CHARACTERISTIC AND NON-CHARACTERISTIC HARMONICS FROM WINDPARKS

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ABSTRACT

This paper presents measurements of harmonic current emissions up till 2 kHz from four different windparks in northern Sweden, all equipped with modern power-electronics converters. A study of the four windparks was performed in terms of 95% value of harmonic current spectrum and the minimum fault-level needed to fulfil the EN 50160 requirements on voltage distortion. The results show that there exists different dominating harmonics and fault-level requirements for different windturbines. Each turbine however shows a broadband component with superimposed narrowband components. The impact on the grid, with reference to permissible levels of voltage distortion, is biggest for the interharmonic components.

INTRODUCTION

Variable-speed modern windturbines are often equipped with power-electronic converters, either as a full-power converter or as part of a double-fed induction machine [1]. The presence of these power-electronic converters explains the interest in the harmonic emission from individual windturbines and from windparks.

The emissions of wind turbines differ from that in industrial installations or other customer installations. Measurements of the harmonic emission by wind-power installations have been presented before, but in those studies the way of presenting the results was based on existing methods, which in turn were developed for the emission from the mentioned more classical sources [2] [3] [4] [5].

This paper presents the different emissions of four windturbine types in northern Sweden, based on measurements during several days of the current distortion in the frequency range up to 2 kHz. Analysis based on the characteristic harmonics and non-characteristic harmonics were performed to study the harmonic emissions in the four types of windturbine.

The next section of this paper describes the measurements that have formed the basis for this analysis presented in this paper; this section also gives some information about the installations at which the measurements were presented. The measurement results are presented detailed in two different ways in the two sections after that.

MEASUREMENT PROCEDURES

The measurements of the harmonic emission were performed with four types of modern windturbines which are all located in the north of Sweden. A Dranetz PowerXplorer PX5 power-quality monitor, which measures harmonics according to IEC 61000-4-7, was used together with the normal voltage and current transformers. The monitor samples the voltage and current waveforms at 256 samples/cycle. At the voltage levels involved here, the existing instrument transformers are of sufficient accuracy for harmonic measurements up to a few kHz [6].

The measurements of the four types of windturbines were obtained using the same setting in terms of the current and the harmonics/interharmonics in the PX5, except the current transformer ratios. All the current waveforms on the three phases were recorded by 10 continuous fundamental frequency periods (or a 200 ms duration) every 10 minutes. The total measurement period lasted between a few days and more than three weeks, per location.

Harmonic groups and interharmonic groups were obtained for each of the three phases every 10 minutes using the standard method according to IEC 61000-4-7 in PowerXplorer PX5. Next to that a 200 ms waveform of the current was obtained for each of the three phases once every 10 minutes.

Parameters of the four measurement windparks are listed in Table 1, where the nominal current refers to the measurement point.

Table 1. The Four Installations.

Location	*Turbine type*	*Rated power*	*Nominal current*	*Nominal voltage*
A	Nordex N90/2500	2500kW	66 A	22 kV
B	Enercon E40/600	600kW × 3	104 A	10 kV
C	Vestas V90/2000	2000kW	36 A	32 kV
D	Enercon E82	2000kW	116 A	10 kV

At location B the measured installation consisted of three smaller turbines (600kW each) connected to the 10 kV grid through one transformer; the other measurements were performed on a single turbine. All these measurements were done on the medium-voltage side of the turbine transformer.

Both locations A and C are equipped converters with IGBT switching type, while locations B and D are equipped with Enercon converters.

95-PERCENTILE OF THE HARMONIC GROUPS

The harmonic groups and interharmonic groups were recorded according to IEC 61000-4-7. The harmonic and interharmonic emissions up to the order 40th have been studied. Here the 95% value of the harmonic and interharmonic groups was introduced into the study. To each harmonic or interharmonic order, the 95% value is obtained as follows: sort harmonic/interharmonic group as $X_1 < X_2 < \dots X_i < \dots < X_N$, find the index of 95% value: $i \approx 95\% \times N$, then the 95% value is X_i. Find the values of order from 0 to 40 for each harmonic/interharmonic group.

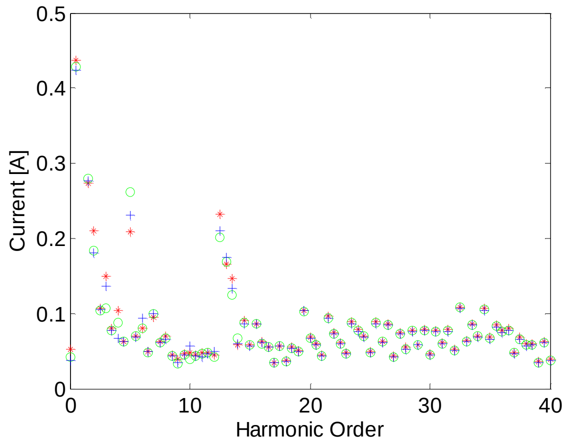

Fig. 1 Spectrum of current at location A; 95% values of the harmonic and interharmonic groups.

Fig. 1 presents the 95% value of the harmonic groups and interharmonic groups for location A. The three colours (red, green and blue) refer to the three phases. Both characteristic harmonics and non-characteristic harmonics are visible. Harmonic orders 0.5, 2, 2.5, 5, 12, 12.5 and 13 exhibit higher magnitudes than the other ones. Beyond these apparent harmonics and interharmonics, other spectral components are present with a level around 0.1A.

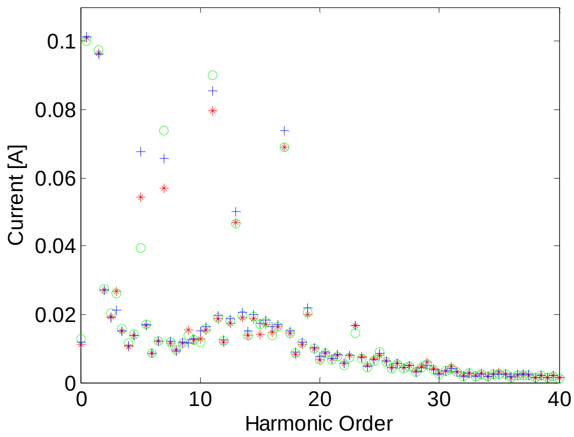

Fig. 2 Spectrum of current at location B; 95% values of the harmonic and interharmonic groups.

Fig. 2 shows the 95% value of the harmonic and interharmonic groups at location B. A clear broadband component together with harmonic orders 5, 7, 11, 13 and 17 are apparent in the figure. With a higher nominal current and a lower harmonic current magnitudes, the harmonic emissions at location B are lower than in location A. Note that these harmonic orders correspond to the characteristic harmonics of a six-pulse converter [6] and [7] as was pointed out for this location in [2].

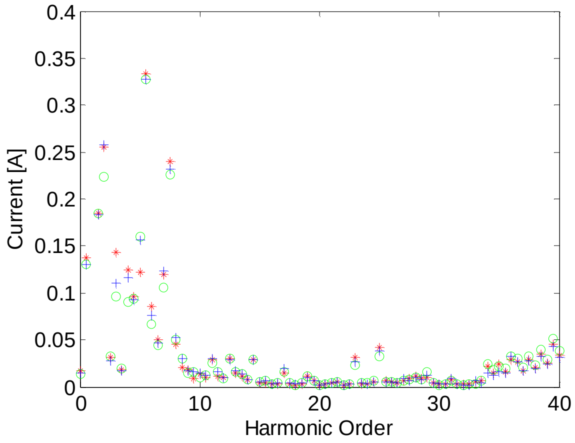

Fig. 3 Spectrum of current for location C; 95% values of the harmonic and interharmonic groups.

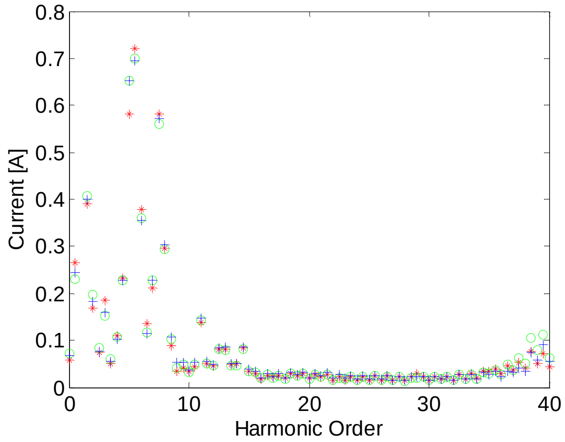

Fig. 4 Spectrum of current for location D; 95% values of the harmonic and interharmonic groups.

Fig. 3 and Fig. 4 present the 95% values at location C and D respectively. Similarly, except the broadband component, the harmonics and interharmonics are mainly apparent up to the 10th order. The 5th and 7th harmonics occupy the dominating harmonics. Towards harmonic 40th at the upper end of the spectrum, the magnitudes are increasing at both locations. At location C, the harmonic emissions remain in a high level because of the lower nominal current of the windturbine.

When comparing the 95-percentile spectra in Fig. 1 through Fig. 4, the followings conclusions can be drawn.

The harmonic and interharmonic emissions in each location are different; but each location also shows the combination of a broadband spectrum covering all harmonic and interharmonic groups, with individual harmonics superimposed on this. It is also worth noting the increase in emission level at the high frequency end of the spectrum, for two of the four locations. The 95-percentile of the harmonic and interharmonic groups can be used to compare with requirements on emission set by the network operator.

MINIMUM SHORT-CIRCUIT RATIO

The minimum fault level needed to keep the harmonic voltage below the EN 50160 limits has been calculated using the same method as in [2]. The minimum short circuit ratio (SCR) is calculated into the study in this section with the following assumptions:

- The source impedance is assumed to increase linearly with frequency.
- The voltage distortion due to the 95% spectrum of the current, is compared with harmonic limits under EN 50160.
- This standard does not give any limits for interharmonics; those were taken as 0.2% of nominal voltage according to IEC 61000-2-2.

The minimum short circuit ratio is obtained from the following formulation:

$$k_{min} = \frac{h \times I_h}{U_h \times I_{nom}}$$

where I_h is the current emission at harmonic order h, U_h the harmonic voltage limit, and I_{nom} the rated current (at fundamental frequency).

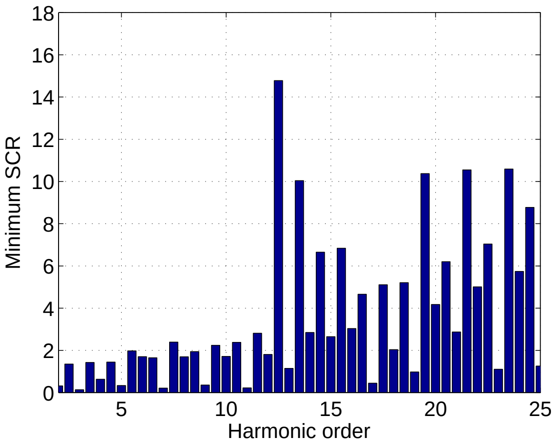

Fig. 5 Minimum fault-level for different harmonic order, to maintain the voltage distortion within the indicated limits, at location A.

For location A, the minimum short circuit ratios up till 25th order are presented in Fig. 5, which contains both harmonics and interharmonics. It is the highest value of the minimum fault level that sets the requirement on the system strength at this location. In this case, the requirement is set by harmonic 12.5 as 15 times the rated power of the windturbine.

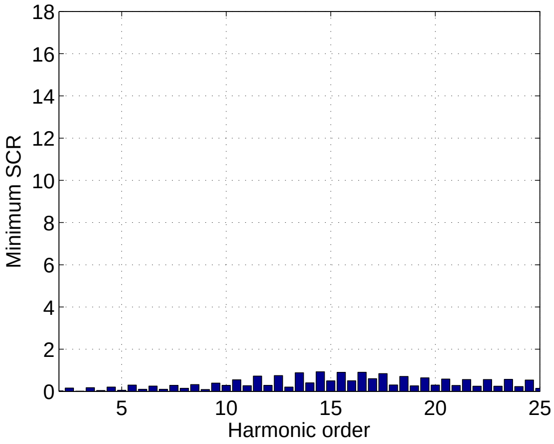

Fig. 6 Minimum fault-level for different harmonic order, to maintain the voltage distortion within the indicated limits, at location B.

At location B, the turbine requires a lower minimum short circuit ratio as in Fig. 6. The highest value about 1 is reached around the 15th order.

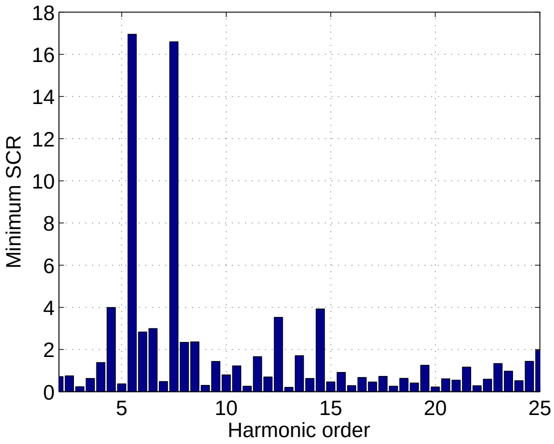

Fig. 7 Minimum fault-level for different harmonic order, to maintain the voltage distortion within the indicated limits, at location C.

There exist strong similarities at locations C and D, as shown in the Fig. 7 and Fig. 8. In both cases, the requirement on system strength is set by harmonics 5.5 and 7.5 with a large difference with the other harmonic orders.

Comparing the four locations (Fig. 5 through Fig. 8), it shows that also here each location is different. However, for each location the required system strength is set by one of the interharmonic groups. For the harmonic groups the requirements are very moderate, at most a factor of five. The reason for the high short-circuit level requirements associated with interharmonics is that the permissible voltage distortion for interharmonics is very low. As mentioned before, the limits according to IEC

61000-2-2 have been used.

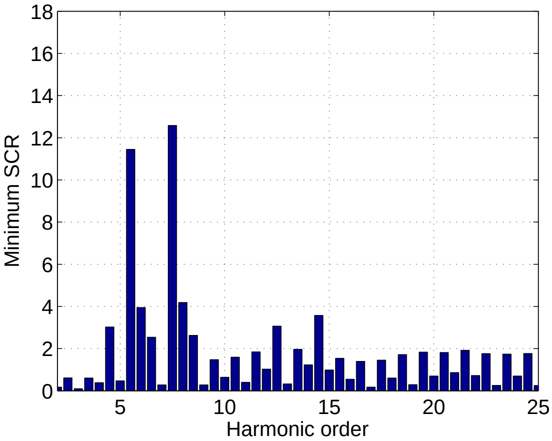

Fig. 8 Minimum fault-level for different harmonic order, to maintain the voltage distortion within the indicated limits, at location D.

It is also worth observing that the fault-level requirements at location B are much less strict than at the other locations. It is not clear whether this is related to the fact that the measurement concerns the emission from three turbines together, whether this is due to the fact that this concerns smaller and older turbines, or whether there is another explanation for this.

It should also be noted that the linear increase of impedance with frequency is only used here as a simplified model to allow an assessment of the severity of the emission from a network viewpoint, but independent of the detailed characteristics of the network. When evaluating the connection of a wind-power installation at a specific location, the actual impedance versus frequency characteristics at that location should be used.

CONCLUSION

Measurements have been performed of the harmonic emission in the frequency range up to 2 kHz with four wind-power installations at four locations in the North of Sweden. In all cases the measurements were performed on medium-voltage side of the turbine transformer, with wind turbines containing a power-electronic converter.

The measurements show that the emission from the turbines is small but that the emission contains a higher level of interharmonics than is normal with harmonic-emission loads. This emission at interharmonic frequencies puts the highest requirements on the fault level needed to keep the voltage distortion below the levels set by international standards. If these levels of emission at interharmonic frequencies turn out to be typical for wind-power installations, a discussion might have to be started about appropriate limits for interharmonic voltages.

A more detailed analysis of the measurements, not presented here, shows that the spectrum as well as the individual components shows strong variations with time. Summarizing, it can be concluded that each location is different and that each period of time is different. A measurement at one location during a short period of time is thus unlikely to be representative for the harmonic emission due to windpower installations.

ACKNOWLEDGMENTS

This work has been financial supported by the Vindforsk program and by Skellefteå Kraft. The authors would like to thank their colleagues in Electric Power Engineering at Luleå University of Technology for their useful discussions before, during and after the measurements.

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