to the IEC Technical Report 61000-3-7 [21]

The above requirements have remained unchanged in the new CEA amendment [18].

B. Control capability

Control capability requirement apply to voltage-reactive power (Q-U) and frequency-active power (P-F) control. More specifically, the following requirements apply:

i. *Reactive power capability:* PGUs shall be capable of supplying the necessary reactive power in order to ensure that power factor is kept within the limits of 0.95 lagging and 0.95 leading

ii. *Frequency range test:* PGUs shall be capable of remaining connected to the network and operate within the frequency range of 47.5 Hz to 52 Hz. In addition, they should be able to deliver rated power in the frequency range of 49.5 to 50.5 Hz, subject to availability of the primary energy source (i.e. wind speed or solar radiation). This performance shall be also achieved with a voltage variation of up to ± 5 %.

iii. *Active power set-point control:* PGUs shall have the capability of set-point control of the active power following the orders given the relevant Load Dispatch Centre.

iv. *Active power ramp rate limitation:* PGUs shall be equipped with the facility for controlling the rate of change of power output at a rate not more than ± 10% per minute.

v. *Frequency sensitive mode:* PGUs shall have the capability to control active power in case of over – and under-frequency at a droop between 3 to 6% and a dead band ≤ 0.03 Hz.

vi. *Synthetic inertia:* For frequency deviations < 0.3 Hz, the station shall have the facility to provide within 1 second power frequency response of at least 10% of the maximum active power capacity.

It should be noted that, according to CEA, requirements from (iii) to (vi) apply for generating stations with installed capacity of more than 10 MW connected at voltage level of ≥33 kV.

C. Fault-ride-though-capability

Fault-ride-through (FRT) capability in the amended CEA Regulation [18], includes also the requirement for OVRT Capability of PGUs. The required voltage profile is shown in TABLE I. and Fig. 1. The requirements for grid support during the voltage dips are the following:

- During the voltage dip, the supply of reactive power has first priority, while the supply of active power has second priority.
- Active power after voltage dips clearance shall be restored to at least 90% of the pre-fault level within 1 sec of restoration of voltage.
- For overvoltage events, the only requirement is that the PGUs shall remain connected to the grid

D. Grid protection system

According to CEA initial Technical Standard [16] the protection system shall reliably detect faults on various abnormal conditions.

TABLE I. MINIMUM REQUIREMENTS OF UVRT/OVRT CAPABILITY OF PGUS ACCORDING TO CEA REQUIREMENTS

Percentage undervoltage at the interconnection point V_T/V_n [a]	Fault duration [ms]
0.15	300
0.85	3000
0.90	10000
$0.90 \leq V \leq 1.10$	Continuous
$1.10 < V \leq 1.20$	2000
$1.20 < V \leq 1.30$	200
> 1.30	0 (Instantaneous trip)

a. V_T/V_n is the ratio of the actual voltage to the nominal system voltage.

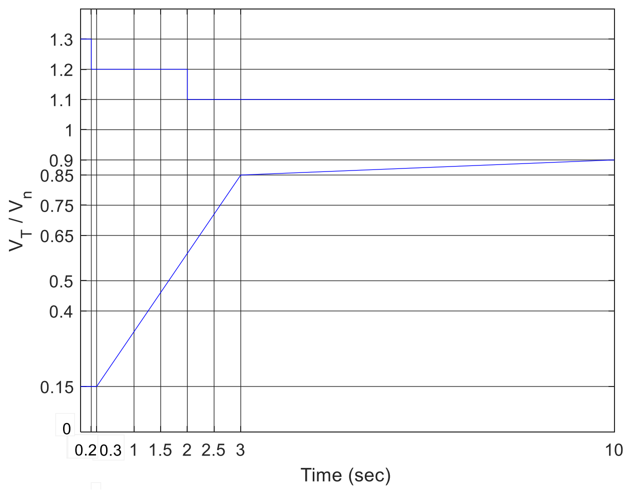

Fig. 1. Lower and upper limit of the voltage-against-time profile of any or all phases at the interconnection point according to the amended CEA Grid Connectivity Standard [18].

III. PROPOSED TESTING PROCEDURE

For the certification of PGUs according to CEA requirements, a proper measurement and testing procedure is necessary. In [19], a detailed test procedure is introduced, following the previous CEA Regulations (2013) [17]. With the new amended CEA Regulation (2019) [18] as well as the release of the new IEC 61400-21-1 standard [9], this procedure needs to be adapted at several parts. Considering these latest developments and based on the experience and know-how acquired by UL with the implementation of the previous CEA Testing procedure over the last 5 years, an updated procedure is proposed in the next. For completeness purposes, the proposed procedure covers the full scope of CEA requirements, including those from the previous amendment which remain active.

A. Flicker measurements and maximum power

The CEA requirements for flicker did not change with the new amended Regulation. The flicker emissions of PGUs should comply with the limits imposed in IEC 61000 series of standards, which in turn corresponds to IEC TR 61000-3-7 [21]. For these measurements, the test procedure of IEC 61400-21-1 is sufficient, as it illustrates the behavior of the tested unit over the complete active power range. The flicker report shall be based on 10-min flicker measurements in continuous operation of a duration, which is long enough so that sufficient data in all 10% power bins from 0% to 100% of the nominal power are collected. In addition to flicker in continuous operation, the relevant flicker produced during switching operations shall be calculated as well as the relevant voltage change. The measurement reports, typically do not include any assessment of compliance with the limits included in the IEC 61000-3-7. The same data set used for the flicker calculations in continuous operation can be also used for the evaluation of the active power. Although the reporting of maximum active power is not explicitly required by CEA, it is recommended that the relevant parameter is also included in the results report.

B. Harmonic measurements

CEA requires that the harmonic current injection of PGUs shall not exceed the limits specified in IEEE standard 519 [20]. This requirement remained also unchanged after the release of the new CEA Regulation but it is necessary that the harmonics measurement procedure to be followed from now on is compatible with the new IEC 61400-21-1 standard [9]. A basic difference between this new IEC standard, compared to the old IEC 61400-21 [8], is the harmonic aggregation method, which is now common with the IEEE 519 method. However, there are still differences between the two guidelines, which have to be taken into account when assessing the relevant grid compatibility, presented in TABLE II. In this table, the contents of the old IEC 61400-21 are also included to highlight the changes in the procedure followed up to now.

It should be stressed at this point, that the harmonic measurement method proposed by the IEEE 519 standard is mainly oriented to loads operating at constant power. From that perspective, measurement on daily and weekly basis may not cover all power levels in case of WTs and may not be sufficient. Therefore, it is recommended that the power-bin-wise measurement procedure is adopted, as per IEC 61400-21-1. The averaging time and the aggregation method of IEEE 519 can be applied afterwards for the evaluation of the harmonic results.

TABLE II. COMPARISON BETWEEN IEC AND IEEE STANDARDS WITH REGARD TO THE HARMONIC EVALUATION PROCEDURE

Parameter / procedure	IEC 61400-21, Ed.2	IEC 61400-21-1, Ed.1	IEEE 519
Instrumentation	Compatible with IEC 61000-4-7 and 61000-4-30		
Averaging time	10 min	10 min	3s / 10 min
Number of measurements	≥ 3 for each 10 % power bin	≥ 7 for each 10 % power bin	≥ 24h for 3s and ≥ 7days for 10 min
Aggregation method	Arithmetic	Arithmetic	Geometric
Harmonic frequencies	up to 9 kHz	Up to 9 kHz	Integer harmonics up to 50th order
Statistical assessment	Max of all measurements per power bin	95th percentiles of all measurements per power bin	95th and 99th percentiles for each 24h
Parameter	Current	Current	Current / Voltage

C. Measurement of DC current injection

Measurement of DC current injection is not addressed in the IEC 61400-21-1. Instead, IEEE standard 1547.1 [25] includes a detailed procedure for the measurement and the data analysis, proposed for inverters that connect to the grid without the use of *dc*-isolation output transformers, which may serve as a guide. Taking this standard into account a dedicated test can be executed, where it is requested to measure harmonics for a period of ≥ 5-min period at three different power levels (33%, 66% and as close to 100% of P_n as possible) and then calculate the *dc* component. This implies that the PGU has to operate with a set-point power but it is acceptable if standard harmonic measurements within the power bins of 30%, 70% and 100% (midpoints) are used, as defined in the IEC 61400-21-1. It is important to note that the current sensors to be used for the measurement of the *dc* current injection must be capable of measuring the zero Hz component correctly.

D. Testing of control requirements

For proving the control capability of the PGUs according to the CEA requirements (*II.B-i* to *II.B-vi*), the procedures described in the corresponding sections of the IEC 61400-21-1 standard can be followed, as given in TABLE IV. The detailed steps for each test are included in the IEC 61400-21-1 and they are not given again in this paper. For some tests, the exact settings to be used may need to be properly adapted to consider the particular requirements of CEA, if necessary. For example, for testing the reactive power capability, the maximum reactive power setting (Q_{max}) of the PGU shall be set to a value that ensures that the power factor will be at least 0.95.

Especially for the frequency range test (*II.B-ii*), this is not covered by the IEC 61400-21-1 and therefore a special procedure shall be followed, as explained below:

i. *Frequency Range Test - Option 1:* This test can be implemented virtually by providing the relevant external frequency signal to the PGU controller (apparently through the use of the proper grid simulator device). Alternatively, a frequency offset signal can be directly implement in the controller software. The Testing Laboratory (TL) shall record the active power of the PGU along with the frequency signal. The test can be considered as successful as soon as the changes in the frequency do not affect the active power production of the PGU and no disconnection takes place during the execution of the test. The number of the frequency steps to be tested can be agreed between the TL and the manufacturer. Obviously, the active involvement of the manufacturer is substantial for the effective execution of this test.

ii. *Frequency Range Test - Option 2:* In case a grid emulator is available (e.g. at a test bench), it is also possible to perform this test by changing the real grid frequency. This option is mainly applicable for solar inverters.

iii. *Frequency Range Test - Option 3:* In case frequency deviations occur during the normal PQ measurement campaign, there data can also be used to support the verification of the PGU capability.

Finally, with regards to the voltage variation of ± 5% as noted in the CEA Regulation, the performance of the Frequency Range Test under different voltage levels increases the complexity, the duration and the cost of the relevant certification. Therefore, it is not recommended to include such a test as mandatory for CEA Certification unless the relevant test facility provides this possibility (e.g. by existence of a step-up transformer with proper tap changers, or using the FRT-test equipment etc.)

E. Functionality of the protection system

The aim of this test is to demonstrate the PGU ability to disconnect from the grid if the voltage or frequency for a given time exceeds a given limit (upper or lower). The intention is to focus on the functionality of the protection system rather than on documenting specific protection levels and times. This is a fundamental requirement in all grid codes and the procedure described in the new IEC 61400-21-1 [9] shall be applied. The tests can be performed either on-site or at a test bench, by applying variable voltage/frequency signals, through a proper grid simulator coupled to the protection device. A separate test of the complete trip circuit has to be performed on-site, in order to demonstrate the efficient performance of the complete PGU protection system, including the response of the relevant circuit breaker.

F. Testing of Fault Ride Through behavior

The UVRT/OVRT testing procedure included in the IEC 61400-21-1 shall be followed. This standard refers to the testing of WTs but the same procedure can be also applied for PVs, as described in IEC TS 62910 [25], as well as for other types of PGUs.

The measurements shall be performed at the high voltage side of the transformer which may coincide or not with the point of common coupling (PCC) of the PGU. Measurement at the plant level, could be also acceptable but it should be taken into account that it is difficult to meet any test equipment with nominal capacity larger than 8-10 MW in the wind industry worldwide. In any case, it should be stressed that the measurement at the terminals of the single unit (e.g. WT or PV) provides results on the safe side.

Regarding the configuration of the testing equipment, IEC 61400-21-1 accepts several principles as soon as they are technically acceptable and capable of emulating the required voltage dips/swells. For UVRT testing, the classic voltage divider is commonly used, the set-up of which is illustrated in Fig. 2. Inverter-based test systems can be also used (AC grid simulators), especially for the testing of solar inverters, which are usually tested at test benches. The emulation of OVRT tests can be performed with several methods such as the changing of the taps of a proper transformer (autotransformer principle), as illustrated in Fig. 3, or by using a capacitor-based test system, shown in Fig. 4. Both types OVRT test emulators are acceptable by IEC 61400-21-1 and reproduce similar voltage swell profiles, according to the experience of UL. Under all circumstances, the specifications and the configuration of the used equipment must meet the operational and accuracy requirements stated in the IEC 61400-21-1.

Regarding the necessary measuring points, it is recommended to measure voltages and currents at all three phases at least at the PGU side (MP2 in Fig.2). Measuring at the LV side (MP1) is typically also performed if the PGU control input signals are referred to the LV side voltage and current. Measurements at the grid side (MP3) and short-circuit branch side (MP4) are optional but recommended in order to provide additional information to the certification body and the grid operator.

In compliance with the requirements of the FGW TR3 Guideline [10], the impedances employed in the testing equipment f or a voltage dip should have an X/R ratio of at least 3. The short circuit apparent power at the testing point must be at least three times the nominal power of the generating station/plant. This represents a grid impedance with a maximum short-circuit voltage of 33%. In order to calculate the impact of the emulated voltage dips/swells on the grid, reliable information concerning the grid short-circuit power and grid impedance angle have to be provided by the grid operator. The minimum acceptable requirements for the acceptable voltage drop/swells at the grid side depend on the characteristics of the PCC and have also to be provided by the local grid operator, prior to the performance of the tests. The calculation results should be included in a preliminary study and ideally submitted to the grid operator for getting the permission for the execution of the tests.

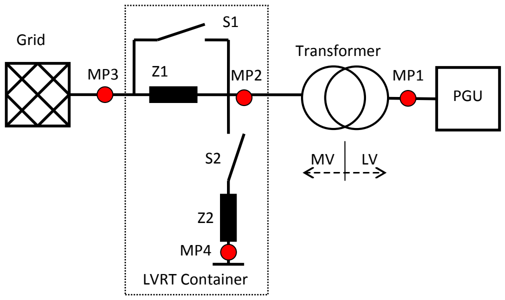

Fig. 2. Example of under voltage ride through test setup at the point of connection of a PGU. The configuration is valid as well as for power plants in the range of 10 MW

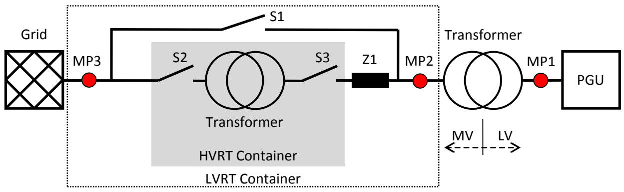

Fig. 3. Example of a transformer-based OVRT test setup combined with the series impedance Z1 of the UVRT test system.

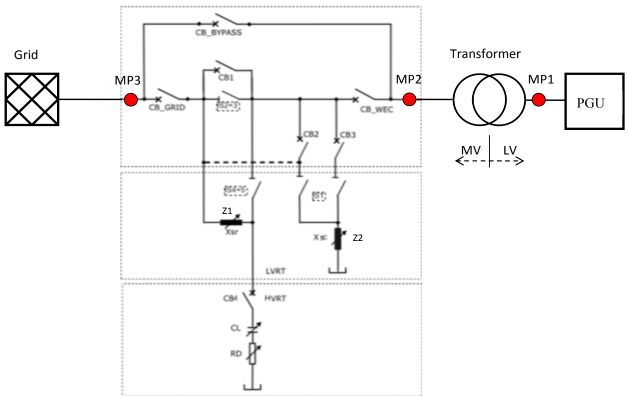

Fig. 4. Example of a combined UVRT/OVRT test system. The UVRT is following the voltage divider principle while the OVRT is capacitor-based.

Testing procedure

The on-site tests must be carried out on the complete PGU following the procedure of IEC 61400-21-1 [9]. A test bench test is permissible for PV units, where the existence of PV modules is not a necessary requirement as the power may be provided by a suitable DC source. The tests to be performed, should be selected in accordance with the voltage profile of Fig.5. In order to obtain a representative view of the behavior of the PGU under the complete range of voltage drops, at least two voltage levels in the linear area of the relevant curve of Fig.5 between 0.3 s and 3 s should be examined. A list of recommended tests at the relevant voltage levels and minimum fault durations is given in TABLE III.

The tests must be carried out for both three-phase and two-phase faults, with the PGU operating at:

- between 0.1 P_n and 0.5 P_n (partial load) and
- above 0.9 P_n (full load)
- Especially for inverter-based units tested at a test bench it is required that the tests are performed at an active power of 100% ± 2% Pn instead of > 0.9 Pn

P_n is the nominal power of the tested unit

TABLE III. Overview suggested tests for the UVRT capability of wind/PV units

Voltage magnitude[a] [pu]	Minimum Duration[a] [ms]	Fault Type	WT/PV load	Number of tests
≤ 0.15 (Test Case 1)	≥ 300	3-ph	No load	1
			$0.1\ P_n \leq P \leq 0.5\ P_n$	2[b]
			$P \geq 0{,}9P_n$	2
		2-ph	No load	1
			$0.1\ P_n \leq P \leq 0.5\ P_n$	2
			$P \geq 0{,}9P_n$	2
0.40 – 0.50 (Test Case 2)	≥ 1650[d]	3-ph	No load	1
			$0.1\ P_n \leq P \leq 0.5\ P_n$	2
			$P \geq 0{,}9P_n$	2
		2-ph	No load	1
			$0.1\ P_n \leq P \leq 0.5\ P_n$	2
			$P \geq 0{,}9P_n$	2
0.65 – 0.75 (Test Case 3)	≥ 2615[d]	3-ph	No load	1
			$0.1\ P_n \leq P \leq 0.5\ P_n$	2
			$P \geq 0{,}9P_n$	2
		2-ph	No load	1
			$0.1\ P_n \leq P \leq 0.5\ P_n$	2
			$P \geq 0{,}9P_n$	2
0.85 – 0.90 (Test Case 4)	≥ 10000	3-ph	No load	1
			$0.1\ P_n \leq P \leq 0.5\ P_n$	2
			$P \geq 0{,}9P_n$	2
		2-ph	No load	1
			$0.1\ P_n \leq P \leq 0.5\ P_n$	2
			$P \geq 0{,}9P_n$	2
>1.10 – 1.20 (Test Case 5)	≥ 2000	3-ph	No load	1
			$0.1\ P_n \leq P \leq 0.5\ P_n$	2[b]
			$P \geq 0{,}9P_n$	2
		2-ph	No load	1
			$0.1\ P_n \leq P \leq 0.5\ P_n$	2
			$P \geq 0{,}9P_n$	2
>1.20 - 1.30 (Test Case 6)	≥ 200	3-ph	No load	1
			$0.1\ P_n \leq P \leq 0.5\ P_n$	2
			$P \geq 0{,}9P_n$	2
		2-ph	No load	1
			$0.1\ P_n \leq P \leq 0.5\ P_n$	2
			$P \geq 0{,}9P_n$	2

a) The specified magnitudes refer to the voltage drop occurring when the unit or plant under test is not connected.

b) Two consecutive tests must be performed for each partial and full load case.

c) It is acceptable to test at additional voltage levels

d) It is acceptable to test at shorter durations as soon as they comply with the CEA voltage profile shown in Fig. 5

It should be mentioned that, especially for partial load tests, the IEC 61400-21-1 [1] suggests that the operating point at partial load should be between 0.25 P_n and 0.5 P_n. However, increasing the partial load range, makes the tests also compatible with the FGW TR3 guideline [10].

The operational mode of the tested units shall be explicitly specified. For each voltage dip/swell level and fault type, the relevant testing equipment configuration must be tested with a no load test. The no load tests should be performed shortly before the relevant under-load tests, in order to ensure that the same grid conditions apply.

To summarize, a graphical overview of the tests recommended in TABLE III. in conjunction with the actual CEA grid code requirements is presented in Fig.5.

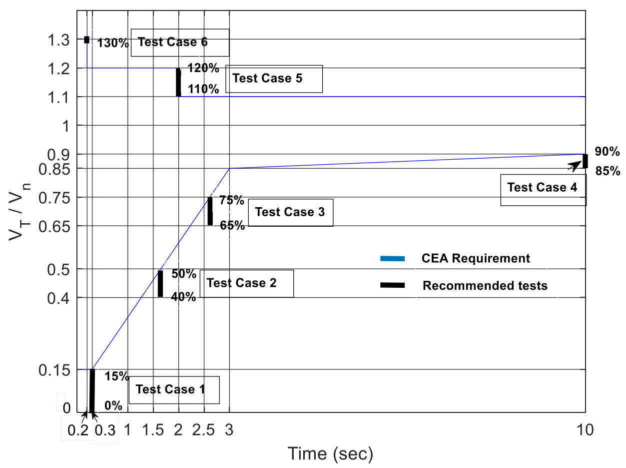

Fig. 5. Overview of the recommended under- and overvoltage ride through tests in conjunction with the CEA grid code requirements

G. General Measurement Requirements

To ensure transparency and traceability of the certification tests, the tests and measurements described in the previous paragraphs must be performed by measuring institutes accredited for the relevant services according to ISO/IEC 17025 [27]. The measurement equipment shall meet the accuracy requirements of IEC 61400-21-1. All currents and voltages must be recorded with a sufficient sampling rate to ensure minimum signal bandwidth of 1500 Hz for flicker and switchings. Sampling frequency of ≥ 10 kHz is recommended for harmonics and FRT testing (typically at least 20 kHz are required in case harmonics up to 9 kHz are displayed in the report).

H. Overview of the recommended tests according to CEA

In TABLE IV. an overview of the suggested certification tests according to the CEA Grid Connectivity Standard is given in relation to the tests included in the IEC 61400-21-1.

TABLE IV. OVERVIEW OF THE RECOMMENDED TESTS ACCORDING TO THE CEA GRID CONNECTIVITY REQUIREMENTS

No	Parameter / Control function	Current CEA Requirement	Proposed test procedure
1	Flicker (continuous operation)	≤ limits specified in IEC 61000	Acc. to IEC 61400-21-1, chapter 8.2.2
2	Flicker (switching operations)	≤ limits specified in IEC 61000	Acc. to IEC 61400-21-1, chapter 8.2.3
3	Maximum power	-	Acc. to IEC 61400-21-1, chapter 8.3.3
4	Harmonics currents/voltages up to 2.5 kHz	≤ limits specified in IEEE 519	Acc. to IEEE 519 and IEC 61400-21-1
5	DC current injection	> 0.5% of I_n	Acc. to IEEE 1547.1 [26]
6	Reactive power capability (II.B-i)	Power factor 0.95 (underexcited) ≤ cosφ ≤ 0.95 (overexcited)	Acc. to IEC 61400-21-1, chapter 8.3.4
7	Frequency Range Test (II.B-ii)	Rated power production between 49.5 Hz and 50.5 Hz and no disconnection between 47.5 Hz and 52 Hz	Special procedure as described in III.D-i
8	Active power set-point (II.B-iii)	Confirm capability	Acc. to IEC 61400-21-1, chapter 8.4.2
9	Active power ramp rate limitation (II.B-iv)	Control of the rate of change of power output at a rate not more than ± 10% per minute	Acc. to IEC 61400-21-1, chapter 8.4.3
10	Frequency sensitive mode (II.B-v)	Frequency control at a droop of 3% to 6%	Acc. to IEC 61400-21-1, chapter 8.4.4
11	Synthetic inertia (II.B-vi)	Real power primary frequency response of at least 10% of nominal capacity within 1 s	Acc. to IEC 61400-21-1, chapter 8.4.5
12	Fault Ride Through Capability (UVRT/OVRT)	As described in II.C. Voltage profile shown in Fig. 1	Acc. to IEC 61400-21-1, chapter 8.5.2
13	Functionality of grid protection system	Verify functionality	Acc. to IEC 61400-21-1, chapter 8.6.2

I. ASSESSMENT OF GRID COMPLIANCE

The tests proposed in the previous Section have to be properly evaluated in order to facilitate the assessment of grid code compliance for Certification according to CEA. To ensure uniformity of the test results, the reporting shall follow the minimum requirements defined in Annex A of IEC 61400-21-1 [9]. Especially for harmonics, it should be taken into account that the presented harmonic frequency and averaging times of IEEE 519 are not identical with the ones required by the IEC 61400-21-1. The relevant report should encounter these differences. An indicative checklist for CEA compliance review of the tested PGUs is included in I

TABLE V. INDICATIVE COMPLIANCE REVIEW CHECKLIST

	No	CEA requirement	Requirements	Passed?
Power Quality	1	Flicker (continuous operation)	a. Reported acc. to IEC 61400-21-1 b. Limits of IEC 61000-3-7	Yes/No
	2	Flicker (switching operations)	a. Reported acc. to IEC 61400-21-1 b. Limits of IEC 61000-3-7	Yes/No
	3	Maximum power	a. Reported acc. to IEC 61400-21-1	Yes/No
	4	Harmonic currents	a. Reported acc. to IEEE 519 b. Limits of IEEE 519	Yes/No
	5	DC current injection	a. Reported b. DC current > 0.5% of I_n	Yes/No

	No	CEA requirement	Requirements	Passed?
Control & Protection	6	Reactive power capability	a. Reported acc. to IEC 61400-21-1 b.Q_{max} setting corresponds to power factor of at least 0.95	Yes/No
	7	Frequency Range Test	Test included in the report	Yes/No
		Active power set-point	Reported acc. to IEC 61400-21-1	Yes/No
		Active power ramp rate limitation	a. Reported acc. to IEC 61400-21-1 b. ≤ ± 10% per minute	Yes/No
	8	Frequency sensitive mode	a. Reported acc. to IEC 61400-21-1 b. Frequency response acc. to the PGU setting	Yes/No
		Synthetic inertia	a. Reported acc. to IEC 61400-21-1 b. Frequency response acc.to the PGU setting	Yes/No
	9	Functionality of grid protection system	a. Reported acc. to IEC 61400-21-1 b. Verify functionality	Yes/No
Fault Ride Through	10	Active power before fault entry	At partial load: 0,1 P_n - 0,5 P_n At full load: ≥ 0,9 P_n	Yes/No
	11	PGU remained connected during and after the dip/swell?	Should remain connected	Yes/No
	12	Fault duration determined from test	≥ times defined in TABLE III.	Yes/No
	13	Voltage drop level defined by the test[a]	within voltage ranges of TABLE III.	Yes/No
	14	Reactive power during the voltage dip	Should be positive (injection of reactive power to the grid)	Yes/No
	15	Active power during the voltage dip	Should be ≥ 0, if possible	Yes/No
	16	Active power response time after voltage dip clearance	Restored to at least 90% of the pre-fault level within 1 s of restoration of voltage	Yes/No

a. to be confirmed based on the no load test because of the voltage change under load conditions

II. CONCLUSIONS

In this paper, a testing procedure to determine the electrical characteristics of all types of power generating units (including wind turbines and solar inverters) in accordance to the latest CEA requirements (2019) is proposed. As far as possible, this testing procedure follows the latest international standards and guidelines, and mainly the IEC 61400-21-1. However, some additional specifications are imposed by CEA, which need to be sufficiently addressed through dedicated tests.

The paper specifies the type and number of field tests and measurements to be performed, the measurement and evaluation specifications (duration of measurements, statistical evaluation process etc.) as well as reporting requirements. In some cases, further discussion on the interpretation of certain CEA requirements is included. In addition, the paper contains proposals for the efficient assessment and interpretation of the results to ensure that the final decision is according to CEA requirements.

The proposed procedure should replace the one used up to now for more than 5 year, which was based on the previous CEA Regulation (2013), and it is expected to contribute to the fast adoption of the new CEA requirements by all involved parties, speeding-up the grid compliance evaluation process followed by the public authorities in India.

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