POWER QUALITY MEASUREMENT PROCEDURE

Version 3
November 2006

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1. 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 mutual evaluation exercises.

2. Introduction

The MEASNET Power Quality Measurement Procedure is the measurement procedure agreed upon by the MEASNET members to be mutually used and accepted. The 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.

3. The reference measurement procedure

The measurement procedure is based on the IEC 61400-21 [1].

4. Additional requirements

In the reference power quality measurement procedure, a number of characteristic power quality parameters are defined, and methods to measure these characteristics are specified. Only, the IEC 61400-21 does not specify characteristics for interharmonics and higher frequency current components, only harmonics up to 50 times the fundamental grid frequency are measured. Wind turbines with power converters emit interharmonics and harmonics above 50 times the fundamental frequency. Therefore, the present Measnet procedure requires measurement of harmonics and interharmonics up to 9 kHz.

Further additional requirements to the reference procedure are given in order to strengthen the quality and inter-comparability of the measurements.

With reference to the chapter numbers of IEC 61400-21, the additional Measnet requirements are:

4.1 Harmonics (IEC chapter 6.7)

“up to 50 times the fundamental grid frequency” is replaced by “up to 9 kHz”.

For a wind turbine with a power electronic converter, the wind turbine’s emission of interharmonic currents up to 2 kHz and of higher frequency current components above 2 kHz up to 9 kHz during continuous operation shall be stated. The individual interharmonic currents below 2 kHz and the higher frequency current components in the range 2 kHz up to 9 kHz shall be given as ten-minute-average data for each frequency at the output power giving the maximum individual interharmonic current or higher frequency current component. The values shall be specified in a table in percent of the rated current. Measurements below 0.1 % of rated current need not to be specified.

4.2 Rated Data (IEC chapter 7.2)

The rated active power P_n, the rated reactive power Q_n, the rated apparent power S_n, the rated voltage U_n and the rated current I_n are based on manufacturer's information, but not necessarily on measurements. Thus the measured current and reactive and apparent power at rated active power can possibly deviate from the rated values.

4.3 Reactive Power (IEC chapter 7.5)

The calculation method of reactive power shall follow Annex B of this guideline.

4.4 Voltage fluctuation (IEC chapter 7.6)

If it can be shown, that the turbulence intensity has no or less influence on flicker, then also measurements could be used outside the turbulence intensity range of 8-16%. But in this case the used range of turbulence intensity must be specified in the report and plots of flicker Pst values as a function of turbulence intensity and turbulence intensity as a function of wind speed must be given.

4.5 Harmonics (IEC chapter 7.7)

The harmonic currents shall be subgrouped as given in chapter 5.6 of IEC 61000-4-7 [2]. The window width shall be 10 (for 50 Hz systems) or 12 (for 60 Hz systems) grid cycles.

For wind turbines with power converters, the wind turbine's emission of interharmonic currents up to 2 kHz and of higher frequency current components between 2 kHz and 9 kHz during continuous operation shall be measured. The results shall be based on observation times of ten minutes. The measurements and evaluations shall be performed according to IEC 61000-4-7 [2] . The accuracy class I shall be used. Interharmonics below 2 kHz shall be subgrouped (interharmonic centred subgroup), as given in Annex A, equation A3 and A4 of the IEC 61000-4-7. The window width shall be 10 (for 50 Hz systems) or 12 (for 60 Hz systems) grid cycles. Higher Frequency current components in the frequency range above 2 kHz up to 9 kHz shall be measured and evaluated according to Annex B of the IEC 61000-4-7. For these measurements a window width of 200 ms (as given in the IEC 61000-4-7) shall be used.

5. Bibliography

[1] IEC 61400-21 (2001-12): Wind Turbine Generator Systems, Part 21: Measurement and assessment of power quality characteristics of grid connected wind turbines.

[2] IEC 61000-4-7 (2002-08) Electromagnetic Compatibility (EMC) Part 4-7: Testing and measurement techniques - General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto"

Annex A

DATA SHEET OF POWER QUALITY MEASUREMENT

According to Measnet Power Quality Procedure, Version 3, November 2006

Report:		Sheet:		page 1 of 4
Wind turbine type designation:			Serial number:	
Wind turbine manufacturer:				

Description of the tested wind turbine, including settings of control parameters:	Document name and date
Description of the test site and grid connection:	
Description of the test equipment:	
Description of test conditions:	

Name and address of test organisation:			
Author:		Checked:	
Date of issue:		Approved:	

Note of exceptions to Measnet Power Quality Procedure:

General Data:

Number of blades:		Generator type and rating(s):	
Rotor diameter [m]:		Frequency converter type rating:	
Hub height [m]:		Special features:	
Blade control (pitch/stall):			
Speed control (fixed/2speed/variable):			

Rated Data, given by the manufacturer:

Rated power, P_n:		Rated apparent power, S_n:	
Rated wind speed, v_n:		Rated reactive power, Q_n:	
Rated voltage, U_n:		Rated current, I_n:	

DATA SHEET OF POWER QUALITY MEASUREMENT

According to Measnet Power Quality Procedure, Version 3, November 2006

Wind turbine type:		Sheet:		page 2 of 4

Maximum power:

Max. permitted power, P_{mc}:		Max. measured 60 sec. average		Max. measured 0.2 sec. average	
P_{mc}	$p_{mc}=P_{mc}/P_n$	P_{60}	$p_{60}=P_{60}/P_n$	$P_{0.2}$	$p_{0.2}=P_{0.2}/P_n$

Reactive power:

Output power bin P/P_n		Output power bin-mean-value [kW]	Reactive power bin-mean-value [kvar]
from	to		
-0.05	<0.05		
0.05	<0.15		
0.15	<0.25		
0.25	<0.35		
0.35	<0.45		
0.45	<0.55		
0.55	<0.65		
0.65	<0.75		
0.75	<0.85		
0.85	<0.95		
0.95	<1.05		
Assessed reactive power at P_{mc} [kvar]			
Assessed reactive power at P_{60} [kvar]			
Assessed reactive power at $P_{0.2}$ [kvar]			

Flicker:

Network impedance phase angle, ψ_k:	30°	50°	70°	85°
Annual average wind speed, v_a(m/s):	Flicker coefficient, $c(\psi_k,v_a)$:			
6.0 m/s				
7.5 m/s				
8.5 m/s				
10 m/s				

DATA SHEET OF POWER QUALITY MEASUREMENT

According to Measnet Power Quality Procedure, Version 3, November 2006

Wind turbine type:		Sheet:		page 3 of 4

Harmonic currents:

Order	Output power [kW]	Harm. current [%]	Order	Output power [kW]	Harm. current [%]	Order	Output power [kW]	Harm. current [%]	Order	Output power [kW]	Harm. current [%]	Order	Output power [kW]	Harm. current [%]
1			11			21			31			41		
2			12			22			32			42		
3			13			23			33			43		
4			14			24			34			44		
5			15			25			35			45		
6			16			26			36			46		
7			17			27			37			47		
8			18			28			38			48		
9			18			29			39			49		
10			20			30			40			50		

Maximum total harmonic current distortion: [% of I_n]		Output power at maximum total harmonic current distortion: [kW]	

Interharmonic currents (frequency f < 2 kHz):

f [Hz]	Output power [kW]	Interharm. current [%]	f [Hz]	Output power [kW]	Interharm. current [%]	f [Hz]	Output power [kW]	Interharm. current [%]	f [Hz]	Output power [kW]	Interharm. current [%]
			525			1025			1525		
75			575			1075			1575		
125			625			1125			1625		
175			675			1175			1675		
225			725			1225			1725		
275			775			1275			1775		
325			825			1325			1825		
375			875			1375			1875		
425			925			1425			1925		
475			975			1475			1975		

Current distortions (2 kHz < f ≤ 9 kHz)

f [Hz]	Output power [kW]	harm. comp. current [%]	f [Hz]	Output power [kW]	harm. comp. current [%]	f [Hz]	Output power [kW]	harm. comp. current [%]	f [Hz]	Output power [kW]	harm. comp. current [%]
2100			4100			6100			8100		
2300			4300			6300			8300		
2500			4500			6500			8500		
2700			4700			6700			8700		
2900			4900			6900			8900		
3100			5100			7100					
3300			5300			7300					
3500			5500			7500					
3700			5700			7700					
3900			5900			7900					

DATA SHEET OF POWER QUALITY MEASUREMENT

According to Measnet Power Quality Procedure, Version 3, November 2006

Wind turbine type:		Sheet:		page 4 of 4

Switching operations:

Case of switching operation:	Start-up at cut in wind speed			
Maximum number of switching operations, N_{10}:				
Maximum number of switching operations, N_{120}:				
Network impedance phase angle, ψ_k:	**30°**	**50°**	**70°**	**85°**
Flicker step factor, $k_f(\psi_k)$:				
Voltage change factor, $k_U(\psi_k)$:				

Case of switching operation:	Start-up at rated wind speed			
Maximum number of switching operations, N_{10}:				
Maximum number of switching operations, N_{120}:				
Network impedance phase angle, ψ_k:	**30°**	**50°**	**70°**	**85°**
Flicker step factor, $k_f(\psi_k)$:				
Voltage change factor, $k_U(\psi_k)$:				

Worst case switching between generators:

Case of switching operation:				
Maximum number of switching operations, N_{10}:				
Maximum number of switching operations, N_{120}:				
Network impedance phase angle, ψ_k:	**30°**	**50°**	**70°**	**85°**
Flicker step factor, $k_f(\psi_k)$:				
Voltage change factor, $k_U(\psi_k)$:				

date signature

Annex B

(informative)

Measurement of active power, reactive power and voltage

This annex gives the recommended procedure to calculate active power, reactive power and RMS voltage based on measurement of instantaneous voltages and currents.

The calculation of active and reactive powers are based on the positive sequence of the fundamental voltage and current components. There are several advantages when this definition is used:

a) The positive sequence of the fundamental is the one that produces torque in the rotating machines. The negative sequence and the harmonics only cause losses;

b) In many cases reactive current is specified instead of the reactive power. Using positive sequence of the fundamental the reactive current component can be calculated explicitly. The same applies to the power factor;

c) Many power system simulators use only the positive sequence of the fundamental. Thus for easy verification of the simulations the measurements should be presented in the similar way.

In order to measure the positive sequence of the fundamental of the voltages and currents a multichannel datalogger with high sampling rate is needed. The analogue anti-aliasing filter (low pass filter) should have the same frequency response in all voltage and current inputs in order to prevent phase errors. Moreover, the amplitude error due to the anti-aliasing filter should be negligible at the fundamental frequency.

When phase voltages and currents are measured, the fundamental's Fourier coefficients are first calculated over one fundamental cycle *T* (equation shown here only for phase a voltage u_a; other phase voltages and currents are calculated similarly)

$$u_{a,\cos} = \frac{2}{T}\int_{t-T}^{t} u_a(t)\cos(2\pi f_1 t)\,dt \qquad (B.1)$$

$$u_{a,\sin} = \frac{2}{T}\int_{t-T}^{t} u_a(t)\sin(2\pi f_1 t)\,dt \qquad (B.2)$$

where f_1 is the frequency of the fundamental.

The effective value of this fundamental phase voltage is

$$U_{a1} = \sqrt{\frac{u_{a,\cos}^2 + u_{a,\sin}^2}{2}} \qquad (B.3)$$

The voltage and current vector components of the fundamental positive sequence are calculated using

$$u_{1+,\cos} = \frac{1}{6}\left[2u_{a,\cos} - u_{b,\cos} - u_{c,\cos} - \sqrt{3}\left(u_{c,\sin} - u_{b,\sin}\right)\right] \qquad (B.4)$$

$$u_{1+,\sin} = \frac{1}{6}\left[2u_{a,\sin} - u_{b,\sin} - u_{c,\sin} - \sqrt{3}\left(u_{b,\cos} - u_{c,\cos}\right)\right] \quad \text{(B.5)}$$

$$i_{1+,\cos} = \frac{1}{6}\left[2i_{a,\cos} - i_{b,\cos} - i_{c,\cos} - \sqrt{3}\left(i_{c,\sin} - i_{b,\sin}\right)\right] \quad \text{(B.6)}$$

$$i_{1+,\sin} = \frac{1}{6}\left[2i_{a,\sin} - i_{b,\sin} - i_{c,\sin} - \sqrt{3}\left(i_{b,\cos} - i_{c,\cos}\right)\right] \quad \text{(B.7)}$$

The active and reactive powers of the fundamental positive sequence are then

$$P_{1+} = \frac{3}{2}\left(u_{1+,\cos} i_{1+,\cos} + u_{1+,\sin} i_{1+,\sin}\right) \quad \text{(B.8)}$$

$$Q_{1+} = \frac{3}{2}\left(u_{1+,\cos} i_{1+,\sin} - u_{1+,\sin} i_{1+,\cos}\right) \quad \text{(B.9)}$$

and the effective phase-to-phase voltage of the fundamental positive sequence is

$$U_{1+} = \sqrt{\frac{3}{2}\left(u_{1+,\sin}^2 + u_{1+,\cos}^2\right)} \quad \text{(B.10)}$$

The effective active and reactive currents of the fundamental positive sequence are

$$I_{P1+} = \frac{P_{1+}}{\sqrt{3}U_{1+}} \quad \text{(B.11)}$$

$$I_{Q1+} = \frac{Q_{1+}}{\sqrt{3}U_{1+}} \quad \text{(B.12)}$$

The power factor of the fundamental positive sequence is

$$\cos\varphi_{1+} = \frac{P_{1+}}{\sqrt{P_{1+}^2 + Q_{1+}^2}} \quad \text{(B.13)}$$

These calculations can be performed in a spreadsheet program or using a special computer program. A new value of the reactive and active power should be calculated at least once in every fundamental period using the latest data.