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Power Quality

# Power Quality under the microscope

## Change in the producer and consumer structure

The change in the producer and consumer structure of the Central European power grids is in full swing. Large power plants, which represent a centralized generation of electrical energy, are gradually being replaced by numerous, but smaller, decentralized producers such as wind, energy or photovoltaic plants. These usually feed into the existing medium-voltage and low-voltage grids with the assistance of power electronic components.

On the other hand, there is an increasing number of consumers on the market who also use power electronic elements as part of their energy efficiency improvements. Their non-linear property is the main cause of higher-frequency voltage and current signal components in electrical power networks.

This development resulted in a complex system with volatile load flows and changing load flow directions. In addition, due to the legally prescribed unbundling of generation, transmission and distribution, the electrical energy product is increasingly being transferred and charged between the various market participants. This means that before it reaches the end customer, the electricity may have been produced by various market participants and even delivered several times.

This structure requires numerous transfer and settlement points, which are neuralgic points with regard to guaranteeing the quality of the voltage.

Special publication

## Effects on electrical energy grids

Due to the massive use of power electronics in decentralized generation plants and the displacement of ohmic loads by power electronic components, the share of disturbing network reactions such as flicker and harmonics has risen sharply in recent years. Thus, the clock frequencies of the power electronics of wind turbines are approx. 2-4 kHz, with solar inverters depending on the power class up to 20 kHz.

Ensuring power quality at the transfer point is precisely regulated in various standards (DIN EN 50160, VDE- AR-N 4120, IEC 61400-21 etc.) on the generator and consumer side as well as on the distribution grid side and forms the basis of the grid connection agreement. In order to determine the harmonic level and the THD factor (Total Harmonic Distortion Factor), so-called Power Quality Measuring Devices (PQ) are required. They determine the characteristics of the electrical energy quality from the measured voltage and current signals. In addition, these devices can be very helpful for fault analysis. They are able to identify harmonics that interfere with electronic components and can significantly shorten their service life.

In addition, every electrical power network has parallel and series resonances that alternate with increasing frequency, starting with a parallel resonance. Harmonic oscillations can stimulate these resonances, which can then lead to considerable damage. On the basis of practical experience, it can be estimated that the above-mentioned phenomena will increasingly occur in the future.

An important reason for this is the reduction of the ohmic loads, i.e. the damping elements.

The more frequent occurrence of higher-frequency voltage and current signal components with larger amplitudes is also the cause of resonance phenomena. According to experience, the resonance frequencies of an MV network are significantly lower than in a low-voltage grid. Accordingly, these resistances can already be excited by low order harmonics. Such interruptions can cause extremely high costs, especially in the case of financially-intensive industrial plants.

A defined transmission behavior of the installed current and voltage transformers is a basic requirement both for trouble-shooting and for monitoring the limit values. Furthermore, only trustworthy measurements for both suppliers and consumers are the basis for defending or asserting liability claims.

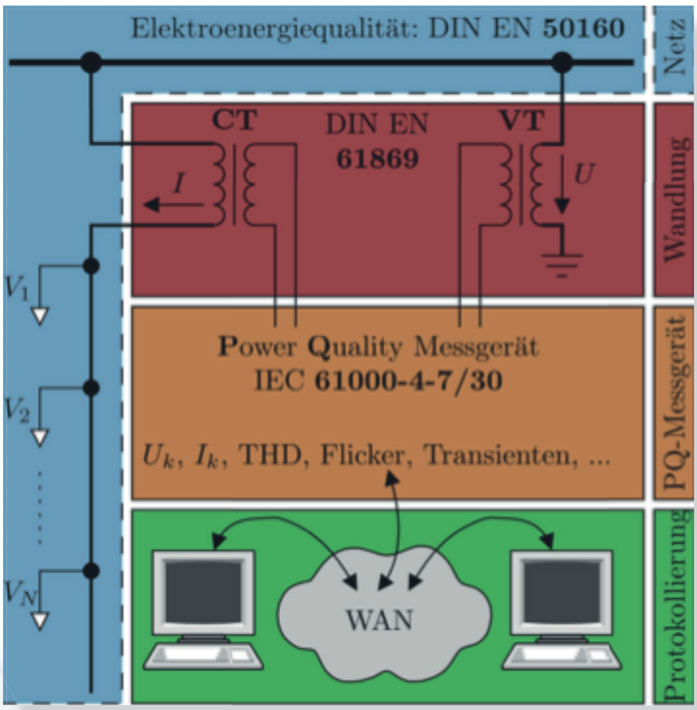


*Figure 1: Measurement chain relevant for PQ measurements*

## Measurement of electrical energy quality

The new producer and consumer structure brings with it an enormous increase in the need for monitoring measures of network conditions, in particular of PQ monitoring systems. Currently, there are devices on the market that record higher-frequency voltage and current components up to 20 kHz.

One aim of the PQ measurements is the monitoring of the characteristics of the voltage in public electrical power networks specified in the EN 50160 standard (in particular the harmonics). The electrode shown in Fig. 1 is relevant for such analyses.

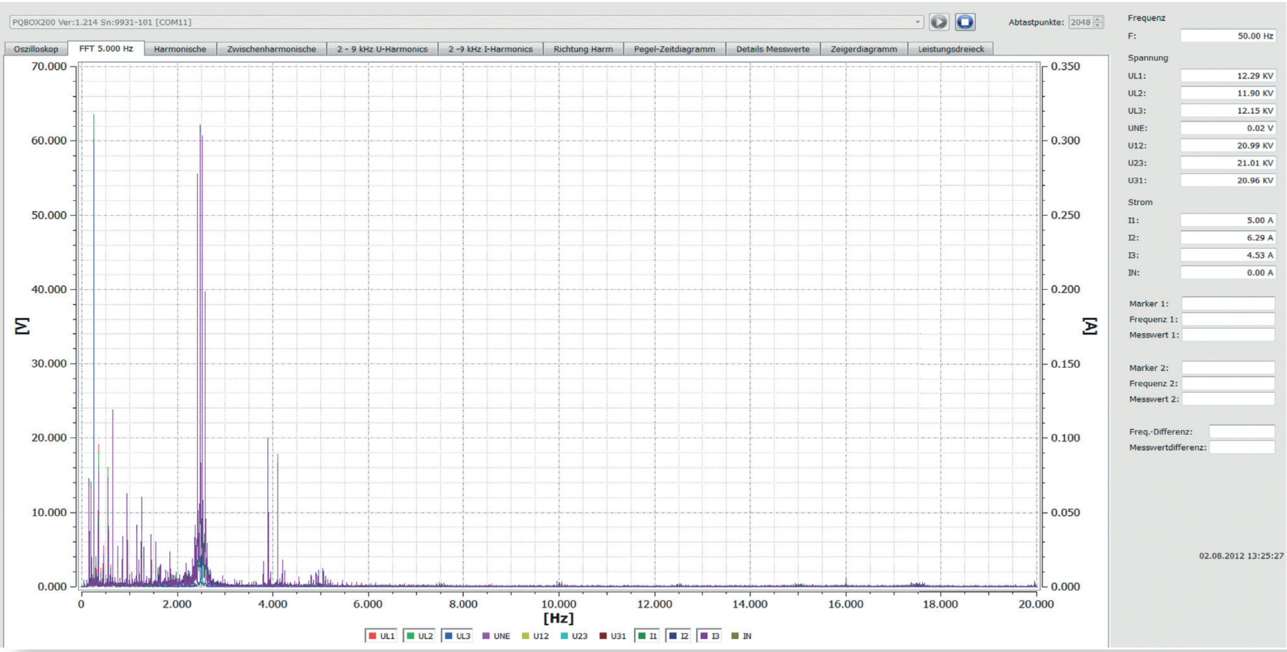


*Figure 2: Spectral analysis using FFT (0 - 20 kHz)*

## Relevant measurement chain for PQ measurements

In principle, standard measuring instruments must provide data that is both legally compliant and traceable. Therefore, the IEC 61000-4-30 measuring instrument standard for Class A instruments fully describes the aggregation and accuracy of the measurement data. The manufacturer has only a few degrees of freedom. Measurement data from different manufacturers can thus be compared. The accuracy of the measuring inputs must be at < 0.1 %, whereas that of the harmonic measurement must be at < 5 %. Example: If the actual value is 49. If the deviation from the measuring instrument is not more than +/- 0.0075 %, the maximum deviation from the measuring instrument in this case must not exceed +/- 0.15 %.

## Measuring transformers – the link between the electrical power grid and the PQ measuring device

The link between the PQ meter and the electrical power grid is the conversion of the current and voltage signals according to the electrode in Fig. 1. However, conventional current and voltage transformers are often used here without hesitation, which are only tested and approved according to IEC 61869, i.e. for operation at nominal frequency. This standard does not address the frequency transfer behavior of transducers in higher order harmonics. Accordingly, the frequency dependence of the transmission ratio has not yet been taken into account.

In practice, this connection is often overlooked and the wall tester is accepted as the ideal transformer and integrated into the measuring chain. However, this procedure involves great uncertainty, as precise information about the frequency-dependent transmission ratio can only be obtained by special measurements.

Figure 2 also illustrates this. It shows the result of a spectral analysis (0 - 20 kHz) of voltage and current signals in a 20 kV medium voltage grid. Two wind turbines from different manufacturers are connected to this grid.

WEA 1 clocks at 2.5 kHz and generates corresponding sidebands. WEA 2 shows reactions at approx. 4 kHz.

In the evaluation it now looks as if WEA 2 emits much lower interference levels into the electrical power grid. Since in this case the measurement was carried out with conventional MS converters, a falsification of the secondary signals in the frequency range 4 kHz is to be assumed. It is no longer possible to draw conclusions about the real height of the spectral components in this range.

Even a correction of the measured values based on the frequency transmission behavior of a transducer is generally not possible, since each transducer has a specific frequency transmission behavior. This can also be influenced by the connected devices. No one will make the effort to have an existing voltage transformer together with all connected devices tested in a laboratory with regard to the frequency and carrying behavior. There are already limit values for harmonics up to 9 kHz for wind turbines and all other feed systems into the low and medium voltage grid.

The calculation methods for voltage and current harmonics are described in the IEC 61000-4-7 standard. In the frequency range 2 - 9 kHz 200 Hz bands of the FFT calculation are combined. The middle frequency of the respective band is indicated in each case.

In the example in Fig. 3, all 5 Hz spectral lines from 2,405 Hz to 2,600 Hz are combined in the frequency band „2.5 kHz". For each voltage and current input there are 35 frequency bands in the range of 2 - 9 kHz, which are permanently monitored by the PQ measuring instruments.

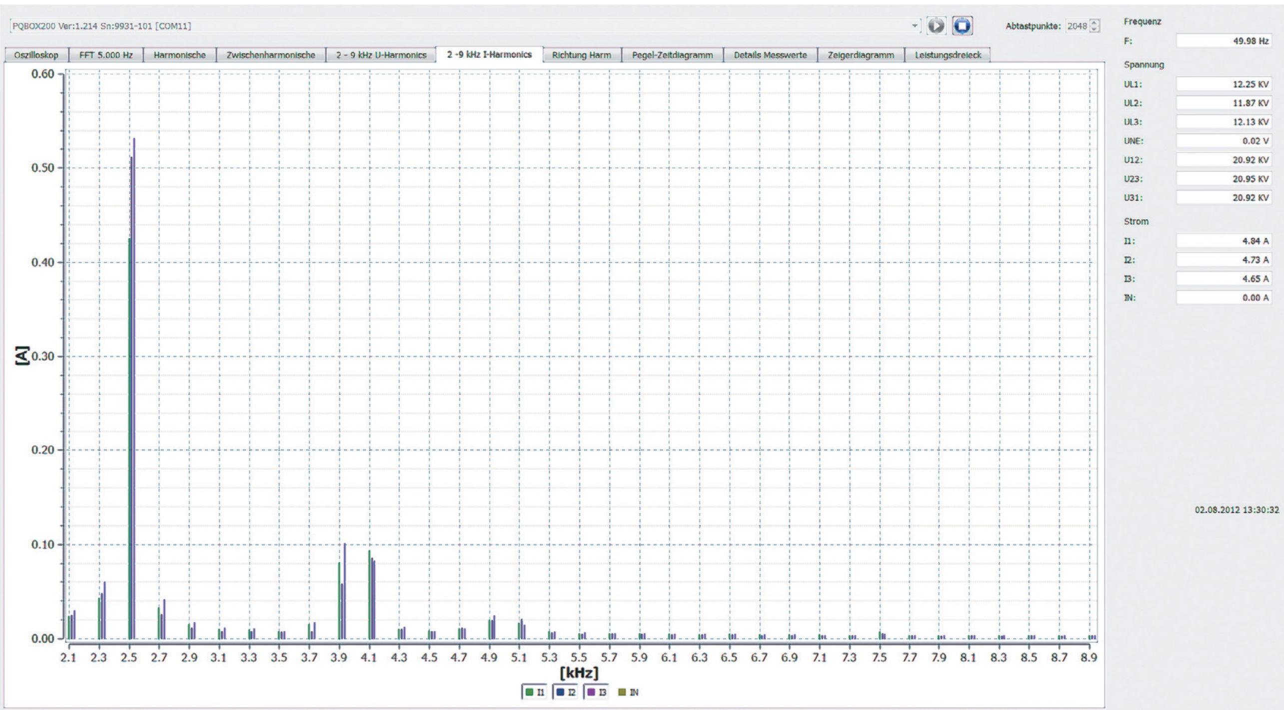


*Figure 3: 200 Hz bands according to standard IEC61000-4-7*

## The clock frequency is not everything yet

In addition to the clock frequency, many other frequency components are formed in the electrical power grid. These so-called sidebands are impressively recognizable in figure 4.

The following formula describes the phenomenon:

$$f_{\mu} = n \cdot f_T \pm 2n \cdot f_I$$

$f_{\mu}$ = Frequency in the grid
n = multiplier (1; 2; 3)
$f_T$ = Clock frequency of the power electronics
$f_I$ = Frequency of the basic oscillation grid (50Hz)

The clock frequency of the inverter, many other sidebands and multiples of the clock frequency can be seen in the measurement results of A. Eberle in Fig. 4 in the mains current and also in the mains voltage. In the example, the following sidebands and multiples of the clock frequency are formed.

| | |
|---|---|
| Clock frequency of the power electronics = | **4,5 kHz** |
| n (2; 3; 4) multiplier = | **9 kHz; 13,5 kHz; 18 kHz** … |
| Frequency sidebands = | **+/- 100 Hz; +/- 200 Hz** … |

For example, a system with a clock frequency of 4.5 kHz generates further spectral lines at 9 kHz and 13.5 kHz, including the respective sidebands, as a feedback effect in the grid.

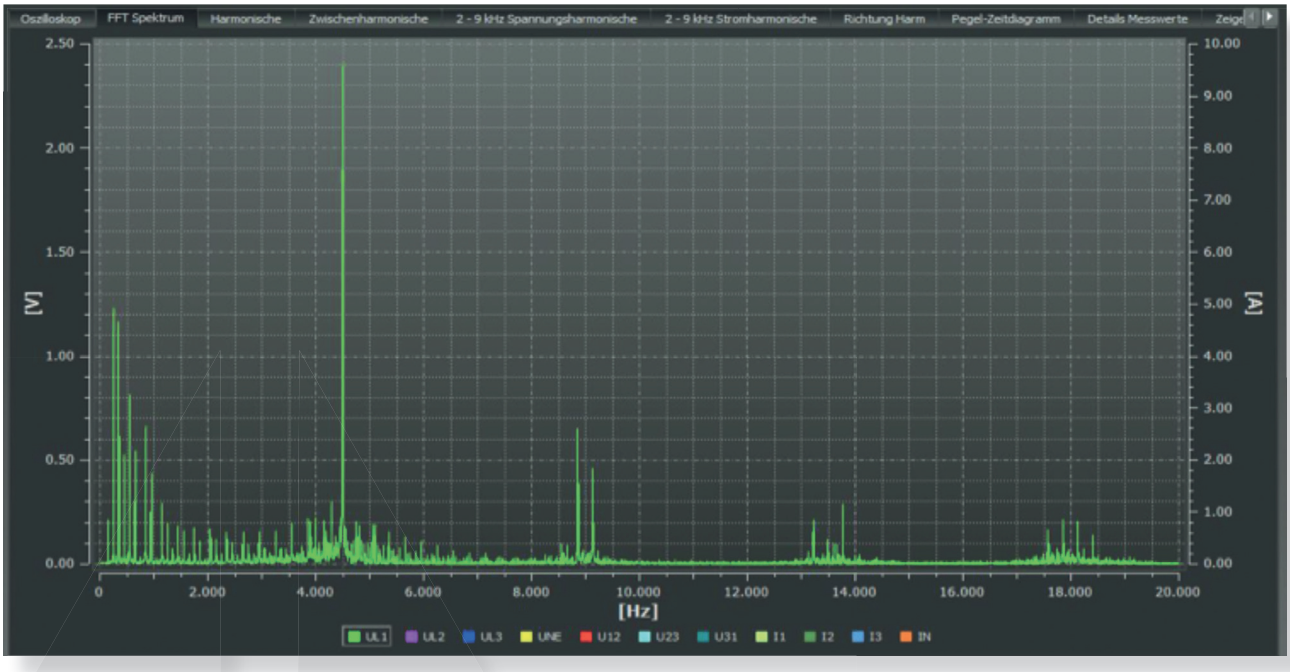


*Figure 4: Spectrogram with clearly recognizable clock frequency, sidebands and multiples of the clock frequency*

## Frequency transmission behavior and development of broadband converters

In research projects with TU Dresden and Leibniz University Hannover, RITZ Instrument Transformers GmbH was able to develop the scientific basis for the development of broadband converters. As a result, RITZ has been offering so-called broadband for current- and voltage measurement [a] since 2012. These optimized devices are especially suitable for harmonic analysis according to DIN EN 61000-4-30 or 61000-4-7.

Figure 5 shows the frequency-dependent translation errors of three conventional voltage transformers in comparison to that of an optimized voltage transformer. These results refer to 20 kV devices and justify the necessity of using broadband converters for PQ measurement purposes. In addition to the transmission errors, standards are indicated. The relevant frequency ranges are highlighted in color.

For example, a 1.8 kHz voltage component measured with the voltage converter “VT 3“ would simply be transmitted incorrectly to the input of the PQ measuring device. This transducer characteristic means that the verification of the characteristics required in EN 50160 with “VT 3“ is not trustworthy. In the frequency transmission behavior, there are areas with strong attenuation or high amplification. As a result, the voltage quality cannot be properly controlled.

For measurements according to the informative part of DIN EN 61000-4-7, all conventional VT 1 - 3 voltage transformers are inadmissible. The VT 4 broadband converter is specially optimized for these measurement purposes and enables reliable PQ parameters to be calculated by an appropriate measuring device in the frequency range up to 9 kHz.

For measurements above 9 kHz, RITZ offers a high-precision ohmic divider (GSER 16), which is used, for example, in conjunction with power analzysers in engine test benches. Currently, the GSER 16 can be used up to 150 kHz. The current version DIN EN 61000-4-30 :2016-01 also deals in its informative part with frequency measurements up to 150 kHz.

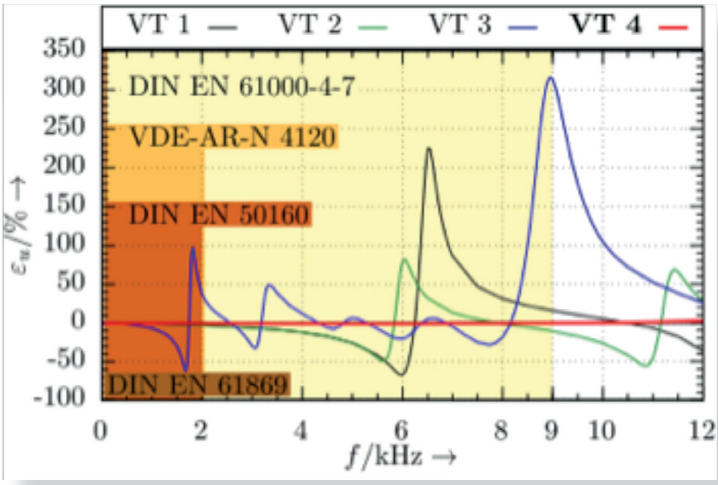


*Figure 5: Transmission errors of conventional (VT 1-3) and an optimized voltage converter (VT 4); Relevant frequency ranges of some standards*

## Conclusion

The specialist for electrical measurement and control technology, A. Eberle from Nuremberg, reacted to the requirements for measurement technology already several years ago. The permanently installed PQ analyzers can measure frequencies up to 20 kHz in the power grid, the mobile measuring devices even up to 1 MHz. This is much more than voltage quality standards demand today, but it is a prerequisite for being able to detect all faults with certainty.

The energy turnaround with the integration of regenerative generation plants and the associated significantly increased use of power electronics on the part of the decentralized producers and consumers have considerably affected the Central European electrical energy networks.

The number of disturbing network perturbations such as flicker and harmonics has risen sharply in recent years. Complete systems consisting of PQ measuring devices and broadband converters are in demand. With such systems, the characteristics of the electrical energy quality can be reliably determined and the causes can be identified and localized within the framework of the disturbance analysis.

A. Eberle and RITZ Instrument Transformers GmbH recognized the signs of the times early on. The course has been set for the development of high-performance solutions.

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