Frequency-optimized medium-voltage transformers

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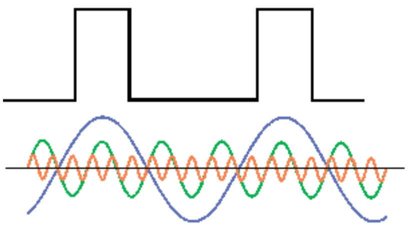

New measuring requirements for inductive current and voltage transformers in the medium-voltage range

Changes to the structure of generation and consumption

Over the last few years, the proportion of renewable energy in Germany has grown massively. Wind, biomass, photovoltaic and hydroelectric plants now make up approximately 30% of the country's energy mix.
Unlike in conventional nuclear or coal-fired power stations, where all synchronous generators are used to produce electricity, here inverters or frequency converters are used. As such, it is not always possible to achieve an undistorted sine wave.
The distortions are caused by the switching semiconductor elements in the inverter. Harmonics generated in this way are whole multiples of the first harmonic and can extend far into the single-digit kilohertz range. The total harmonic distortion (THD) factor[1] specifies the undesirable distortion ratio of the 50 Hz sinusoidal oscillation and regularly reaches between 10 and 30%.
The currently valid "Technical guideline for generation plants in the medium-voltage grid" by the BDEW provides measurements and limit values for harmonic currents up to 9 kHz and is the basis for the plant certifications of f.e. wind turbines. In addition, the product standard EN 50160 for electrical energy in Europe allows a maximum THD_U of 8 % for harmonic voltages up to 2 kHz. This value is not very restrictive in international comparison. For example, the comparable IEEE standard 519 in the US limits the THD_U for critical infrastructure such as hospitals and airports to max. 3 %.

In addition to the harmonics produced by inverters on the generator side, there have also been changes on the consumer side in recent years. Non-linear consumers such as LED or energy-saving lamps are pushing linear ones, like traditional incandescent bulbs, out of our daily lives almost completely.
Plug-in power supply units for mobile phones and laptops are no longer made from small transformers either, but from semiconductor circuits known as switching power supplies. It would not be possible to create such small, light power supply units any other way. But these benefits are set against one big disadvantage: the current is drawn from the public grid not as a sinusoidal waveform, but in pulses. The figure below illustrates this:

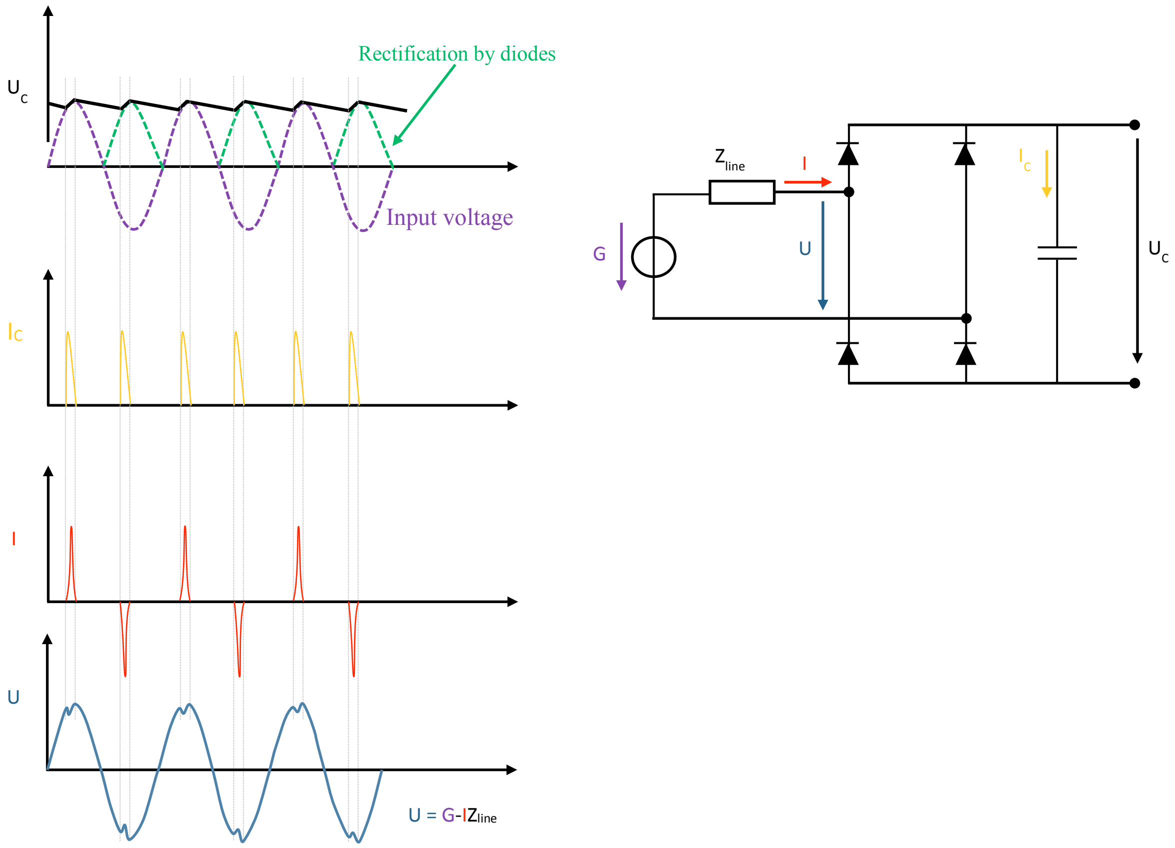

Figure 1: Bridge rectifier with pulsed current draw

[1] The THD is the ratio of the harmonic component to the first harmonic

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The filter capacitor shown in the diagram not only smooths the required DC output voltage, it is also recharged in pulses by the rectifier diodes. These steep current peaks generate reactive power on the one hand, and harmonics on the other.

Moreover the current peaks have an influence on the voltage quality due to the line impedance. The characteristic “dent” in the peak of the voltage amplitude is now recognizable in many medium-voltage grids in Europe.
However, if the THD_U value at the point of common coupling is still below 8 %, there is usually no reason for anyone to act.

Standards regulate limit values – but not always!

There is already a corresponding set of international norms that limits harmonic currents in end devices with a power consumption > 75 W. Devices under 75 W are not currently covered by standards. In the interests of keeping costs down, manufacturers do not usually implement filter measures or complex power factor correction. The EN 61000-3-2 set of standards does not come into play until the 25 W mark for lamps either; for example, where energy-saving lamps are concerned, THD_I values of 30 to 70% and higher are not uncommon during warm-up and in continuous duty. It should also be noted that, even when they do kick in, the standards only define limit values up to 2 kHz. As a result, manufacturers have hardly taken interference suppression into account at all when developing electronic products for the frequency range > 2 kHz in the past.
In addition, more and more electrical motors with variable-frequency drive technology are being used in the industrial sector. Today already, the percentage of electrical motors sold that have a frequency-controlled drive stands at around 40%. The majority of these motors utilise pulse width modulation technology, which can generate THD_I values in the range from 100 to 120%. Clean sine waves are almost impossible to identify at these values.

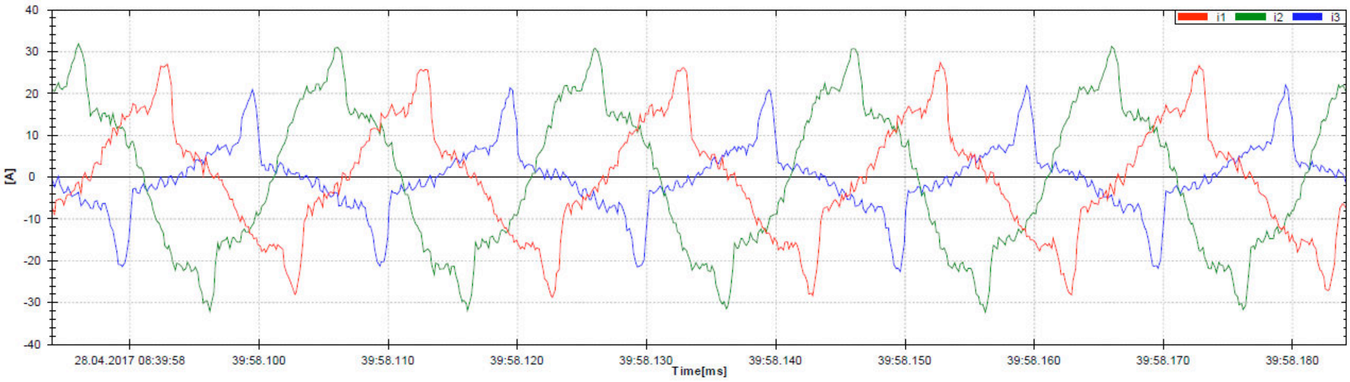

Figure 2: Flow of current for an industrial customer on the low-voltage grid

Power electronics have so many benefits that we can categorically state there will be no return to linear consumers such as the traditional incandescent bulb. In fact, we can expect harmonic loads to increase even further in European grids, due to the development of alternative sources of energy and the growth of non-linear consumers. We should also bear in mind that having lots of consumers that are not regulated by standards could cause considerable interference overall.
Filter systems have already had to be installed in office buildings where just computers, telephone systems and energy-efficient bulbs are used, in order to bring problems with harmonics under control.

Effects of harmonics

If high harmonic currents are permitted, they can strongly influence the quality of the voltage at the point of common coupling in the medium-voltage. Neighbouring facilities can thus be affected. For this reason, extensive control of the voltage quality becomes more and more important for the customer and the network operator. With appropriate power quality devices the contractually fixed voltage quality acc. EN 50160 can be controlled.

While the EN 50160 only describes the voltage quality, harmonic currents can also have direct negative influences, because a higher harmonic distortion causes higher RMS values and thus increased heat dissipation in the systems.

Grid operators are primarily interested in the economic effects of harmonics. When it comes to harmonic **currents**, the most important phenomena are as follows[1]:

- Overloading of neutral conductors
- Overheating of transformers
- False tripping of circuit breakers/miniature circuit breakers
- Overstressing of power-factor correction capacitors
- Skin effects

If the distortion level in the supply voltage reaches a value > 10%, this shortens the lifetime of devices considerably. This reduction is estimated as follows:

- 32.5% for 1-phase machines
- 18% for 3-phase machines
- 5% for transformers

To maintain the lifetime expected from the nominal load, the devices named above must be over-dimensioned.

Future standard regulations

The grids and facilities must be suitably protected against these negative effects. The latest draft of the VDE-AR-N 4110 (medium-voltage) therefore specifies measurements of harmonic currents up to 9 kHz for **generating plants**, **receiving plants** and **storage systems**. The directive will apply from May 2019. Until now, current measurements up to 9 kHz have only been requested for generating plants as part of the plant certification by the BDEW published "Technical guideline for generation plants in the medium-voltage grid". Often the certification companies carried out only one-off measurements. According to experts a permanent monitoring is advisable, as different operating modes of the system can generate different levels of harmonics. In addition there are always disagreements between the calculation and the actual measured values at the grid connection point. Capital-intensive filter systems up to 9 kHz are already in operation.[2]

For the network operator the EN 50160 and the VDE-AR-N 4110 result in the following measuring tasks at all grid connection points:

- Measurement of harmonic currents up to 9 kHz (VDE-AR-N 4110)
- Measurement of harmonic voltages up to 2 kHz (EN 50160)

The question arises whether conventional instrument transformers in the medium-voltage can meet these requirements or not.

Transmission behaviour of conventional current and voltage transformers

MV current transformers

Unfortunately there is no general statement in the current standards regarding inductive transformers. The technical report „IEC/TR 61869-103 Instrument transformers – The use of instrument transformers for power quality measurements" only lists measurement results of different measurement campaigns for current transformers in the range of 1 to 52 kV. While a release cited in this report indicates a phase and amplitude error of 5 % up to 5 kHz, other quoted reports refer to a bandwidth of only 2 kHz with acceptable error values.
For current harmonic measurements up to 9 kHz a qualitative statement by the manufacturer is absolutely necessary for this reason.

[1] Schneider Electric Wiki (accessed 09/01/2018) http://de.electrical-installation.org/dewiki/Wirtschaftliche_Auswirkungen#St.C3.B6rungsausl.C3.B6sung_und_Anlagenausfall

[2] The first high-frequency filter for the Offenbach wind farm provides clean power grids in the frequency range up to 9 kHz https://www.reinhausen.com/en/desktopdefault.aspx/tabid-42/16_read-8497/

MV voltage transformers

Increasingly, inductive voltage transformers are being used in practice for power quality measurements. In this case special care is required. The construction of the voltage transformers induces a first resonance point in the single-digit kilohertz range. Deviations of 100 to 300 % in the voltage amplitude and 80 to 160° error in the phase angle are to be expected. In general it can be assumed, that the higher the rated voltage of the transformer is, the closer the resonance point is to the rated frequency.

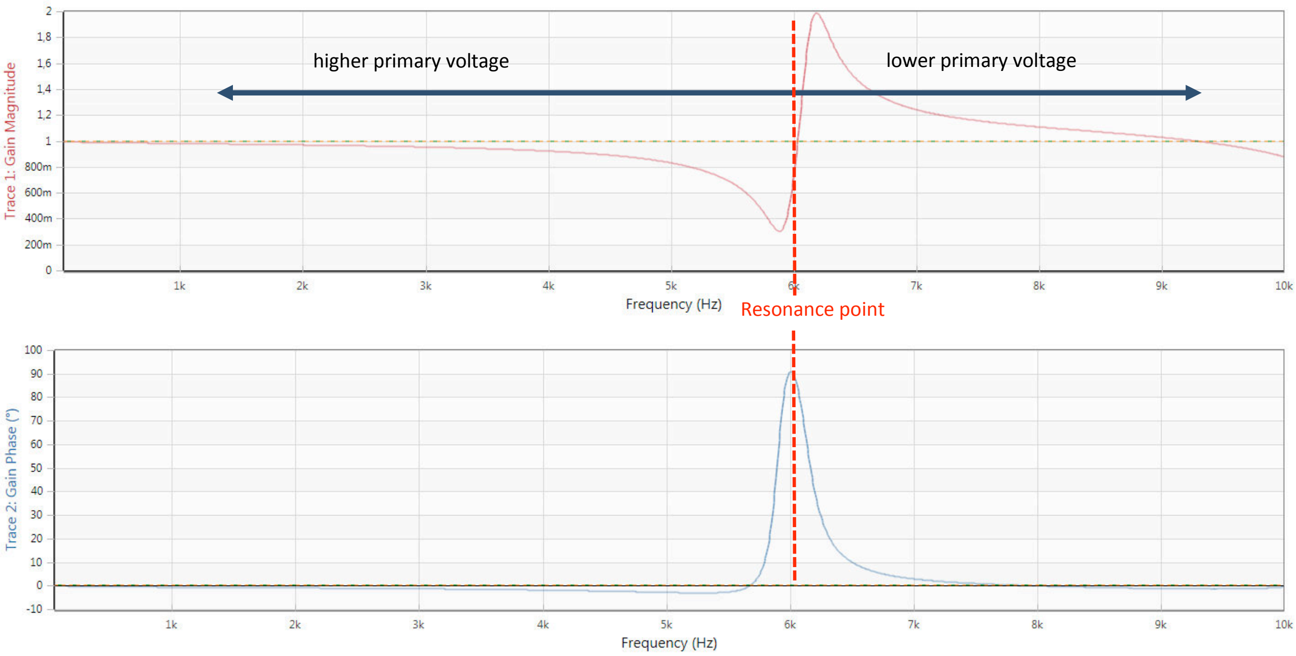

Figure 3: Frequency transmission behaviour of a 10 kV voltage transformer with high-impedance load

In the IEC/TR 61869-103 with respect to inductive voltage transformers for a system voltage of 1 to 52 kV, an adequate transmission behaviour is confirmed for high-impedance loads up to 2 kHz. At the same time, it is pointed out that this cut-off frequency is not always reached by all devices.
With regard to this, the European organizations CIGRÉ and CIRED have also addressed this issue in the joint working group (WG C4.112) and have published the following table in the technical brochure 596.

	Voltage level	Order of the harmonic		
		2. to 7.	8. to 20.	21. to 50.
Medium-voltage	10 kV	Yes	Yes	Yes
	20 kV	Yes	Yes	Uncertain
	30 kV	Yes	No	No
High-voltage	60 kV	Yes	Yes (?)	Uncertain
	110 kV	Yes	Yes	No
Extra-high-voltage	≥ 220 kV	Uncertain	No	No

Chart 1: CIGRE / CIRED Guidelines for power quality monitoring WG C4.112 TECHNICAL BROCHURE 596
Limitations for harmonic measurements with inductive voltage transformers

Here it becomes clear that the harmonic measurements of EN 50160 (up to 2 kHz or 40th harmonic) can only be performed with voltage transformers up to a system voltage (Phase-to-phase voltage) of 10 kV without additional metrological verification. Even the voltage transformers for 20 kV cannot be used with complete safety up to 50th harmonics. Therefore a metrological proof of the manufacturer is required.

Effects on the metering measurements in the medium-voltage

In addition to the limited possibilities of a power quality measurement, there is another and no less significant problem with the most common metering systems. For example, the energy meters ZxQ Qualigrid from Landis & Gyr as well as the LZQJ-XC from EMH are counting the active power up to the 30th resp. 32nd harmonic (current and voltage). The literature generally confirms the transmission behavior of medium-voltage current transformers up to at least 2 kHz[1], but voltage transformers for 20 kV are not recommended to use above the 21st harmonic in combination with above mentioned energy meters without metrological verification by the manufacturer. The voltage measurement up to the 30th resp. 32nd harmonic contains considerable measurement uncertainties due to the voltage transformers. It is even more dramatic for 30 kV voltage transformers. When using energy meters, which take the active power on the harmonics into account for the active power calculation, it has to be ensured that the voltage transformer has been approved by the manufacturer for the required frequency range. Some network operators already refer to this fact in their technical connection conditions (TABs). Customers and system builders are therefore obliged to consider appropriate instrument transformers in the measuring field or switchgear.

Due to these market conditions MBS AG has developed frequency-optimized medium-voltage current transformers with a measuring accuracy of 3 % up to 9 kHz and frequency-optimized medium-voltage voltage transformers up to 36 kV with a measuring accuracy of 5 % to at least 2 kHz. A test report is enclosed with each device. The customer benefits from reliable measuring results for the frequency range up to 2 kHz as specified in EN 50160. Network operators can take action on inadmissible grid pollution without delay. In addition the measuring chain is precisely defined with regard to the active power calculation.

[1] IEC/TR 61869-103

Frequency-optimized medium-voltage current and voltage transformers up to 36kV
with PTB approval suitable for metering measurements

Description:

On multiple customer request we have extended our product range of medium-voltage transformers by frequency-optimized versions. On request our medium-voltage current and voltage transformers can be equipped with one or more frequency-optimized cores resp. windings.

On the one hand, it is possible to implement the transformers with an additional core or an additional winding for power quality measurements.
This is of particular interest for the medium-voltage current transformers, since the VDE-AR-N 4110 specifies the measurement of harmonics up to 9 kHz. With our current transformers the permanent monitoring is possible as recommended by experts.

On the other hand, it is possible to monitor and supervise the power quality in the medium-voltage grid up to 2 kHz according to EN 50160 with our frequency-optimized voltage transformers.

In addition to the execution of our medium-voltage transformers with separate core or winding for power quality measurements, also the metering core or winding used for counting can be realized with frequency option. Common medium-voltage energy meters calculate the active power up to the 30^{th} harmonic. Especially medium-voltage transformers for 20 kV and 36 kV have no secure transmission behaviour above the 21^{st} harmonic. A use in combination with such energy meters is not recommended without metrological proof of the manufacturer.

MBS AG offers both current and voltage transformers in frequency-optimized design with a detailed test protocol on request, in which you can see the exact transmission behaviour of the complete frequency range.

Technical parameters:

	12/28/75 kV	**24/50/125 kV**	**36/70/170 kV**
Current transformers			
Primary nominal current:	5 A – 3000 A reconnectable: 2x5 A – 2x600 A	5 A – 1600 A reconnectable: 2x5 A – 2x600 A	5 A – 600 A reconnectable: 2x5 A – 2x300 A
Secondary nominal current:	5 A or 1 A	5 A or 1 A	5 A or 1 A
Harmonic transmission:	ε ≤ 2% / Δφ ≤ 3°, 0.05 – 5 kHz ε ≤ 4% / Δφ ≤ 4°, 5 – 9 kHz	ε ≤ 2% / Δφ ≤ 3°, 0.05 – 5 kHz ε ≤ 4% / Δφ ≤ 4°, 5 – 9 kHz	ε ≤ 2% / Δφ ≤ 3°, 0.05 – 5 kHz ε ≤ 4% / Δφ ≤ 4°, 5 – 9 kHz
Weight::	approx. 22 kg	approx. 28 kg	approx. 51 kg
	12/28/75 kV	**24/50/125 kV**	**36/70/170 kV**
Voltage transformers			
Primary nominal voltage:	3,000/√3 V – 11,000/√3 V resp. 3,000 – 11,000 V	13,800/√3 V – 22,000/√3 V resp. 13,800 – 22,000 V	24,000/√3 V – 33,000/√3 V resp. 24,000 – 33,000 V
Secondary nominal voltage:	100/√3 V or 110/√ resp. 100 V or 110 V	100/√3 V or 110/√ resp. 100 V or 110 V	100/√3 V or 110/√ resp. 100 V or 110 V
Harmonic transmission:	ε ≤ 5% / Δφ ≤ 5°, 0.05 – 2 kHz	ε ≤ 5% / Δφ ≤ 5°, 0.05 – 2 kHz	ε ≤ 5% / Δφ ≤ 5°, 0.05 – 2 kHz
Weight:	approx. 22 kg	approx. 29 kg	approx. 32 kg

Subject to technical modifications without notice

Please note, that the above mentioned data are standard values. Other values on request.

- Current transformers for industry
- Current transformers for tariffs
- Accessories for current transformers
- Medium-voltage transformers
- Bus bar insulators / -supports
- Shunts
- Voltage transformers
- All current sensors
- Measuring transducers
- Energy meters with or without MID approval
- Accessories for energy meters
- Panel board heaters, filter fans, roof fans and control units

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