measnet

Measuring-Network of Wind Energy Institutes

Procedure for Measurement of Electrical Characteristics

Document: ECExG.PMEC.DOC 2019.06 v1

List of Contents

Foreword

MEASNET is a network of measurement institutes which have been established to harmonise wind energy related measurement procedures. The institutes of MEASNET are all actively performing wind energy related measurements. Each institute has to document the skills and quality of measurements, to apply agreed “MEASNET measurement procedures” and to participate as required in comparative assessment experiments.

This version 1 cancels and replaces the MEASNET Power Quality Measurement Procedure version 4.

Introduction

The MEASNET Procedure for Measurement of Electrical Characteristics is the measurement procedure agreed upon by the MEASNET members to be mutually used and accepted. This Procedure is considered to be the most internationally accepted procedure on which a common interpretation and understanding has been exercised in accordance with the MEASNET Quality Evaluation Program, based on the objective of continuously improving quality in measurements.

1. Scope

This MEASNET Procedure includes:

- Clarifications in the procedure and the definitions of specific parameters of IEC 61400-21-1 [2], for a more consistent and uniform determination of the relevant electrical characteristics of grid-connected wind turbines, where necessary (Annex A)
- Measurement procedure for quantifying the electrical characteristics according to the Grid Connectivity Standards issued by the Central Electricity Authority (CEA) of India (Annex B)
- Measurement procedure for quantifying the electrical characteristics according to the European Commission Network Code for Generators (EU) 2016/631 of 14 April 2016 (Annex C)
- Measurement procedure for quantifying the electrical characteristics according to the Grid Code of China (Annex D)
- Measurement procedure for the measurement and the evaluations of current and voltage harmonics according to the IEEE 519 standard (Annex D)
- Description of the methodology for calculating the uncertainty of the electrical characteristics (Chapter 3)

The above measurement procedures are recommended to be followed in case of no other specific requirement (e.g. from the grid codes).

In case of other grid codes where no specific measurement procedure and/or requirements are available, it is recommended that the measurement procedure according to IEC 61400-21-1 is followed, as described in Annex A.

For the improvement of the quality of measurements and the more accurate determination of the current and voltage harmonics, it is recommended that the calibration of the current and voltage transducers to be used, is performed according to the MEASNET Calibration Procedure for Transducers [4].

2. Normative references

[1] ISO/IEC 17025: 2017: General requirements for the competence of testing and calibration laboratories

[2] IEC 61400-21-1: 2019, Wind energy generation systems – Part 21-1: Measurement and assessment of electrical characteristics – Wind turbines, Ed.1.

[3] ISO/IEC Guide 98-3:2008, Uncertainty of Measurement-Part 3: Guide to the expression of uncertainty in measurement (GUM 1995)

[4] MEASNET, Calibration Procedure for Transducers, Revision 1, 16th April 2019

Further references are given in the specific annexes.

3. Evaluation of measurement uncertainty

3.1. Types of Uncertainty

Evaluation of measurement uncertainty is a requirement of ISO/17025 standard for accredited laboratories. For the calculation of the uncertainty the general rules described in ISO/IEC Guide 98-3: 2008 should be followed [3].

The basic measured electrical characteristic (EC) parameters in the testing of wind turbines to be considered for the uncertainty evaluation are the voltages and currents. The other EC parameters such as active and reactive power, flicker and harmonics etc. are calculated from the measured voltages and currents. Wind speed is also recorded during the testing campaigns, however its uncertainty has limited influence on the evaluation of the electrical characteristics.

In general, uncertainty consists of two types:

- **Type A uncertainty**, which is associated with the statistical distribution of measurements and
- **Type B uncertainty**, which is associated with systematic errors introduced by measuring instruments and software tools and can be estimated using data provided in instruments' calibrations, manufacturer's specifications and round robin (proficiency) tests.

The **Total Uncertainty** of a measurement is a combination of both types.

The general way of estimating **Type A uncertainty** of the average value based on a measured data set X is by calculating the standard deviation (σ). Then the standard Type A uncertainty can be estimated as

$$\boldsymbol{u_A} = \frac{\boldsymbol{\sigma}}{\sqrt{\boldsymbol{n}}} \qquad (1)$$

where n is number of measurements in the data set X.

A **Type B uncertainty** is introduced by measuring instruments and can be evaluated from manufacturer specifications and calibration certificates. This information usually allows estimating accuracy for only upper and lower limits of measurement range. It is assumed in [3] that a probability distribution with constant probability density between limits (rectangular probability distribution) can be used for possible variability of the measured quantity. This is taken into account by dividing the Type B standard uncertainty by $\sqrt{3}$.

The Type A and Type B uncertainties presented above, correspond to the standard uncertainty of the true value of the measured quantity, which in practice means that the true value could be within the defined uncertainty range with a level of confidence of approx. 67%, assuming that the considered values are normally distributed. According to the requirements of the ISO/IEC 17025 the expanded uncertainty should presented, in order to provide a range with a level of confidence close to 95%. For this reason the expanded uncertainty ***U*** is calculated by multiplying the standard uncertainty by a coverage factor ***k=2*** as follows:

$$\boldsymbol{U} = \boldsymbol{k} \cdot \boldsymbol{u} \qquad (2)$$

3.2. *Uncertainty evaluation*

For the evaluation of the total uncertainty in the measurement if electrical characteristics, the following procedure should be followed:

a. Type A Uncertainty

Type A uncertainty is not relevant for the measurement of electrical characteristics according to this Procedure because of the averaging effects and the defined minimum number of measurements to be collected.

b. Type B Uncertainty

Type B uncertainty consists of the sensors' and data acquisition uncertainty and the evaluation software uncertainty.

The sensors' and data acquisition uncertainty is associated with the instruments' uncertainties and more specifically to the current/voltage transducers, the measuring system and the A/D card. The wind speed uncertainty includes also the uncertainties due to the mounting of the anemometer on the wind mast.

Table 1. Type B Uncertainty in measurement of currents, voltages, powers and wind speed

Uncertainty component	Assumptions	Uncertainty value, u_i
Uncertainty of current/voltage measurement transducers at nominal frequency and up to 2 kHz	▪ According to MEASNET Calibration Procedure of Current/Voltage Transducers [4]	u_{CT}, u_{VT} (% of the nominal value)
Uncertainty of current/voltage measurement transducers at higher frequencies	▪ According to MEASNET Calibration Procedure of Current/Voltage Transducers [4]	$u_{CT,>2kHz}$, $u_{VT,>2kHz}$ (% of the nominal value)
Uncertainty of signal conditioning and data acquisition equipment at nominal frequency and up to 2 kHz	▪ According to the calibration report and specifications sheet ▪ The maximum uncertainty of all channels to be considered ▪ Typical error follows a rectangular distribution	u_{SC_DAQ} (% of the nominal value)
Uncertainty of signal conditioning and data acquisition equipment at higher frequencies	▪ According to the transducer's calibration report. ▪ The maximum uncertainty of all channels to be considered ▪ Typical error follows a rectangular distribution	$u_{SC\_DAQ,>2kHz}$ (% of the nominal value)

Uncertainty component	Assumptions	Uncertainty value, u_i
Total uncertainty of current/voltage measurement at nominal frequency and up to 2 kHz	▪ $u_{A,meas} = \sqrt{u_{CT}^2 + u_{SC\_DAQ}^2}$ ▪ $u_{V,meas} = \sqrt{u_{VT}^2 + u_{SC\_DAQ}^2}$ ▪ In the above equation u_{CT}, u_{VT} and u_{SC_DAQ} are considered as absolute values	$u_{A,meas}$, $u_{V,meas}$ (% of the nominal value)
Total uncertainty of current/voltage measurement at higher frequencies	▪ $u_{A,meas,>2kHz} = \sqrt{u_{CT,>2kHz}^2 + u_{SC_{DAQ},>2kHz}^2}$ ▪ $u_{V,meas,>2kHz} = \sqrt{u_{VT,>2kHz}^2 + u_{SC\_DAQ,>2kHz}^2}$ ▪ In the above equation $u_{CT,>2kHz}$, $u_{VT,>2kHz}$ and u_{SC_DAQ} are considered as absolute values	$u_{A,meas,>2kHz}$, $u_{V,meas,>2kHz}$ (% of the nominal value)
Uncertainty in active power measurement	▪ In each phase: $u_{P_i} = \sqrt{\left(\frac{\partial P}{\partial I} \cdot u_{A,meas}\right)^2 + \left(\frac{\partial P}{\partial V} \cdot u_{V,meas}\right)^2} = \sqrt{\left(U_n \cdot u_{A,meas}\right)^2 + \left(I_n \cdot u_{V,meas}\right)^2}$ ▪ p.u. values should be used in the above formula ▪ Total (3-phase) Active Power: $u_{P,meas} = \sqrt{\sum_{i=1}^{3} u_{P_i}^2}$ ▪ U_n, and I_n are the voltage and current nominal values in Volts and Amperes respectively ▪ In the above equation $u_{A,meas}$ and $u_{V,meas}$ are considered as absolute values	$u_{P,meas}$ (in % of nominal active power)
Uncertainty in reactive power measurement	▪ The uncertainty in reactive power measurement is equal to the uncertainty of the active power increased by a certain factor due to the effect of the phase angle error. This factor can be derived from sensitivity analysis. ▪ A factor of 10% is used as a minimum reference value. ▪ Total Reactive Power: $u_{Q,meas} = 1.1 \cdot u_{P,meas}$	$u_{Q,meas}$ (in % of nominal active power)
Uncertainty in frequency measurement	▪ According to the equipment's calibration report or the specifications of the measurement equipment (e.g. grid simulator) ▪ Alternatively, in case frequency is calculated directly from the voltage phase angle, the sampling frequency has to be taken into account	u_F (% of the reference value)
Uncertainty in wind speed measurement	▪ The uncertainty of the sensor should be less than $^{1}/_{\sqrt{3}}$ m/s	u_w (m/s)

- The uncertainty values of current and voltage ($u_{A,meas}$,, $u_{V,meas}$) should be calculated for each measuring channel and each sampling frequency. The maximum uncertainty should then be presented.
- As wind speed uncertainty is not critical for the evaluation of electrical characteristics, a maximum level of uncertainty is given in the Table based on the requirements of IEC 61400-21-1. It is up to the testing laboratory to estimate the level of uncertainty of the measured wind speed signal depending on the measurement procedure. Correction of the nacelle anemometer signal with the power curve of the wind turbine (as measured or given by the manufacturer) is not strictly required but it should be mentioned in the test report if the presented wind speeds are corrected or not.

3.3. Software Uncertainty

The analytical uncertainty estimation of power and flicker calculations cannot be easily implemented due to the non-linearity of the relevant models. Instead, a comparative approach could be followed based on the results of relevant inter-laboratorial tests. The derived uncertainties are included in Table 2.

Table 2. Type B - Software Uncertainty in power, flicker and harmonic calculations

Uncertainty component	Assumptions	Standard Uncertainty value, u_i
Uncertainty in active power calculation	• Standard uncertainty in active power calculation equal to e_P estimated as the standard deviation of Round Robin test results.	$u_{P,Soft} = e_P$
Uncertainty in reactive power calculation	• Standard uncertainty in reactive power calculation equal to e_Q estimated as the standard deviation of Round Robin Test results.	$u_{Q,Soft} = e_Q$
Uncertainty in flicker calculation	• Standard uncertainty in flicker power calculation equal to e_{FL} estimated as the standard deviation of Round Robin Test results	$u_{FL,Soft} = e_{FL}$
Uncertainty in the calculation of voltage change factor k_u	• Standard uncertainty in k_u calculation equal to e_{ku} estimated as the standard deviation of Round Robin Test results	$u_{k_u,Soft} = e_{k_u}$
Uncertainty in calculation of integer harmonics and interharmonics	• Standard uncertainty in harmonic calculation equal to e_H estimated as the standard deviation of Round Robin Test results.	$u_{H,Soft} = e_H$
Uncertainty in calculation of higher frequency harmonics	• Standard uncertainty in harmonic calculation equal to $e_{H,>2kHz}$ estimated as the standard deviation of Round Robin Test results.	$u_{H,Soft,>2kHz} = e_{H,>2kHz}$

3.4. Evaluation of Total Uncertainty

The Total (combined) Standard Uncertainty of the results is then derived, following the assumptions presented in Table 3.

Table 3. Total Uncertainty in power, flicker and harmonic results

Uncertainty component	Assumptions	Standard uncertainty value, u_i
Uncertainty in active power	• $u_P = \sqrt{u_{P,meas}^2 + u_{P,Soft}^2}$ • The value of u_P is expressed in % of the nominal active power	$u_P(\%)$
Uncertainty in reactive power	• $u_Q = \sqrt{u_{Q,meas}^2 + u_{Q,Soft}^2}$ • The value of u_Q is expressed in % of the nominal active power	$u_Q(\%)$
Uncertainty in flicker	• $u_{FL} = \sqrt{u_{A,meas}^2 + u_{FL,Soft}^2}$ • $u_{A,meas}$ is the uncertainty in current measurement in % of Reference Value (see Table 1)	$u_{FL}(\%)$
Uncertainty in flicker step factor	• The uncertainty u_{k_f} is directly related to flicker estimation uncertainty u_{FL} • $u_{FL} = u_{k_f}\ (\%)$ • u_{FL} is the flicker total uncertainty	$u_{k_f}(\%)$
Uncertainty in voltage change factor	• The uncertainty u_{k_u} is related to current measurement uncertainty $u_{A,meas}$ (see Table 1) and the software uncertainty $u_{k_u,Soft}$ • $u_{k_u,meas} = 2 \cdot u_{A,meas}\ (\%)$, where the number 2 derives from the hypothesis that the values $U_{fic.,max}$ and $U_{fic.,min}$ are fully correlated • $u_{k_u} = \sqrt{u_{k_u,meas}^2 + u_{k_u,Soft}^2}$	$u_{k_u}(\%)$
Uncertainty in current/voltage integer harmonics and interharmonics	• $u_{AH} = \sqrt{u_{A,meas}^2 + u_{H,Soft}^2}$ • $u_{VH} = \sqrt{u_{V,meas}^2 + u_{H,Soft}^2}$	$u_{AH}(\%)$ $u_{VH}(\%)$
Uncertainty in current / voltage harmonics at higher frequencies	• $u_{AH,>2kHz} = \sqrt{u_{A,meas,>2kHz}^2 + u_{VH,Soft,>2kHz}^2}$ • $u_{VH,>2kHz} = \sqrt{u_{V,meas,>2kHz}^2 + u_{VH,Soft,>2kHz}^2}$	$u_{AH,>2kHz}(\%)$ $u_{VH,>2kHz}(\%)$
For the expanded uncertainty *U_i*, a coverage factor of k=2 (see equation (2)) should be considered for calculating the above uncertainties		

Annex A:

IEC 61400-21-1: 2019

Wind energy generation systems – Measurement and assessment of electrical characteristics – Wind turbines.

A.1. Scope

Further additional requirements and clarifications to the IEC 61400-21-1 [1] are given in order to enhance the quality and inter-comparability of the measurements.

With reference to the chapter numbers of the IEC 61400-21-1 additional MEASNET requirements and clarifications are:

A.2. Wind turbine specification (IEC section 6)

The nominal current I_n shall be calculated according to section 3.14 of IEC 61400-21-1.

The nominal apparent power S_n is numerical equal to the nominal active power P_n, which is given by manufacturer information.

A.3. Dynamic performance (IEC chapter 8.5)

Settling times and response times are generally related to the positive sequence vales of power and current. If required by the grid code the settling times and response times of the negative sequence values can be given additionally.

The following relevant times are recommended in case no specific requirement is given (e.g. from a grid code).

Explanations of IEC 61400-21-1 /Table A.39 – Results for tests where the WT is not connected

	No.	Parameter description	Phase reference	Relevant time	Units
General data	1	Test number	-	-	-
	2	Date	-	-	[dd/mm/yyyy]
	3	Time	-	-	[hh:mm:ss.f]
	4	Three phase / two phase voltage dip	-	-	-
	5	Series impedance X1	-	-	[Ω]
	6	Series impedance R1	-	-	
	7	Series impedance X2	-	-	
	8	Series impedance R2	-	-	
	9	Time of entrance of voltage dip/swell (t_{fault})	Phase-to-phase	-	[s]
	10	Time of clearance of voltage dip/swell (t_{clear})			
	11	Duration of the voltage dip/swell (measured from test)			
	12	Magnitude of pos. sequence of voltage dip/swell related to pos. sequence of U_{pre} (measured from test)	pos. sequence	t_{fault}+100ms until t_{clear}-20ms and t_{fault}-10s until t_{fault}	[p.u.]
	13	Magnitude of neg. sequence of voltage dip/swell related to pos. sequence of U_{pre} (measured from test)	neg. sequence		
Before voltage dip/swell	14	Steady state voltage (U_{pre})	pos. sequence	t_{fault} -10s until t_{fault}	[p.u.]
During voltage dip/swell	15	Steady state voltage	pos. sequence	t_{fault}+100ms until t_{clear}-20ms	[p.u.]
	16	Response time of voltage	-	-	[s]
	17	Settling time of voltage	-	-	
After voltage dip/swell	18	Steady state voltage	pos. sequence	t_{clear}+5s until t_{clear}+10s	[p.u.]
	19	Response time of voltage	-	-	[s]
	20	Settling time of voltage	-	-	

The results for the no-load tests should be stated on the voltage level, where the test equipment is installed.

Explanations of IEC 61400-21-1/ Table A.40 – Results for tests where the WT is connected

	No.	Parameter description	Phase reference	Relevant time	Units
General data	1	Test number	-	-	-
	2	Date	-	-	[dd.mm.yyyy]
	3	Time	-	-	[hh:mm:ss.f]
	4	Operational mode of WT (e.g. Reactive power, K-factor, FRT Mode)	-	-	-
	5	Active power range	pos. sequence	t_{fault} -10s until t_{fault}	[p.u.]
	6	Three phase / two phase voltage dip/swell	-	-	-
	7	Wind speed	-	-	[m/s]
	8	WT tripped (Y/N)	-	-	-
	9	Time of entrance voltage dip/swell (t_{fault})	Phase-to-phase	-	[s]
	10	Time of clearance voltage dip/swell (t_{clear})			
	11	Duration of the voltage dip/swell (measured from the test)			
	12	Magnitude of pos. sequence of voltage dip/swell related to pos. sequence of U_{pre} (measured from test)	pos. sequence	t_{fault} +100ms until t_{clear} - 20ms and t_{fault} -10s until t_{fault}	[p.u.]
	13	Magnitude of neg. sequence of voltage dip/swell related to pos. sequence of U_{pre} (measured from test)	neg. sequence		
	14	Tolerance band**	-	-	[p.u.]
Before voltage dip/swell	15	Steady state voltage	pos. sequence	t_{fault} -10s until t_{fault}	[p.u.]
	16	Steady state active power			
	17	Steady state reactive power			
	18	Steady state active current			
	19	Steady state reactive current			
During voltage dip/swell	20	Steady state voltage	pos. sequence	t_{fault}+100ms until t_{clear}-20ms	[p.u.]
	21	Steady state active power *			
	22	Steady state reactive power *			
	23	Steady state active current *			
	24	Steady state reactive current *			
	25	Response time of active current *	-	-	[s]
	26	Response time of reactive current *			
	27	Settling time of active current *			
	28	Settling time of reactive current *			
After voltage dip/swell	29	Steady state voltage	pos. sequence	t_{clear}+5s until t_{clear} +10s	[p.u.]
	30	Steady state active power			
	31	Steady state reactive power			
	32	Steady state active current			
	33	Steady state reactive current			
	34	Response time of active current	-	-	[s]
	35	Response time of reactive current			
	36	Settling time of active current			
	37	Settling time of reactive current			
	38	Active power response time			

*For voltage dips below 5% of the remaining voltage, steady state apparent current magnitude shall be presented instead of parameters 21 to 28.

** In case there is more than one tolerance band, then list all of them in line 14.

Annex B:

Measurement procedure for CEA

Technical Standards for Connectivity to the Grid

B.1. Scope

The following gives the measurement and testing procedure for the „Technical Standards for Connectivity to the Grid" of the Central Electricity Authority (CEA) in India. If not otherwise specified, the tests shall follow the IEC 61400-21-1. This Annex focuses on WT testing. CEA requirements apply also for other Power Generating Units (PGUs).

B.2. Normative references

[1] Central Electricity Authority (CEA), "Technical Standards for Connectivity to the Grid – Regulations 2007", New Delhi, the 21st February 2007.

[2] CEA, "Technical Standards for Connectivity to the Grid – Amendment Regulations, 2013", New Delhi, the 15th October 2013.

[3] CEA, "Technical Standards for Connectivity to the Grid - Amendment Regulations, 2019", New Delhi the 6th February, 2019.

[4] IEC 61400-21-1: 2019, Wind energy generation systems – Part 21-1: Measurement and assessment of electrical characteristics – Wind turbines, Ed.1

[5] Technical Report IEC/TR 61000-3-7, "Electromagnetic compatibility (EMC) – Part 3-7: Limits – Assessment of emission limits for the connection of fluctuating installations to MV, HV and EHV power systems", Edition 2.0, 02-2008.

[6] IEEE Standard 519-2014, "IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems".

[7] IEEE Standard 1547.1-2005, "IEEE Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems".

B.3. Power quality

B.3.1 Flicker in continuous operation

a. Description

CEA requires that the flicker emissions should be kept within the limits specified in the IEC 61000, which refers to the IEC Technical Report 61000-3-7.

b. Procedure

The flicker measurement procedure shall be according to IEC 61400-21-1.

c. Reporting

Reporting of flicker results shall be according to IEC 61400-21-1.

B.3.2 Switching operations

a. Description

Flicker from switching operations is part of the requirement of IEC 61000-3-7.

b. Procedure

The relevant procedure of IEC 61400-21-1 shall be followed.

c. Reporting

Reporting of flicker results shall be according to IEC 61400-21-1.

B.3.3 Harmonics

a. Description

With regard to harmonic current emissions, CEA requires that they should not violate the limits specified in the standard IEEE 519 of the Institute of Electrical and Electronics Engineers (IEEE).

b. Procedure

The test procedure shall follow the procedure given in Annex E (IEEE 519).

c. Reporting

Shall follow the report format given in Annex F (IEEE 519).

B.3.4 DC Current Injection

a. Description

According to CEA, the DC current injection of the PGUs at the point of connection should not be greater than 0.5% of the rated current.

b. Procedure

This test should be performed in case there is no LV/MV transformer as part of the WT.

c. Reporting

The measurement should be performed by applying the methodology of IEEE 1547.1 standard. More specifically:

Measurement of harmonics for a period of 10-min at three different 10% power bin levels (mid-points at 30%, 70% and 100% of Pn) and then calculation of the DC component.

Suitable current clamps for measuring DC current shall be used for this test.

B.4. Steady state operation

B.4.1 Maximum power

a. Description

CEA does not require the measurement of the maximum power during steady state operation. However, it is very important for the power system to know this value.

b. Procedure

The relevant procedure of IEC 61400-21-1 shall be followed.

c. Reporting

Reporting of maximum power shall be according to IEC 61400-21-1.

B.4.2 Reactive power characteristic (Q=0) and Reactive power capability

a. Description

According to CEA all (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, which must be achieved even if power system voltage varies in the range of up to ±5%

b. Procedure

- For the measurement of 0.95 lagging power factor, the wind turbine shall be set to the operational mode, which gives the minimum lagging power factor (≤ 0.95) in the whole power range (Qmax underexcited)
- For the measurement of 0.95 leading power factor, the wind turbine shall be set to the operational mode, which gives the minimum leading power factor (≤ 0.95) in the whole power range (Qmax overexcited)

For each of these two setting modes the measurement procedure of IEC 61400-21-1 should be followed (§8.3.5). Measurement of the Reactive power characteristic (Q=0) shall be also performed according to IEC 61400-21-1 (§8.3.4 and Annex A).

c. Reporting

Reporting of power factor capability should be done the same way as the reactive power capability according to IEC 61400-21-1 ((§8.3.4, §8.3.5 and Annex A).

B.5. Control of Active Power and Frequency

a. Description

Generating stations shall have the capability of set-point control of the active power following the orders given the relevant Load Dispatch Centre.

b. Procedure

- For the testing of the *Active power set point control*, the procedure of IEC 61400-21-1 (§8.4.2*)* shall be followed
- For the testing of the *Active power ramp rate limitation*, the procedure of IEC 61400-21-1 (§8.4.3*)* shall be followed
- For the testing of the *Frequency Control at specific droop*, the procedure of IEC 61400-21-1 (§8.4.4*)* shall be followed. The droop setting can be set between 3% and 6% according to CEA 2019 [3].
- For the testing of the capability of the Generation Station to provide an immediate (within 1 second) real power primary frequency response of at least 10% of the maximum Alternating Current active power capacity according to CEA 2019 [3], the procedure of IEC 61400-21-1 (§8.4.5 – Synthetic Inertia*)* shall be followed.
- For the testing of the *Frequency Range*, special procedure as defined in section B.6 shall be followed.
- Reactive power set point control and Reconnection Time are not required and can be performed optionally.

c. Reporting

Reporting of the control tests shall be according to the corresponding chapters of IEC 61400-21-1. Reporting of the Frequency Range test shall be done according to B.6.

B.6. Frequency range test

a. Description

According to CEA, the 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 and solar radiation). This performance shall be also achieved with a voltage variation of up to ± 5 %.

b. Procedure

The following alternative methods may be followed:

Option 1. Measurements in normal operation with the frequency measured, if the frequency is changing to this range.

Option 2. Provision of a propose frequency offset signal to the controller of the PGU at the desired frequency levels.

Performance of the tests under voltage variations of ± 5% is optional because it cannot be easily simulated in the field unless it is possible to use a proper configuration of an Fault Ride Through (FRT) container or the local substation provides the facility of tap changing.

c. Reporting

The report should include the measured frequency signal and the actual active power of the PGU along with the available power. The behavior of the PGU should remain unchanged before and after the frequency change.

B.7.Dynamic performance

a. Description

The aim is, to show the capability of the generation unit to ride through the voltage dip and support the grid as requested:

- PGUs shall remain connected to the grid when voltage at the interconnection points on any or all phases dips/swells to the level, given in [3].
- During the voltage dips, the supply of reactive power has first priority, while the supply of active has second priority and the active power preferably be maintained during voltage drops, provided, a reduction in active power within the plant’s design specifications is acceptable
- After voltage dip, active power shall be restored to at least 90% of the pre-fault level within 1 sec of restoration of voltage. .

b. Procedure

The setup of the test and of the test equipment shall follow IEC 61400-21-1.

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 WT.

The impedances employed in the testing equipment for a voltage dip must 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. The correct configuration of the testing equipment for each specific voltage dip 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.

The on-site tests must be carried out in accordance with IEC 61400-21-1. The list of the required tests including relevant voltage levels and minimum fault durations and the operational point of the WT is given in Table B1.

Table B1. Overview of UVRT/OVRT tests

Voltage magnitude a) [pu]	Minimum Duration [ms]	Fault Type	WT/PV load	Number of tests b)
≤ 0.15	≥ 300	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
0.40 – 0.50 c)	≥ 1650	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	≥ 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	≥ 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	≥ 2000	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
>1.20 – 1.30	≥ 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 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 against time profile

Regarding the necessity of performing single phase UVRT tests, the following should be taken into account:

- Due to the protection settings at the circuit breakers at the grid side, it is often not possible to perform these tests without putting the security of grid supply at risk
- In principle, faults to ground impose higher danger than the phase-to-phase ones on people working in the area and the equipment.

Based on the above remarks and considering that the single phase fault ride through capability is related more to the proper settings and the cooperation of the protection systems than to the injection of the proper amounts of active and reactive power, it is suggested that single phase dips are not required to be included within the relevant FRT certification campaigns.

c. Reporting

Reporting of FRT tests shall be done according to IEC 61400-21-1, Annex A.

B.8.Grid Protection

a. Description

The functionality of the PGU grid protection system should be demonstrated.

b. Procedure

The relevant procedure of IEC 61400-21-1 shall be followed.

c. Reporting

Reporting shall be according to IEC 61400-21-1.

Annex C:

Measurement procedure for EU Network Code Requirements for grid connection of generators

C.1. Scope

This Annex proposes a measurement and testing procedure for the Network code on requirements for grid connection of generators issued by the European Commission. A relevant test procedure is currently under development by CENELEC Working Group TC8X WG03 with the title: '*CLC/TS 50549-10 - Requirements for generating plants to be connected in parallel with distribution networks - Part 10: Tests demonstrating compliance of units*'. The contents of this Annex can be used as reference until the official issue of the above CENELEC document and can still be used as a guide afterwards.

According to the EU Network Code, all power generating modules are categorized in four types depending on their maximum capacity and the voltage level at the connection point (Type A, B, C and D). Requirements for grid connection depend on the Type of the unit and escalate from some limited Frequency Control and Protection requirements for Type A units to a full frequency – voltage control and FRT capability requirements for the larger units.

Considering the large size of the wind turbines available in the market and the fact that the connection point of large wind farms may be even at voltage levels of > 110 kV, it is recommended that the full scope testing procedure is applied in all cases, as described below.

Unless otherwise stated, the tests shall follow IEC 61400-21-1.

C.2. Normative references

[1] Commission Regulation (EU) 2016/631 of 14 April 2016, "Establishing a network code on requirements for grid connection of generators".

[2] IEC 61400-21-1: 2019, Wind energy generation systems – Part 21-1: Measurement and assessment of electrical characteristics – Wind turbines, Ed.1

C.3. Power quality (Flicker, Switchings and Harmonics)

a. Description

EU Network Code on requirements for grid connection of generators focused mainly on the frequency and voltage stability. However, for the completeness of the proposed measurement procedure, measurement and assessment of power quality shall be also included.

b. Procedure

The measurement procedure for flicker in continuous operation, switching operations and harmonics shall be according to IEC 61400-21-1.

c. Reporting

Reporting of results shall be according to the corresponding chapters of IEC 61400-21-1.

C.4. Steady state operation

C.4.1 Maximum power

a. Description

Currently the EU Network Code on requirements for grid connection of generator does not require the measurement of the maximum power during steady state operation.

b. Procedure

The relevant procedure of IEC 61400-21-1 shall be followed.

c. Reporting

Reporting of maximum power shall be according to IEC 61400-21-1.

C.4.2 Reactive power capability and Voltage dependency of PQ diagram

a. Description

According to EU Network Code on requirements for grid connection of generator, the relevant system operator in coordination with the relevant TSO shall specify the reactive power provision capability requirements in the context of varying voltage.

b. Procedure

Measurement procedure of the reactive power capability and voltage dependency of PQ diagram shall be according to IEC 61400-21-1 (chapters 8.3.5 & 8.3.6).
According EU Network Code, tests shall be carried out at maximum reactive power, both leading and lagging and shall verify the following parameters:

(i) operation in excess of 60 % of maximum capacity for 30 min
(ii) operation within the range of 30-50 % of maximum capacity for 30 min
(iii) operation within the range of 10-20 % of maximum capacity for 60 min

Further specifications for the U-Q/P_{max} profile can be found in Article 21 of the EU Network Code. The relevant settings for this test can be adapted accordingly.

c. Reporting

Reporting shall be done according to IEC 61400-21-1.

C.5. Control

C.5.1 Active power setpoint and ramp rate limitation

a. Description

According to EU Network Code power generating modules shall be able to control active power following an instruction from the system operator

b. Procedure

Active power control measurement procedure shall be according to IEC 61400-21-1 (chapters 8.4.2 and 8.4.3).

c. Reporting

Active power control results shall be according to IEC 61400-21-1 (chapters 8.4.2 and 8.4.3).

C.5.2 Reactive power

a. Description

According to EU Network Code power generating modules shall be able to control reactive power automatically by either voltage control mode, reactive power control mode or power factor control mode.

b. Procedure

Reactive power control measurement procedure shall be according to IEC 61400-21-1 (chapter 8.4.6).

The relevant specifications of the EU Network Code, Article 21 shall be taken into account.

c. Reporting

Reactive power control results shall be according to IEC 61400-21-1 (chapter 8.4.6).

C.5.3 Frequency and Synthetic Inertia

a. Description

According to EU Network Code power generating modules shall be able to provide active power frequency response in cases of over- and under-frequency. In addition, Synthetic Inertia response is also requested.

b. Procedure

Frequency control measurement procedure shall be according to IEC 61400-21-1 (chapters 8.4.4 and 8.4.5).

The selection of the specifications of the tests shall be done in accordance with the EU Network Code Articles 13 – 16 (e.g. droop setting between 2% and 12%) and active power response delay < 2 s).

c. Reporting

Frequency and Synthetic Inertia control results shall be according to IEC 61400-21-1 (chapters 8.4.4 and 8.4.5).

C.6. Dynamic performance

C.6.1 Fault Ride Through Capability (FRT)

a. Description

According to EU Network Code on requirements for grid connection of generator each TSO shall specify a voltage-against-time-profile at the connection point for fault conditions, which describes the conditions in which the power-generating module is capable of staying connected to the network and continuing to operate stably after the power system has been disturbed by secured faults on the transmission system.

b. Procedure

The test and test equipment setup shall follow IEC 61400-21-1 (chapter 8.5).

c. Reporting

Reporting of FRT tests shall be done according to IEC 61400-21-1, Annex A.

C.7. Grid Protection, Rate of Change of Frequency and Reconnection Test

a. Description

According to European's Union Network Code on requirements for grid connection of generator, the relevant system operator shall specify the schemes and settings necessary to protect the network, taking into account the characteristics of the power-generating module. The protection schemes needed for the power- generating module and the network as well as the settings relevant to the power-generating module shall be coordinated and agreed between the relevant system operator and the power-generating facility owner.

b. Procedure

The relevant procedure of IEC 61400-21-1 (chapter 8.6.2, 8.6.3 and 8.6.4).

c. Reporting

Reporting shall be according to IEC 61400-21-1 (chapter 8.6.2, 8.6.3 and 8.6.4).

Annex D:

Measurement procedure for the Regulations of China Technical Standards for Connectivity to the Grid

D.1. Scope

The aim of the present procedure is summarize the basic requirements for the testing of electrical characteristics of wind turbines in China.

Right now in China, there are two kinds of compulsive electric integration tests for the wind turbine generators (WTGs) which want to connect to the grid. One is the power quality test (including power control) and the other is the voltage fault ride through (FVRT) test.

At present, the undervoltage test for the new type of wind turbine is compulsive but the overvoltage test is optional. A new standard for FVRT was published in 28 Dec. 2018, effective after 1st of July 2019.

D.2. Normative references

[1] National Standard of the People's Republic of China: Wind Turbines - Test procedure of voltage fault ride through capability, GB/T 36995-2018

[2] National Standard of the People's Republic of China: Technical rule for connecting wind farm to power system, GB/T 19963-2011

[3] National Standard of the People's Republic of China: Measurement and assessment of power quality characteristics of wind turbine generator systems, GB/T 20320-2013 / IEC 61400-21, 2008

D.3. Procedure

D.3.1 Power Quality

The power quality test operated as the requirements specified in the standard GB/T 20320-2013. This standard is identical to the IEC 61400-21:2008.

The measurement items are as shown in table D.1. The Chinese wind farm operators generally refuse the test institute to do the reconnection time test in their wind farm.

Table D.1. Power quality measurement items

No.	Measurement Items
1	Flicker coefficient
2	Flicker step factor
3	Voltage change factor
4	Harmonics current
5	Interharmonics current
6	Higher frequency current components
7	Maximum measured active power
8	Active power ramp rate limitation
9	Active power set point control
10	Max inductive reactive power
11	Max capacitive reactive power
12	Reactive power set point: Q=0
13	Reactive power set point step change
14	Grid protection

D.3.2 Fault ride through technical requirements

a. Fault voltage curve

Fig. D.1 shows the fault voltage ride through (FVRT) curve of the wind turbine. When the voltage at point of common coupling of the wind turbine is in the region between curve 1 and curve 2 including curves themselves, wind turbine should not be cut out from the grid and operate continuously. When the voltage at grid connection point is below curve 1or above curve 2, wind turbine can be cut out from the grid.

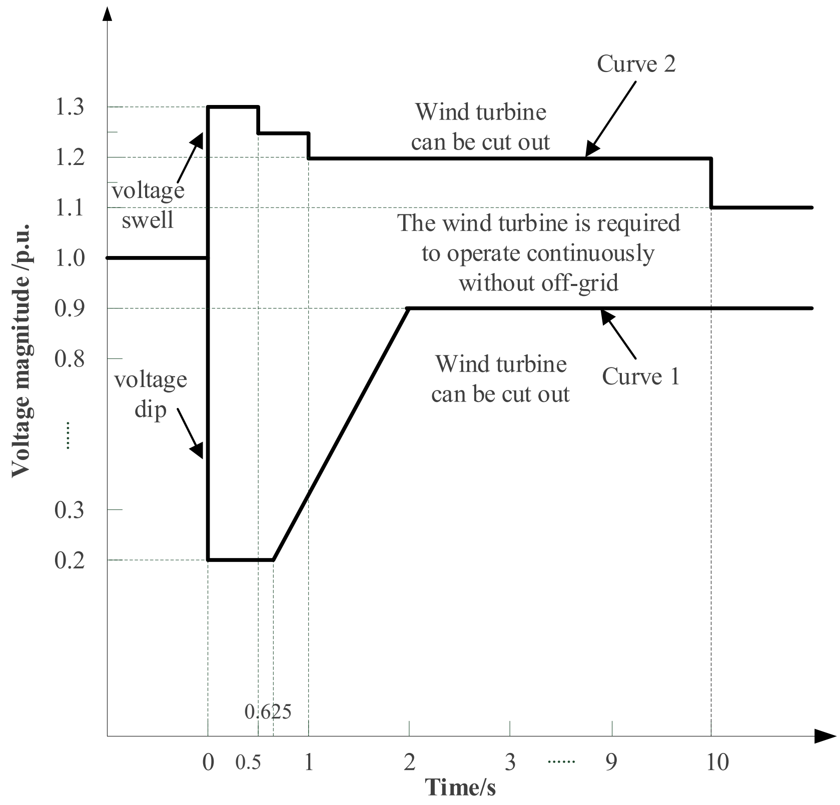


Fig. D.1. FVRT curve of wind turbine

The assessment voltage levels for different voltage fault types are shown in Table D.2.

Table D.2 Assessment voltage levels for wind turbine FVRT

Voltage fault type	Assessment voltage
Three-phase symmetric voltage fault	Line voltage at grid connection point of wind turbine
Three-phase asymmetric voltage fault	Line voltage at grid connection point of wind turbine

b. FVRT requirements

The wind turbine FVRT including undervoltage ride through (LVRT)， overvoltage ride through (OVRT) and voltage cascading fault (optional). The detailed requirements are as follows:

(1) **LVRT requirements**: the wind turbine should have the ability to operate continuously without off-grid within the voltage / time region specified by curve 1 of Fig D.1. Requirements are as follows:

a) Active power recovery: for wind turbine without off-grid during voltage dip, from the moment when the voltage returns to normal, the active power should restore to the output power corresponding to the actual wind condition with change rate of power of at least 10%P_n/s;

b) Dynamic reactive power support capability: when three-phase symmetrical voltage dip occurs at grid connection point, wind turbine should response rapidly from the moment of voltage dip and support the voltage recovery by injecting capacitive reactive current into the grid. The specific requirements are as follows:

- The response time of the dynamic capacitive reactive current control should be no more than 75ms from the moment of voltage dip at the grid connection point, and the capacitive reactive current should continuously injected into grid during the voltage fault;

- The dynamic capacitive reactive current provided by the wind turbine should meet the requirements of equation (1) :

$$I_{TC} \geq 1.5\times(0.9-U_T)\, I_n, (0.2 \leq U_T \leq 0.9) \ldots\ldots\ldots\ldots (1)$$

When the three-phase asymmetrical voltage dip occurs at the grid connection point, wind turbine should inject capacitive reactive current to support voltage recovery.

(2) **OVRT requirements**: the wind turbine should have the ability to operate continuously without off-grid within the voltage/time region specified by curve 2 in Fig. 1. Requirements are as follows:

a) Active power output: for wind turbine without off-grid, when the voltage swells and returns to normal, the amplitude of active power fluctuation should be within the range of ±50% P_n, and the amplitude of fluctuation should be greater than zero, and the fluctuation time should be no more than 80ms. During the voltage swell, the output active power fluctuation amplitude should be within±5% P_n. After the voltage returns to normal, the output power should be as much as the output power corresponding to the actual wind condition.

b) Dynamic reactive power support capability: when three-phase symmetrical voltage swell occurs at the grid connection point, the wind turbine should response rapidly from the moment of voltage swell and support the voltage recovery by injecting inductive reactive current into the grid. The specific requirements are as follows:

-The response time of the dynamic inductive reactive current control should be no more than 40 ms from the moment when the voltage at the grid connection point rises, and the inductive reactive current should continuously injected into grid during the voltage fault.

- The dynamic inductive reactive current provided by the wind turbine should meet the requirements of equation (2):

$$I_{TC} \geq 1.5\times(U_T-1.1)\, I_n, (1.1 \leq U_T \leq 1.3) \ldots\ldots\ldots\ldots (2)$$

When the three-phase asymmetrical voltage swell occurs at the grid connection point, wind turbine should inject inductive reactive current to support voltage recovery.

D.4. Test contents

The different voltage levels for undervoltage test shown in Table 2, the different voltage levels for overvoltage test can shown in Table 3. The tests shall be carried out for the wind turbine operating at :

a) between 0.1 P_n and 0.3 P_n

b) above 0.9 P_n.

The voltage levels shown in Table D.3 and Table D.4 are in the no-load state. At every voltage level both symmetrical and asymmetrical voltage fault test should be carried out.

Table D.3 Voltage levels for LVRT

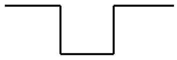
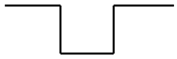
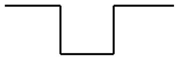
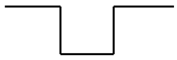
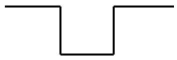
No.	Magnitude of voltage dip U_T p.u.	Duration of voltage dip ms	Waveform of voltage dip
1	0.90-0.05	2000±20	
2	0.75±0.05	1705±20	
3	0.50±0.05	1214±20	
4	0.35±0.05	920±20	
5	0.20±0.05	625±20	

Table D.4 Voltage levels for OVRT

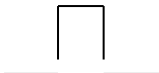
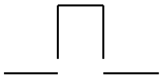
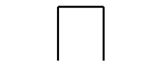
No.	Magnitude of voltage swell U_T p.u.	Duration of voltage swell ms	Waveform of voltage swell
1	1.20±0.03	10000±20	
2	1.25±0.03	1000±20	
3	1.30±0.03	500±20	

Table D.5. Power quality measurement items

No.	Measurement Items
	LVRT

No.	Measurement Items
1	3-phase voltage dip, 90%U_n, $0.1P_n \leq P \leq 0.3P_n$
2	3-phase voltage dip, 90%U_n, $P>0.9P_n$
3	2-phase voltage dip, 90%U_n, $0.1P_n \leq P \leq 0.3P_n$
4	2-phase voltage dip, 90%U_n, $P>0.9P_n$
5	3-phase voltage dip, 75%U_n, $0.1P_n \leq P \leq 0.3P_n$
6	3-phase voltage dip, 75%U_n, $P>0.9P_n$
7	2-phase voltage dip, 75%U_n, $0.1P_n \leq P \leq 0.3P_n$
8	2-phase voltage dip, 75%U_n, $P>0.9P_n$
9	3-phase voltage dip, 50%U_n, $0.1P_n \leq P \leq 0.3P_n$
10	3-phase voltage dip, 50%U_n, $P>0.9P_n$
11	2-phase voltage dip, 50%U_n, $0.1P_n \leq P \leq 0.3P_n$
12	2-phase voltage dip, 50%U_n, $P>0.9P_n$
13	3-phase voltage dip, 35%U_n, $0.1P_n \leq P \leq 0.3P_n$
14	3-phase voltage dip, 35%U_n, $P>0.9P_n$
15	2-phase voltage dip, 35%U_n, $0.1P_n \leq P \leq 0.3P_n$
16	2-phase voltage dip, 35%U_n, $P>0.9P_n$
17	3-phase voltage dip, 20%U_n, $0.1P_n \leq P \leq 0.3P_n$
18	3-phase voltage dip, 20%U_n, $P>0.9P_n$
19	2-phase voltage dip, 20%U_n, $0.1P_n \leq P \leq 0.3P_n$
20	2-phase voltage dip, 20%U_n, $P>0.9P_n$
	OVRT
21	3-phase voltage dip, 120%U_n, $0.1P_n \leq P \leq 0.3P_n$
22	3-phase voltage dip, 120%U_n, $P>0.9P_n$
23	2-phase voltage dip, 120%U_n, $0.1P_n \leq P \leq 0.3P_n$
24	2-phase voltage dip, 120%U_n, $P>0.9P_n$
25	3-phase voltage dip, 125%U_n, $0.1P_n \leq P \leq 0.3P_n$
26	3-phase voltage dip, 125%U_n, $P>0.9P_n$
27	2-phase voltage dip, 125%U_n, $0.1P_n \leq P \leq 0.3P_n$
28	2-phase voltage dip, 125%U_n, $P>0.9P_n$
29	3-phase voltage dip, 130%U_n, $0.1P_n \leq P \leq 0.3P_n$
30	3-phase voltage dip, 130%U_n, $P>0.9P_n$

No.	Measurement Items
31	2-phase voltage dip， 130%U_n， $0.1P_n \le P \le 0.3P_n$
32	2-phase voltage dip， 130%U_n， $P > 0.9P_n$

D.5. **Reporting**

Reports shall follow the structure and format indicated in IEC 61400-21.

Annex E:

Measurement procedure for Harmonics according to IEEE 519

IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems

E.1. Scope

The following gives the measurement and testing procedure for the „ IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems”. If not other-wise specified, the tests shall follow the IEEE 519-2014. This measurement procedure gives additional recommendations and shall be suitable for WTs, i.e. where the magnitude of the current harmonics produced can be expected to change over the periods of a few seconds.

E.2. Normative references

[1] IEEE Std. 519-2014, Recommended Practice and Requirements for Harmonic Control in Electric Power Systems

[2] IEC Standard 61000-4-7, General Guide on Harmonics and Interharmonics Measurement and Instrumentation, for Power Supply Systems and Equipment Connected Thereto.

[3] IEC Standard 61000-4-30, Power Quality Measurement Methods.

[4] IEC 61400-21-1: 2019, Wind energy generation systems – Part 21-1: Measurement and assessment of electrical characteristics – Wind turbines, Ed.1

E.3. Procedure

For the purposes of assessing harmonic levels for comparison with the recommended limits, any instrument used should comply with the specifications of IEC 61000-4-7 and IEC 61000-4-30.

MEASNET recommendations for data aggregation

For site specific measurements, a one-week measurement acc. to IEC61000-4-30 can be followed.

For test bench measurements, at least seven 10 min time-series of instantaneous current measurements (including all three phases) shall be collected for each 10% power bin.

For free field prototype measurements, the following procedure is recommended:

The harmonics of WTs are varying with the active power production. Due to this fact, the collection of measurement data set is recommended to follow the approach of IEC 61400-21-1 - means collection of data and classify into active power bins from 0, 10, 20, …, 100 % of rated power.

This consideration provides results covering the complete active power range of the tested WT and its more representative than considering strictly daily or weekly periods, where periods of low or no-wind might be also included.

The harmonic values are accumulated over the whole measurement period. At least a one-week measurement acc. IEC6100-4-30 can be followed. The measurement period shall be extended until at least seven 10 min time-series of instantaneous current measurements (including all three phases) shall be collected for each 10% power bin.

The measurements and grouping of the spectral components shall be performed according to harmonic subgroups as given in Clause 5.6 of IEC 61000-4-7:2002.

MEASNET recommendations for assessment method

Statistical evaluation

The percentiles shall be calculated for all phases and for all measurements.

Total harmonic distortion

For currents only the TDD-values are required. The maximum demand current is set to rated current.

For voltages the THD-values are required.

E.4. Reporting

E.4.1 Very short time (3-second) integer harmonics

99th percentile 3-second harmonic currents up to the 50th harmonic order

Harmonic order (H)	2	3	4	5	6	7	8	9	10	11	12	13	14
99thperc.													
Harmonic order (H)	15	16	17	18	19	20	21	22	23	24	25	26	27
99th perc.													
Harmonic order (H)	28	29	30	31	32	33	34	35	36	37	38	39	40
99th perc.													
Harmonic order (H)	41	42	43	44	45	46	47	48	49	50			
99th perc.													

E.4.2 Very short time (3-second) voltage harmonics

99th percentile 3-second harmonic voltage up to the 50th harmonic order

Harmonic order (H)	2	3	4	5	6	7	8	9	10	11	12	13	14
99th percentile													
Harmonic order (H)	15	16	17	18	19	20	21	22	23	24	25	26	27
99th perc.													
Harmonic order (H)	28	29	30	31	32	33	34	35	36	37	38	39	40
99th perc.													
Harmonic order (H)	41	42	43	44	45	46	47	48	49	50			
99th perc.													

E.4.3 Short time (10-minute) current harmonics

99th and 95th percentile 10-minute harmonic current up to the 50th harmonic order

Harmon order (H)	2	3	4	5	6	7	8	9	10	11	12	13	14
99th perc.													
95th perc.													
Harmonic order (H)	15	16	17	18	19	20	21	22	23	24	25	26	27
99th perc.													
95th perc.													
Harmonic order (H)	28	29	30	31	32	33	34	35	36	37	38	39	40
99th perc.													
95th perc.													
Harmonic order (H)	41	42	43	44	45	46	47	48	49	50			
99th perc.													
95th perc.													

E.4.4 Short time (10-minute) voltage harmonics

99th and 95th percentile 10-minute harmonic voltage up to the 50th harmonic order

Harmonic order (H)	2	3	4	5	6	7	8	9	10	11	12	13	14
99th perc.													
95th perc.													
Harmonic order (H)	15	16	17	18	19	20	21	22	23	24	25	26	27
99th perc.													
95th perc.													
Harmonic order (H)	28	29	30	31	32	33	34	35	36	37	38	39	40
99th perc.													
95th perc.													
Harmonic order (H)	41	42	43	44	45	46	47	48	49	50			
99th perc.													
95th perc.													