Grid harmonics

"The Switch has been working on correction methods for better electrical signals to satisfy current and future standard requirements. These measures help eliminate harmonics to the limits required by the standards and our customers' specifications."

Valentin Dzhankhotov
R&D Engineer at The Switch

Proper filtering leads to lowest harmonic distortion:

Purifying the electric signal for the grid

Power electronic converters used in wind turbines are a well-known source of harmonic distortion, which can cause all types of negative effects, such as overheating, equipment failure, motor losses and network tripping. Therefore, harmonic current emissions are becoming an increasing area of interest for power system operators and those responsible for defining international standards. The Switch has been studying this problem in depth and offers various correction measures to ensure that the wind turbine's output power matches the strictest regulations.

Problems with harmonics and key affecting factors

Ideally, the sinusoidal periodical signal (50 Hz in Europe or 60 Hz in the US) should be supplied from a power converter to the grid. However, electrical signals always contain some amount of noise. It is convenient to analyze this noise in the frequency domain with the help of Fourier transformation. In accordance with Fourier transformation, any periodical signal can be represented as a sum of sinusoidal signals, or harmonics. Each harmonic can be described by its own frequency, which is a multiple of a base frequency, along with amplitude and phase.

Generally speaking, all the components involved in energy transmission contribute to harmonic distortion. Key factors creating harmonic distortion on the grid side of the wind power converter are the power converter itself, the filter, the power transformer and finally the actual grid.

The real problem with harmonic distortion is that it is hard to differentiate which level of distortion comes from the grid and which level comes from the power converter.

Power converter harmonics

To answer the demand for high energy efficiency and a desire for accurate process control in wind power generation, frequency converters now represent state-of-the-art technology in the industry. The shape and frequency range of the harmonic spectrum are directly related to the characteristics of the power converters used in the individual wind turbines as well as the harmonic filters selected.

Frequency converters use a pulse-width modulation (PWM) method to generate the required current waveform. This method of control offers the advantages, for instance, of very good performance, low price, small dimensions and a low mass. However, the PWM patterns contain high-frequency noise, which can be harmful for a load.

If we consider the power converter PWM pattern spectrum in the frequency domain, we see a set of harmonics. *See Figure 1.*

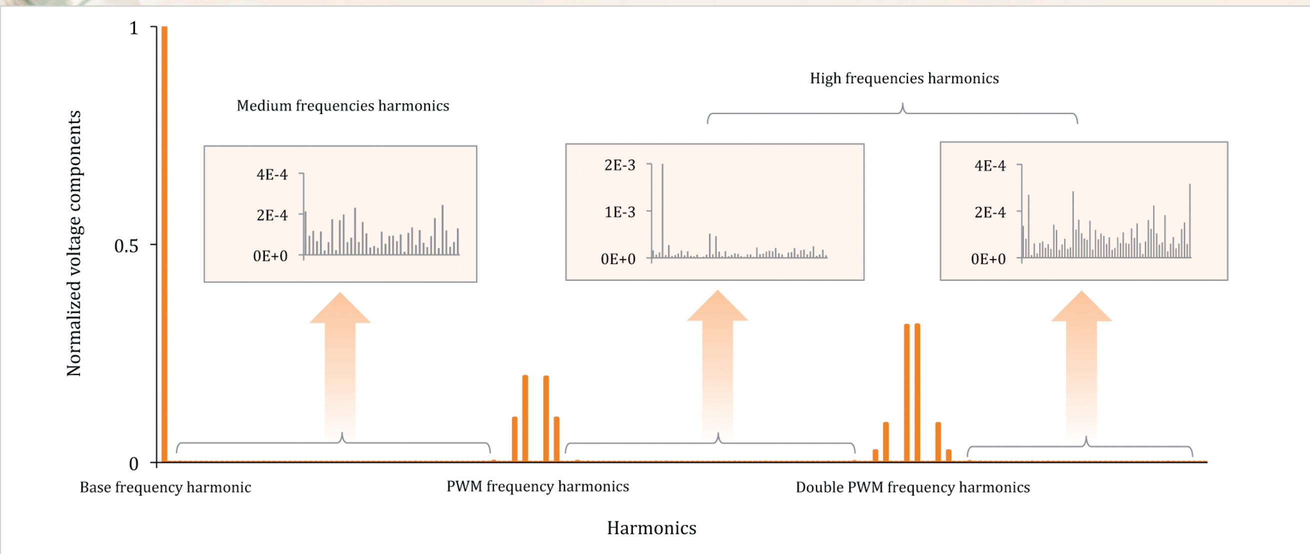

Figure 1. Voltage harmonic spectrum

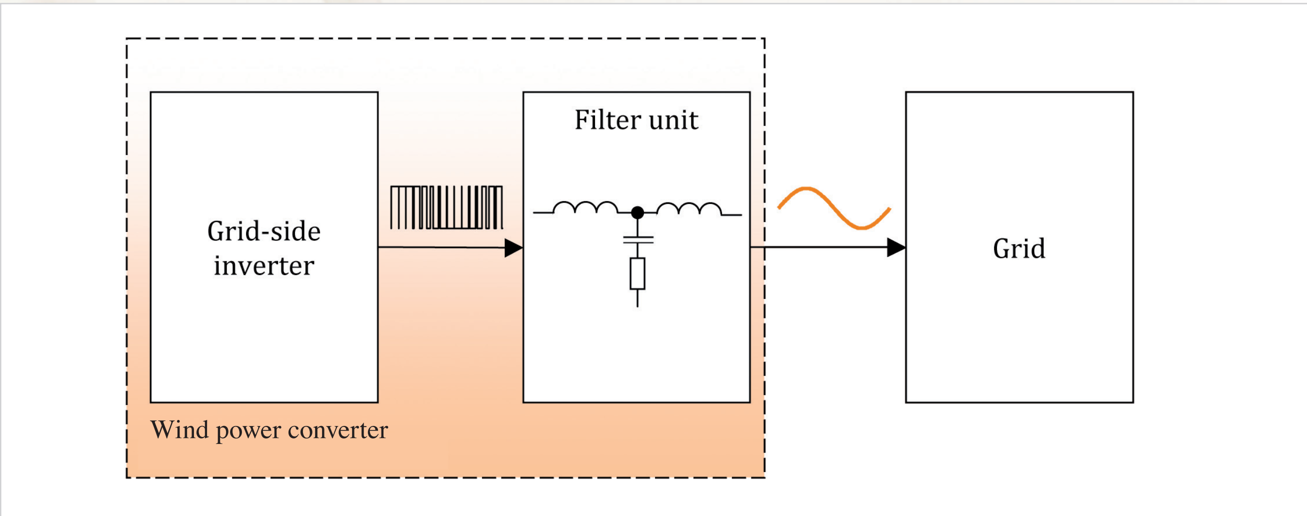

Figure 2. Filter effect

The base frequency component is usually the only one required for the customer. Low-frequency harmonics of PWM voltages have very small amplitudes, if there are no intentionally injected low-frequency harmonics from the control system. Harmonic amplitudes near PWM frequency and higher are significant, and should be excluded from the current spectrum. For these reasons, sinusoidal filters are used. *See Figure 2.*

Filters

Although filters are intended to decrease harmful harmonics, they may also lead to an increase in harmonic levels. This is because the filters usually consist of reactive components (inductors and capacitors) in order to achieve a good attenuation.

It is well known that the circuits containing both inductive and capacitive elements have resonance at certain frequencies. This resonance has an amplification effect so that some of the low-amplitude voltage harmonics, occurring between the base and the switching frequency, are actually amplified in the current spectrum.

Sometimes the internal resistance of a filter may be enough to satisfy the standards without special measures. When the opposite occurs, damping resistors can be used. Passive damping allows acceptable characteristics to be achieved with the insertion of a resistor in a series with filter capacitance. However, this also is characterized by considerable power losses, and the high-frequency attenuation of the filter worsens. In practice, the selection of the damping resistors is always a tradeoff between the price and quality.

A filter's high-frequency performance can also be improved using an extra inductor connected in a series with a transformer. In this case, the filter is more expensive and generates additional losses.

Transformer

In the grid transformer, the saturation and hysteresis effects can cause a distortion in current. *See Figure 3.* This effect gives essential content of the 3rd harmonic in phase currents, especially in no-load mode, which is close to the conditions in the early morning. *See Figure 4.* It is well known that the 3rd harmonic can be minimized if one of the windings of a three-phase transformer is connected in star and another one is connected in delta.

Current harmonics increase losses and cause more heating in the transformer than the fundamental frequency harmonic. Therefore, special measures in the control system should be taken to make necessary corrections.

Load

The load, too, contains a set of active and reactive components that cause dynamic changes. For one, the load determines the network harmonic impedance. For another, the load changes dynamically from year to year, from winter to summer, from morning to night. On one hand, the complex structure of the load is difficult to predict. On the other hand, load distribution between phases is usually unequal and causes significant unbalances of phase currents and voltages. Unbalances, in their turn, also contribute to the harmonic content. For example, the 3rd harmonic may appear regardless if one of the windings of the transformer is connected in star and the other one is connected in delta.

Increasing requirements of international standards

The most highly regarded international standards today are IEC 61000-3-6, IEEE 512-1992 and the newest German BDEW standard. In addition, every grid code can have its own rules.

The IEC standard is stricter than the IEEE standard with regard to limits on voltage harmonics, but they are almost identical when it comes to limits on current harmonics.

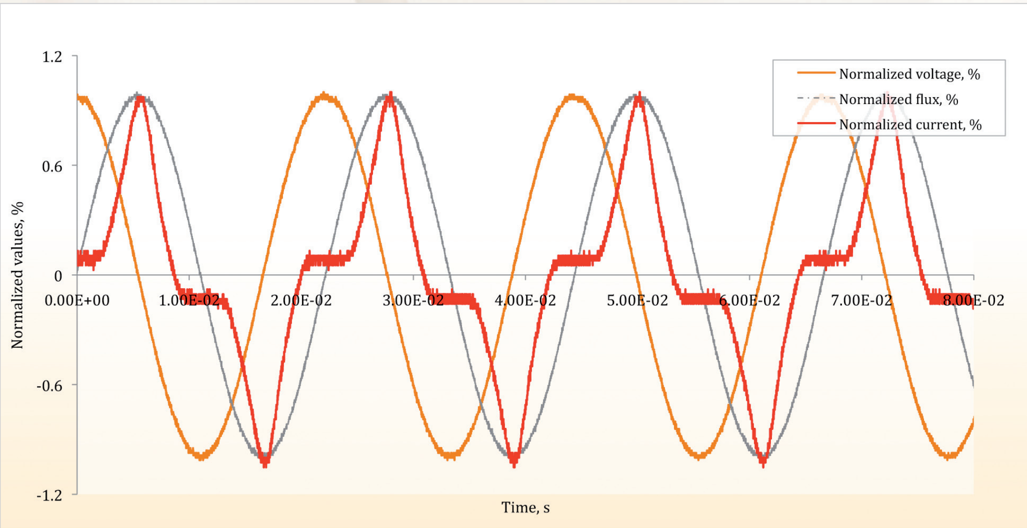

Figure 3. Current distortion effect due to transformer saturation and hysteresis

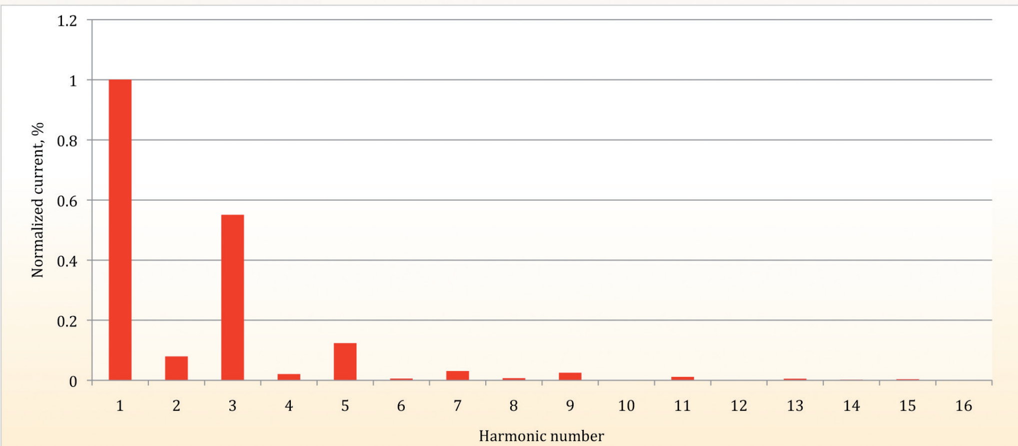

Figure 4. Spectra of current distorted in transformer

Although IEC and IEEE standards are widely used in the industry, they are fairly old and not renewed yet. Germany's new BDEW standard, however, is much stricter than the other two standards. A comparison of current harmonics limits required by IEC 61800-3 and BDEW standards is presented in *Figure 5.* Thus, we can expect that IEC and IEEE standards will become even stricter in the future.

It can be stated that a filtering system that complies with the new BDEW standards is significantly more expensive, bulky and incurs more losses than a filtering system that complies with the IEC and IEEE standards.

Correction methods for better electrical signals

The Switch has been working for several years to determine correction methods for better electrical signals that will satisfy current and future standard requirements.

Sinusoidal filters are required to significantly improve the content of power converter harmonics. Harmonics that are amplified by LC filter resonance may be attenuated with the help of damping resistors. The damping circuit should be carefully selected in order to retain the required high-frequency filter performance. To eliminate transformer harmonics that are multiples of three, a delta-star connection can be implemented in the windings. Low-frequency asymmetry and unbalances are a very important question. The main cause of asymmetry may come from loads. The Switch power converter is capable of minimizing harmonics distortion caused by asymmetry effects.

As a result, all of these measures help to eliminate harmonics to the limits required to meet the standards and specifications of customers.

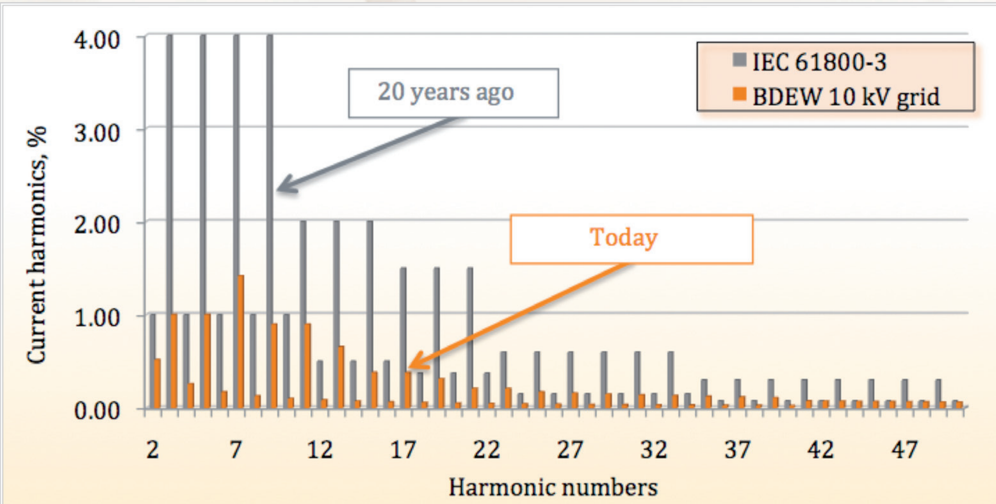

Figure 5. Comparison of old IEC 61800-3 and new German BDEW standards in respect to current harmonics limits