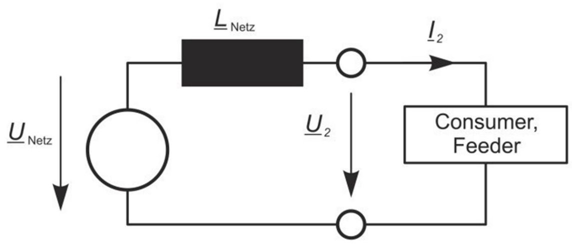
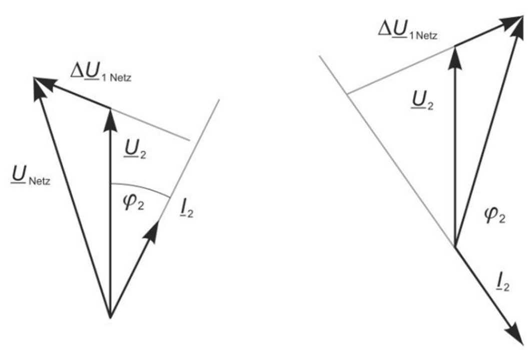
Info Letter

Direction of harmonics
Sources of harmonics in the power system

The direction of the power flow of harmonics is determined by the sign of the active power. The figure shows the equivalent circuit of a network/consumer configuration (single phase); the figures shown the corresponding vector diagrams for the two energy flow directions, energy consumption and energy recovery.





The figure considers only the inductive part of the network

The active power is calculated with pure sinusoidal waveforms:

$$P_2 = U_2 \cdot I_2 \cdot \cos\phi_2$$

In the angular range $0 \leq \phi_2 \leq 90°$ and $270° \leq \phi_2 \leq 0°$ there is a consumer structure and P receives a positive sign.

For $\phi_2 = 90° \leq \phi_2 \leq 270°$, P is calculated with a negative sign, so power can be supplied.

Harmonic generator in a clean network

The consumer is connected in a "clean" sine wave network. At the measurement point, the Fourier transform provides both the amplitude and the angle of the respective harmonics. If the angle between the current and the voltage is > ± 90°, with these harmonics the consumer acts as a generator, i.e. it injects harmonics into the network (contaminates the network).

Sinusoidal network voltage - current affected by harmonics

From the definition of the active power, with a current affected by harmonics the corresponding active power is given by:

$$P = U \cdot \frac{i_1}{\sqrt{2}} \cdot \cos\phi_1$$

where

$$i_{(t)} = i_1 \cdot \sin(\omega_1 t) + \sum_{h=2}^{\infty} i_h \cdot \sin(h \cdot \omega_1 t + \phi_h)$$

It is apparent from this that only the fundamental frequency of the current i1(t) determines the active power.

Current and voltage are affected by harmonics

With the approach to the non-sinusoidal current load (i.e. Current I is composed of the fundamental frequency and harmonics), calculating the active power is more complex.

In this case, analogous to the current, the voltage also has a fundamental frequencyand harmonics.

$$u_{(t)} = u_1 \cdot \sin(\omega_1 t + \phi_{u1}) + \sum_{h=2}^{\infty} u_h \cdot \sin(h \cdot \omega_1 t + \phi_{uh})$$

$$i_{(t)} = i_1 \cdot \sin(\omega_1 t + \phi_{i1}) + \sum_{h=2}^{\infty} i_h \cdot \sin(h \cdot \omega_1 t + \phi_{ih})$$

Only when the voltage harmonics and the current harmonics are at the same frequency do they combine to produce an active power.

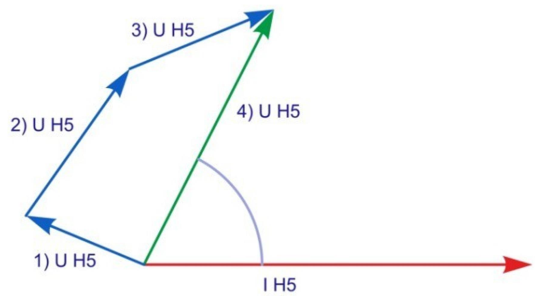
Harmonic generator in a "contaminated" (real) network

If the consumer is connected in an industrial network, the parallel networks and neighbouring consumers both generate harmonics. The harmonic voltage of the individual harmonics results from a superposition of the individual components. This influences both the amplitude and the angle of the harmonic voltage vectors. The harmonic power now measured, and hence the direction of the harmonics are influenced more by the neighbouring networks and consumers than by the measured consumers themselves.

– The results of this measurement are unreliable –

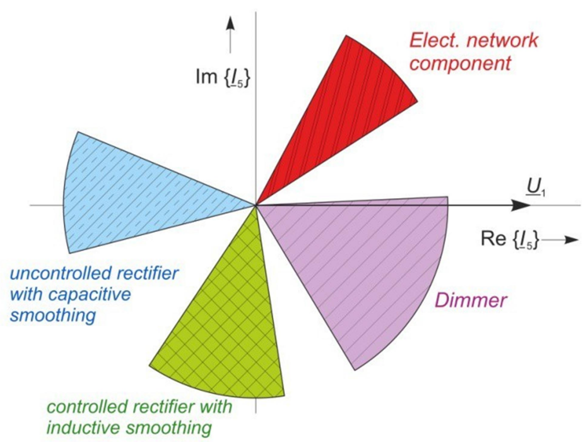
Example:

The system current IH5 produces a voltage drop "1) UH5" in a network impedance. To this value are also added the 5th Voltage harmonics from the upstream network "2) UH5" and the voltage drop of the other consumer cur- rents in the network "3) UH5". The resulting voltage drop at the measurement point, "4) UH5", is shown in green in the example. The angle ϕ of the 5th harmonic is in this case shifted by the other consumers in the network from Quadrant II to Quadrant I, which would constitute a re- versal of the power flow for this frequency.



The question is not the direction of harmonic power in the network, but rather how favourably or unfavourably the various current harmonics in the network add.

As an example, the figure shows the angle of the current harmonics of the 5th ordinal relative the fundamental frequency of the voltage U1. Most electronic consumers produce current harmonics in the network. The phase position of the various devices can however be in differ- ent quadrants, so that in the best case they can cancel out these current harmonics.



All portable and permanently installed Power Quality equipment measure the angle of the current har- monics with respect to the respective fundamental volt- age frequency. Hence it is possible to evaluate the effects of multiple consumers at a common network connection.

An example for the 5th harmonic is described in the figure below.

If a current of 92 A ϕ (100°) is determined for customer "A" and 123 A ϕ (255°) from customer "B" at each trans- fer point, the load on the common transformer can be calculated by adding the complex numbers.

The result is then a load of 55.5 A ϕ (210.5°). This would be a better result for the network, as the different groups of consumers are partially compensated here.