Power Quality

Components for reactive power compensation

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Components for reactive power compensation.

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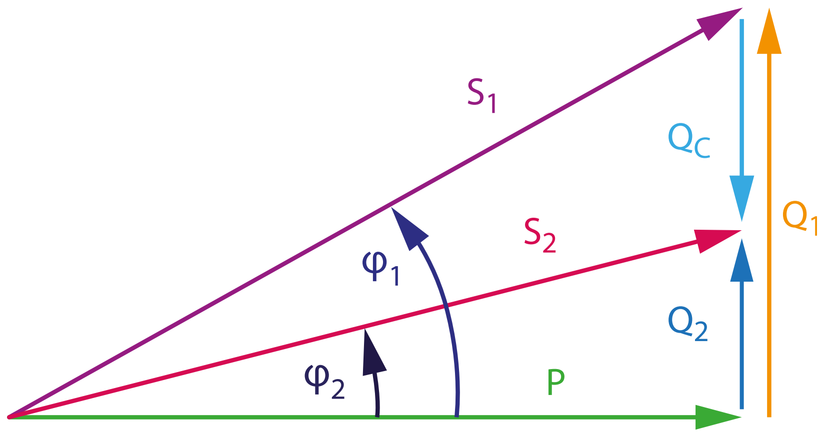
KBR Energy Management

Reactive power basics

Reactive power is the power required to create a magnetic field in inductive consumers like motors, transformers, ballasts, induction furnaces, etc., that is, coils of any design.

Reactive power is also known as magnetizing power. It oscillates between the consumer and the energy provider at twice the network frequency and thus loads cables, fuses and transformers.



Power triangle

- S_1 Apparent power without compensation system
- S_2 Apparent power with compensation system
- Q_1 Reactive power without compensation system
- Q_2 Reactive power with compensation system
- Q_c Capacitor power
- P Active power
- φ_1 Uncompensated power factor
- φ_2 Compensated power factor

As can be seen from the power triangle, using a compensation system reduces the reactive current requirement (reactive energy costs) and thus the apparent power.

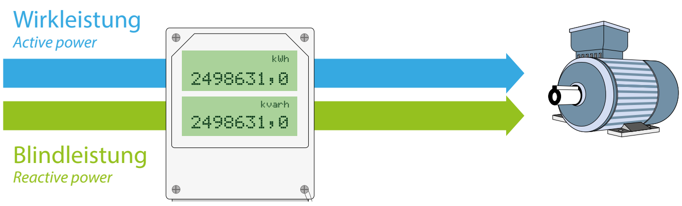
Reactive current compensation

In practical operation, reactive current compensation in commercial and industrial power networks is an issue that often raises many questions.

For technicians, the term compensation describes the interaction between different parameters which - in the best case scenario - cancel each other out. The objective of this is to reverse the negative effect of an interfering physical parameter with a second parameter. In our case, we want to compensate inductive with capacitive reactive power.

Electrical energy generated by power stations or through regenerative methods is transformed into largely usable energy such as light, heat or kinetic energy, depending on the consumer. Some consumers require inductive reactive power from the energy supply network to create a magnetic field. Typical inductive consumers are motors and transformers.

The active power resulting from the product of voltage and current is billed by the energy provider as consumed energy in kWh. Things are different with reactive power. It changes between provider and consumer and is not "consumed" in the literal sense.



Energy transfer without compensation

Why does the energy provider bill the reactive energy?

The degree of load created by network transformers, transmission lines and power plants is expressed as apparent power (S). It is calculated from the active power (P) and reactive power (Q).

$$S = \sqrt{P^2 + Q^2}$$

As can be seen from the formula, the transmission equipment of the network operator is additionally loaded by the reactive power. To keep the current-related losses to a minimum and to guarantee economic energy transport, network operators stipulate a minimum power factor cosφ. This describes the ratio of active to apparent power.

$$\cos\varphi = \frac{P}{S}$$

Energy meters for commercial and industrial use not only measure the active energy but also the reactive energy, which is billed in accordance with the electricity supply agreement. For most energy supply networks, a cosφ of 0.9 is specified. Here, 50% of the consumed active energy obtained from the power supply network may be taken as reactive energy free of charge in the billing period.

Other reasons for reactive current compensation

Thus, the main objective of compensation is to reduce the reactive current costs billed by the energy provider to "zero".

Another reason for reactive power compensation is to reduce the current load. Let's take a closer look at the formula for active power:

$$P = U \times I \times \cos\varphi \times \sqrt{3}$$

If we apply it to the current, this results in the following formula:

$$I = \frac{P}{U \times \cos\varphi \times \sqrt{3}}$$

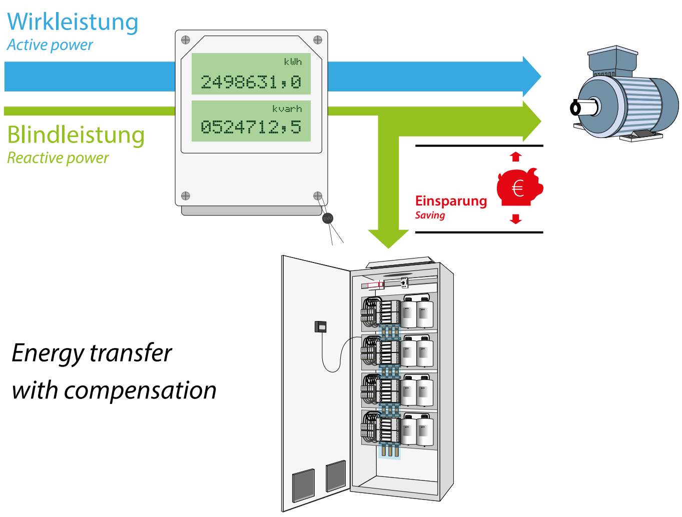
The current thus depends on the power factor cosφ. Let's calculate the current reduction using an example:

An additional consumer with a power consumption of 35 A is to be connected to a sub-distribution unit with 250 A at an outgoing line. The following values were measured:

U = 400 V
I = 238 A
cosφ = 0.72

$$P = U \times I \times \cos\varphi \times \sqrt{3} = 400\,V \times 238\,A \times 0{,}72 \times \sqrt{3} = 118.700\,W$$

If you increase the power factor to cosφ 0.97 by compensation, the current is reduced from 238 A to:



Energy transfer with compensation

$$I = \frac{P}{U \times \cos\varphi \times \sqrt{3}} = \frac{118.700\ W}{400\ V \times 0{,}97 \times \sqrt{3}} = 176\ A$$

By compensation of the reactive power, the current consumption was reduced by 62 A. Now, the consumer still required can be connected with 35 A.

Improving network quality

Reactive power compensation is also used for improving the network quality. In modern industrial installations, consumers with power electronics (e.g. frequency converters) are used for energy efficiency measures. The input current of these "linear consumers" is no longer sinusoidal. As a result, network feedback is created as harmonic voltage. This can cause malfunctions in the consumers connected to the same network.

By using a compensation system as an absorption circuit, the harmonic voltage level can be reduced, rectifying the disturbance in the consumers. The principle of an absorption circuit system corresponds to that of a detuned reactive power compensation system with the resonance frequency close to the interfering harmonic frequency.

Another possible application is renewable energy generators, such as solar and wind power plants. According to applicable laws, these energy generation plants feeding energy into the public grid with an output of more than 100 kW have to contribute to keeping the voltage constant. If the network voltage drops, the voltage can be increased by switching on capacitors. A distinction is made between medium-voltage and low-voltage systems. In low-voltage systems, a Q / P characteristic curve has to be compensated, in medium-voltage systems, a Q / U characteristic curve.

Calculating the required capacitive reactive power

The capacitive reactive power is calculated using the following formula:

$$Qc = P \times (\tan\varphi 1 - \tan\varphi 2)$$

Qc = required capacitive reactive power
P = active power
tanφ1 = tangent of the power factor cosφ prior to compensation
tanφ2 = tangent of the power factor cosφ after compensation

When calculating **central compensation**, we do not have the necessary values as would be specified on a motor. In practice, the compensation power required is calculated using the most recent electricity bills or by taking long-term readings (network analysis).

In the **electricity bill**, the energy provider provides the following values on a monthly basis.

From this, the reactive power required can already be calculated using the formula introduced earlier.

$$Q = P \times (\tan\varphi 1 - \tan\varphi 2)$$

P = the active power specified in the electricity bill
tanφ1 = tangent of the power factor cosφ before compensation
tanφ2 = tangent of the power factor cosφ after compensation

The power factor desired is defined by the operating technician. In most cases, it is between 0.92 and 0.97 inductive. In our case, we calculate the reactive power compensation at 0.95 inductive, as is common practice.

$$Q = 498\ kW \times (0{,}7025 - 0{,}3287) = \mathbf{186\ kvar}$$

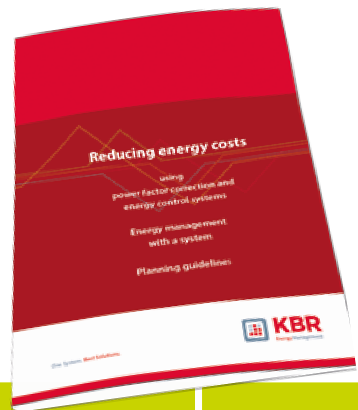
Active power taken from the electricity bill

$$I = \frac{kvar}{kWh} = \frac{166.023\ kvar}{(78.608 + 157.716)\ kWh} = 0{,}7025\ A$$

(values from the electricity bill)

tanφ2 of the desired cosφ 0.95

In this example, we choose the next size up for standard systems, which is 200 kvar.



Our brochure
„Reducing energy costs by reactive power compensation“ is available as download online:
www.kbr.de/en/services/brochures

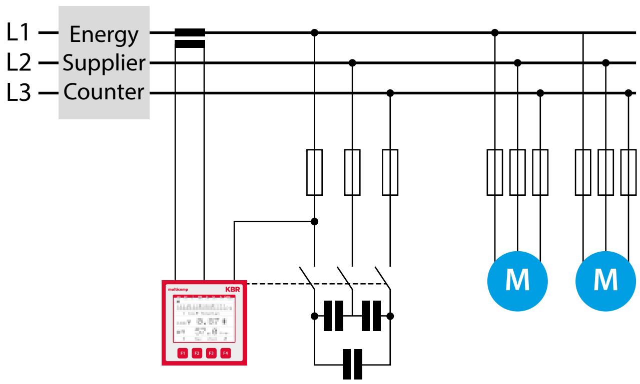
Measurement-based definition of the compensation system size

The power required can also be defined by network analysis. For this purpose, a suitable measuring device is installed in the supply line of the energy provider for one week. Installation takes place without an interruption of the energy supply. The measuring device is installed while the lines are live by a trained specialist wearing protective gear.

The measured data obtained can be used not only to define the required compensation system size but also to evaluate the network quality according to DIN EN 50001.

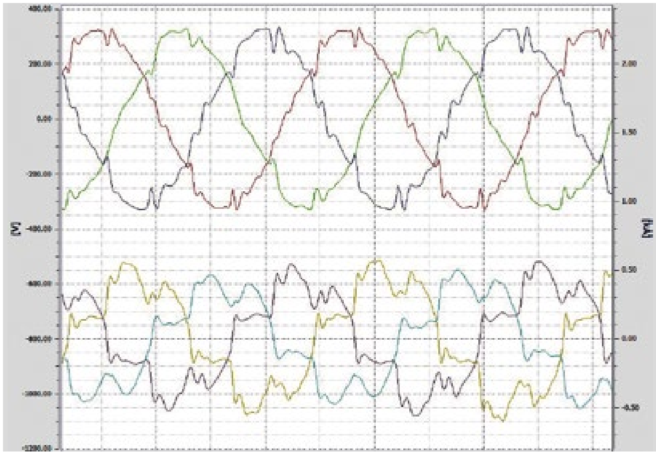
Installing reactive power compensation

Connection to the distribution is done in a similar way as for a larger consumer. The wire cross-section and back-up fuse are defined depending on the compensation selected. In our example, the 200 kvar system consumes 288 A of current (1.44 A per kvar). 3x240/120 mm² is chosen as the wire cross-section and 400 A for the back-up fuse.



Schematic structure of a reactive current compensation system

To enable automatic control, the instantaneous cosφ is needed for the controller. This is determined by way of a current and voltage measurement. The controller takes the measuring voltage from the supply voltage for compensation. With a current transformer installed in the supply line to the energy provider, the controller can now calculate the reactive power required and compensate the system of the customer.



Oscilloscope image of a network measurement with superimposed harmonic voltages

Amortization

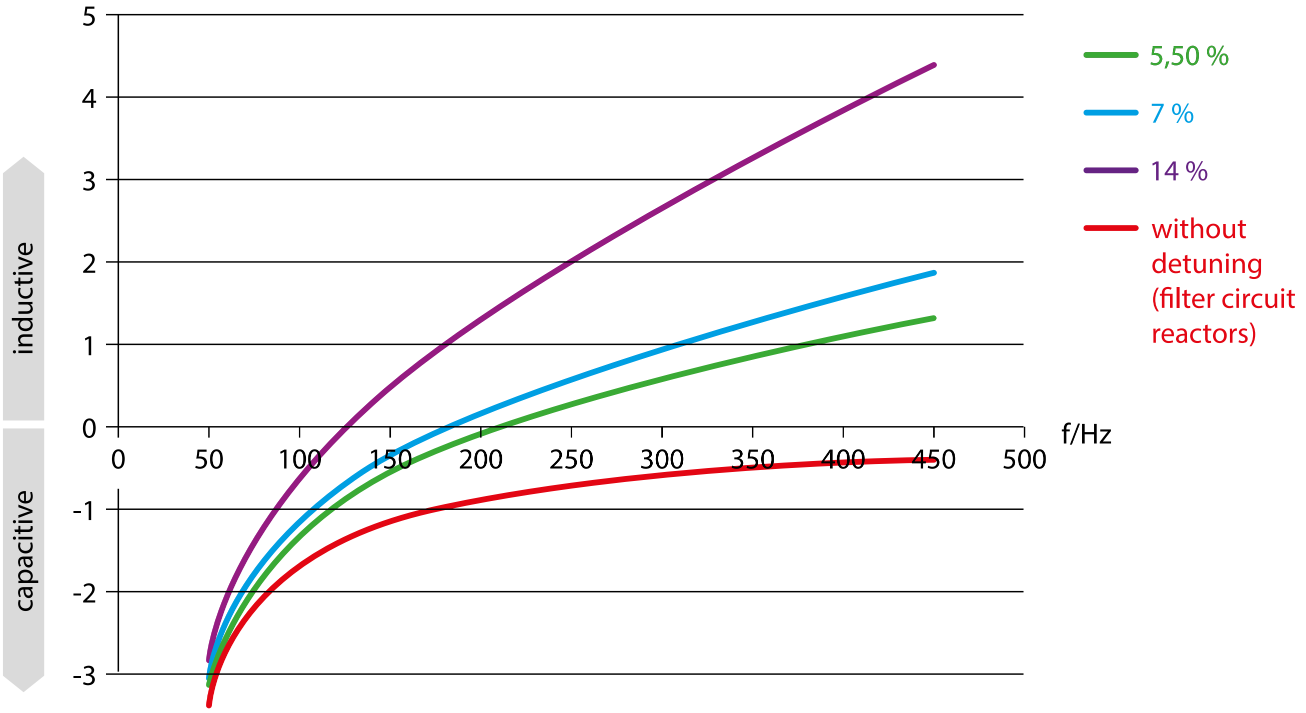
The amortization period depends on the company's operating hours. It is usually between 2 and 4 years.

Disturbances in compensation systems

Consumers have changed in recent years. Motors are for example equipped with frequency converters, electronic control gears have become standard in illumination and clocked power supply units in power electronics. The current consumption of these consumers is not sinusoidal, creating a voltage drop at the network impedances. This drop is sinusoidal but has many times the fundamental frequency. These harmonic voltages occur with frequencies of 150 Hz, 250 Hz, 350 Hz, etc.
How does a capacitor function in a network where harmonic voltage is present? The reactance Xc of a capacitor depends on the frequency.

$$Xc = \frac{1}{2 \times \pi \times f \times C}$$

Looking at the formula, it becomes clear that with higher frequencies, the reactance Xc of the capacitor decreases. What does this mean for us in practice? Depending on how much it is loaded with harmonic voltages, the amount of current a capacitor draws increases. This in turn results in a higher thermal load on the capacitor, leading to a shorter operating life. In an information brochure on the operating life of power capacitors, the ZVEI (German Electrical and Electronic Manufacturers' Association) states that a capacitor's operating life is shortened by 50 % if the maximum temperature at its surface is exceeded by 7 °C.
Another problem in this context is the possible **resonance** in low-voltage networks. In this case, the reactance of the



Curves of detuned compensation systems

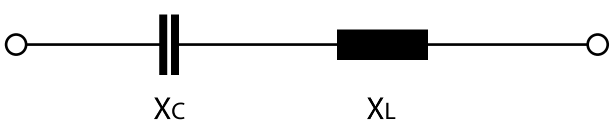
inductance and capacitance is the same at the resulting resonance frequency. The resonance frequency fr can be calculated using the following formula:

$$fr = \frac{1}{2 \times \pi \times \sqrt{L \times C}}$$

Detuned compensation systems

Which measures can be taken to prevent possible resonances? To deal with the continuously increasing harmonic load, detuning compensation systems has been common practice for years. But what does "detuning" mean?

For detuning, each capacitor stage is set up as a series resonant circuit with an inductor connected in series.



Equivalent circuit diagram of a detuned compensation stage
The inductor connected upstream of the capacitor stage ensures a defined resonance frequency.
Common detuning factors are:

Detuning	5.5 %	7%	12.5%	14%
Resulting frequency	214 Hz	189 Hz	141 Hz	134 Hz

Below the resulting detuning frequency, the capacitor stage acts like a capacitor. Above that frequency, the stage is inductive. If you set up the series resonance frequency of the detuned compensation system below the smallest possible harmonic voltage (e.g. 150 Hz, 250 Hz, 350 Hz, etc.), there are no resonances, as two inductances cannot form a resonant circuit.

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KBR Kompensationsanlagenbau GmbH

Am Kiefernschlag 7
D-91126 Schwabach,
Germany

T +49 (0) 9122 6373-0
F +49 (0) 9122 6373-83
E info@kbr.de

www.kbr.de