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RESONANCE: When electrical power grids start "swinging" – Effective elimination of network resonance

YOUR VOLTAGE – OUR PASSION

RESONANCE: When electrical power grids start "swinging" – Effective elimination of network resonance

In addition to the "traditional" issues concerning low-frequency harmonics, for some time now – and to an ever-increasing extent – our energy supply networks have been experiencing oscillations of significantly higher frequencies, which are superimposed on the fundamental oscillation, often greatly distorting it and, as a result, leading to a variety of problems.

These higher-frequency oscillations are referred to by experts as 'resonance'. Expressed in concrete terms: The network goes out of balance. This imbalance can often be perceived acoustically by a "buzzing" or "humming" of the equipment involved in the resonance
(e.g. transformers, chokes, power supplies). In terms of the frequency range involved, resonant oscillations such as these typically occur above approx. 1000 Hz (20th order in the 50 Hz network). They are thus categorized as so-called 'supra-harmonics'.

The exact frequency at which a resonance develops and its amplitude depends on various factors, such as the actual network short-circuit power and the total capacitance switched on in the respective network. Experience clearly indicates that potential disruptions, based on resonance phenomena, are usually much higher than those of low-frequency disruption levels. Particular caution is required in this respect, as in most cases, even a moderate resonance-induced disruption level can cause severe "complications" (e.g. system failures) in a network.

A brief refresher on the fundamentals: What are the "classic" low-frequency harmonics and how do they arise?

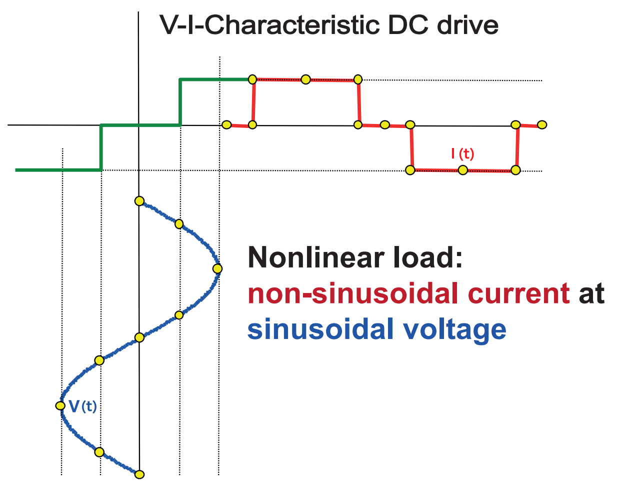

Figure 1: Non-linear U-I characteristic.

Equipment with a non-linear U-I characteristic curve (non-linear current-voltage characteristic, see Fig. 1) or non-steady operating behavior will inevitably take up a non-sinusoidal current despite sinusoidal supply voltage. Due to its in-feed against the existing network impedance, this leads to non-sinusoidal voltage drops and thus to distortion of the in feeding voltage supply (system perturbations can thus occur).

These devices are mainly frequency converters, power converters or power supply units. This means devices that contain a rectifier on the input side (network side).

The following example of a switched-mode power supply unit illustrates how harmonic currents are generated in detail: Explanation of the operating behavior of the switched-mode power supply unit:

Due to the smoothing capacitor on the DC side of the power supply unit, the diode rectifier only draws current on the network side if the supply voltage UAC - abstractly represented in sinusoidal form - is greater than the DC voltage UDC. Since this fact only exists in the range of the apex of the AC supply voltage (when the smoothing capacitor is recharged), the rectifier accordingly draws a pulse-shaped current with a relatively small power flow angle (Fig. 2).

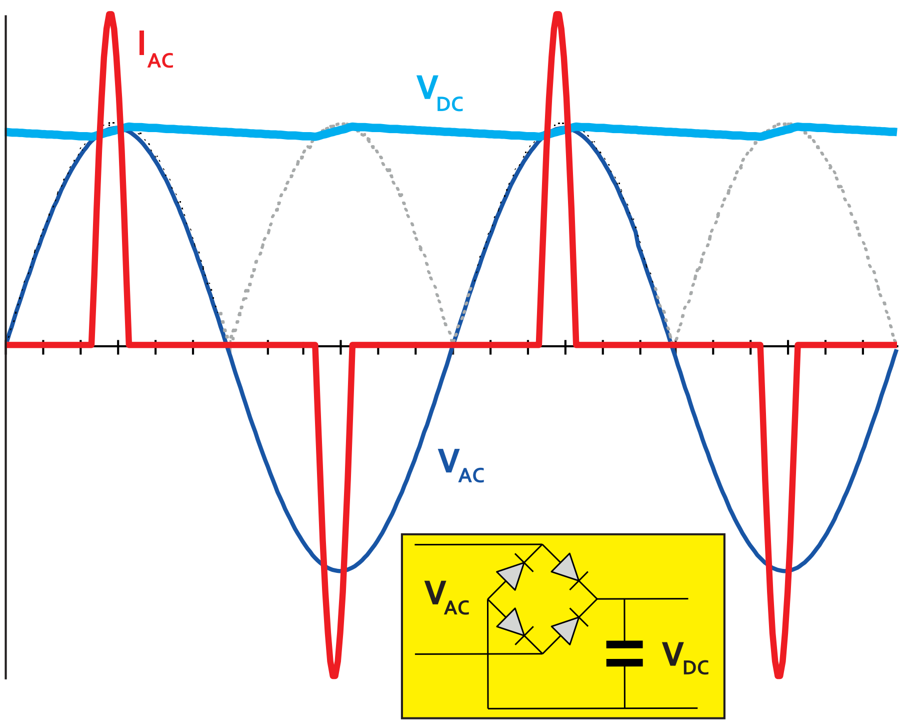

Figure 2: Switched-mode power supply unit, circuit and current and voltage characteristics

If we now analyze the frequency spectrum of this non-sinusoidal, but periodically running current, we discover that with regard respect to the frequency components it contains, there are also various integer multiples besides the fundamental oscillation frequency (1st order). We can see that in this specific current characteristic, the 3rd, 5th, 7th and 9th harmonics dominate (cf. Figure 3).

In the network, these harmonic currents meet impedance and then, according to Ohm's law, form equivalent voltage levels, causing a corresponding distortion of the voltage, in addition to exciting any resonance points in the network.

IEC 61000-2-4, as the key product standard, specifies defined thresholds for maximum permissible voltage distortion. Systems are required to function perfectly within these thresholds. If these thresholds are exceeded, equipment and processes may be disturbed without the manufacturer being held liable (loss of warranty claims). In cases such as these, the customer is required to bear the costs of repairs and production downtimes. The additional financial burdens that can arise, especially if entire production processes fail, may quickly add up to a multiple of what suitable measures to reduce the original voltage distortion would have cost upfront. Thus, it is the customer's responsibility to ensure that the existing voltage distortions in his supply network are reduced to a normatively acceptable level.

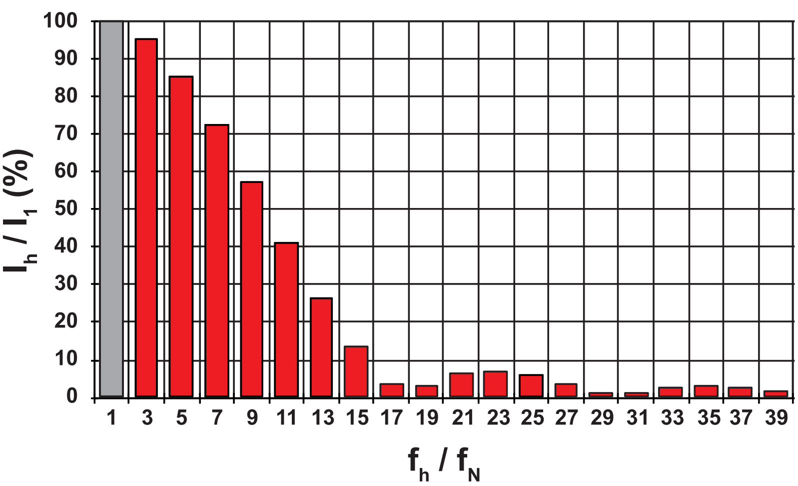

Figure 3: Typical frequency spectrum of a switched-mode power supply unit.

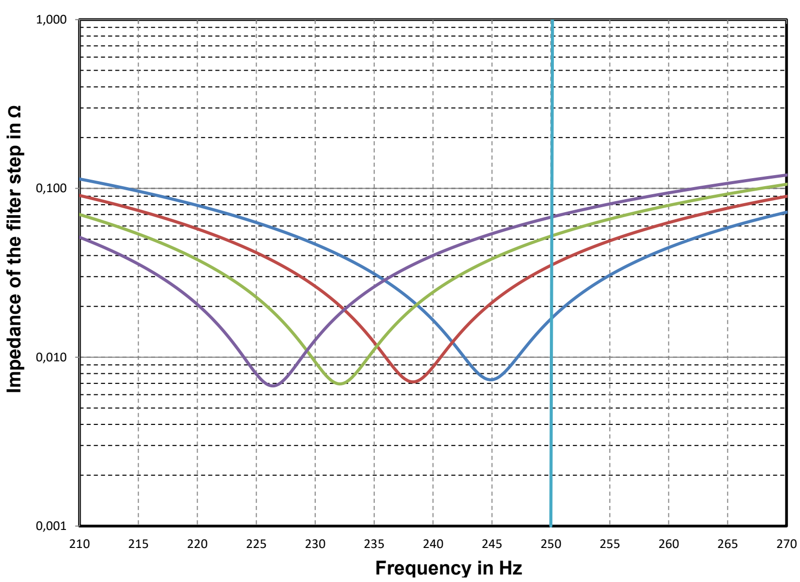

Figure 4: Impedance curves of an intelligent passive filter for the 5th harmonic (250 Hz).

Measures for reducing "classic" harmonics

Depending on the origin, cause and strength of existing harmonic levels, different filter techniques from the areas of active and passive systems can be used for effective reduction. Hybrid systems, i.e. the combination of active and passive components, are a proven means of "harmonic" filtering.

Put in simple terms, in a passive filter circuit, a capacitor and a choke (LC series resonant circuit) are matched to the harmonic order(s) to be primarily filtered. The impedance minimum of this structure then forms in the

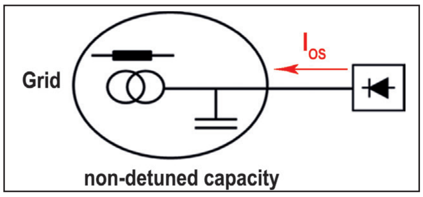

Figure 5: Schematic network diagram with transformer, capacitor without detuning and a harmonic generator.

$$V_{OS} = I_{OS} \times Z_{res.}$$

Figure 7: Formal relationship between the exciting harmonic current I_{OS}, the resonance impedance Z_{res}. and the resulting voltage level U_{OS}.

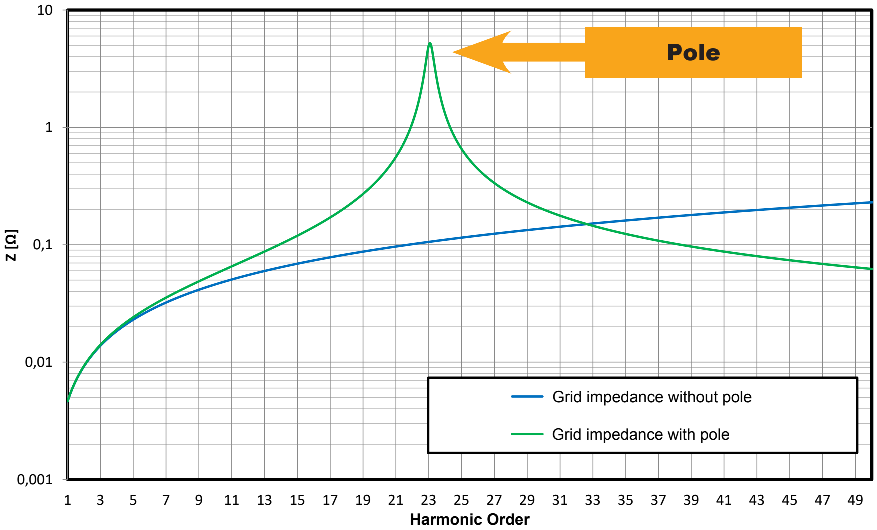

Figure 6: Impedance curve of a network without (blue vector) and with resonance point (green vector).

corresponding order, whereby the harmonic level is "suctioned off", so to speak, and reduced accordingly.

A commercially available active filter, on the other hand, measures the load current and feeds in phase opposition (180° opposite) compensation currents into the network, which - starting from the load - are highly effective at "extinguishing" the respective harmonic current at the connection point of the active filter. In selecting the filter system most suitable for the given application, there are a number of technical and economic advantages and disadvantages for active and passive filters. Based on these criteria, a decision must be made as to which concept should be deployed. The still relatively new passive filter concept of intelligent impedance matching offers a combination of the various advantages of passive and active systems, and at the same time avoids having to accept the disadvantages. By varying the resulting capacitance of the LC series resonant circuit tuned to the harmonic frequency to be filtered, its resonant frequency is varied to achieve an almost constant filter current. This completely avoids a potential overload of the passive filter.

What is resonance and how does it develop?

When we speak of resonance in technical jargon - viewed physically and in simple terms - it involves a vibrating structure, which is "initiated" by an external force and thus made to vibrate (oscillate). The frequency of the oscillation corresponds to the natural frequency (and thus the resonance frequency) of the system.

This vibrating constellation is created in an electrical network by the "unfavorable" interaction of inductive and capacitive components.

In a conventional electrical supply network, it is always possible to identify inductive and, in the meantime, mostly also capacitive elements. Basically, nowadays there is more or less a resonance point "somewhere" (at any frequency) in every network. However, this does not always result in a distinct oscillation with a high interference amplitude. The frequency at which the resonance point develops depends largely on how powerful the network is and how many capacitors are in operation in the respective network (i.e. how high the total capacitance is).

With regard to inductance, the feeding transformer with its ohmic-inductive characteristic typically plays a primary role. The capacitive part is usually based on the following equipment/components:

- EMC filters (from inverters or other electronic power devices)
- PFC system with no detuning
- extensive cable networks
- compensating capacitors of light sources
- smoothing capacitors (converters, power supplies...)
- …

Together with the network inductance, these capacitors form a parallel circuit and thus an LC parallel resonant circuit with a tuning frequency (resonant frequency), defined according to the formula

$$f = \frac{1}{2\pi\sqrt{LC}}$$

The impedance maximum of this LC parallel resonant circuit is set exactly at this system natural frequency (resonant frequency) (cf. Fig. 6). Such a structure thus behaves exactly opposite to the principle of a passive harmonic filter, which has its impedance minimum at the tuning frequency. Mathematically speaking, there is a so-called pole in the network. At this point, the impedance exceeds that of a prospective network many times over. This resonance oscillates or constantly moves the energy back and forth between the involved resources - i.e. the inductance and capacitors. How long the oscillation lasts (until it has decayed) and in which order of magnitude it appears, ultimately depends primarily on the damping and secondarily on the real short-circuit power of the network.

Fig. 6 indicates that the resulting network impedance with resonance point (green curve) exceeds the prospective impedance curve (brown curve), which is based on linear behavior, in a relatively wide frequency range.

In this context, we refer to an increase in impedance or an increased impedance curve. This cited impedance increase actually occurs up to √2times the actual resonance frequency (pole).

For the feeding transformer, a nominal apparent power of 1600 kVA at a relative short-circuit voltage of 6% was taken into account in this simulation and a short-circuit power of 80 MVA for the upstream network level (medium voltage). In this scenario, the "interference capacitor" without detuning, which ultimately brings about the pole (resonance point), has a capacitive power of 40 kvar (roughly 2.5 % of the transformer's rated power).

In this illustrative example of a 400 V network, the pole, i.e. the impedance maximum, is formed at the 23rd order. As a result, the network impedance is amplified up to the 32nd order (23 x √2 = 32).

If there is now a harmonic current (e.g. emanating from a frequency converter) whose frequency corresponds approximately to the resonant frequency of the parallel resonant circuit, this current, due to the greatly increased impedance in the area of the pole point, can excite a pronounced resonant oscillation even with a relatively low "interference" amplitude and subsequently cause a correspondingly high voltage level.

In a resonant network, all voltage levels in the entire spectrum of impedance amplification (not only at the pole itself) are thus raised, analogous to network impedance.

The current characteristic in Figure 8, which was thus recorded in an actual industrial network, shows how regularly (at short intervals) resonant - damped - oscillations are repeatedly excited. After an oscillation has been initiated, it begins to decay exponentially periodically (black circle in Fig. 8), until it is then excited again after a few milliseconds – even before it completely decayed. This process continues and can lead to massive problems in the network.

If a load, due to its specific operating behavior, initiates an existing resonance point practically continuously (repeatedly) – as is the case, for example, with an electric arc furnace – and there is insufficient damping on the part of the overall system, the situation can continue to "escalate" and the resonant oscillation can assume an ever-increasing amplitude. This then leads to flashovers and destruction of equipment.

Resonance (in addition to harmonic currents) can already be stimulated by a single event such as a voltage jump, a switching operation or a transient (quick/rapid current or voltage changes) in the power supply network. This triggering event does not necessarily occur in the low-voltage grid in which the resonance is creating noticeable distortion, but can also originate at the upstream, higher network level (medium-voltage network).

What are possible consequences/ramifications of resonance:

- Multiple zero crossings of the voltage, consequence: Malfunction of complex industrial plants and electronic control systems
- Overloading of EMC filters, diodes and DC link capacitors of the frequency

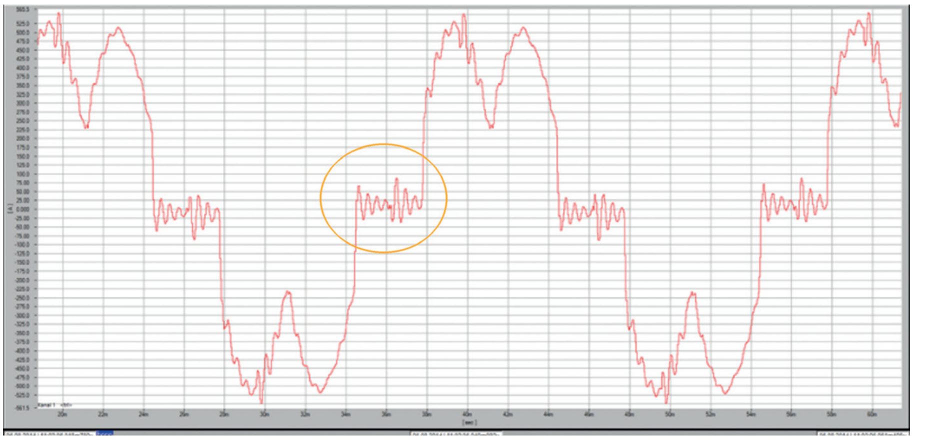

Figure 8: Illustration of current characteristic with resonance (superimposed higher-frequency oscillations).

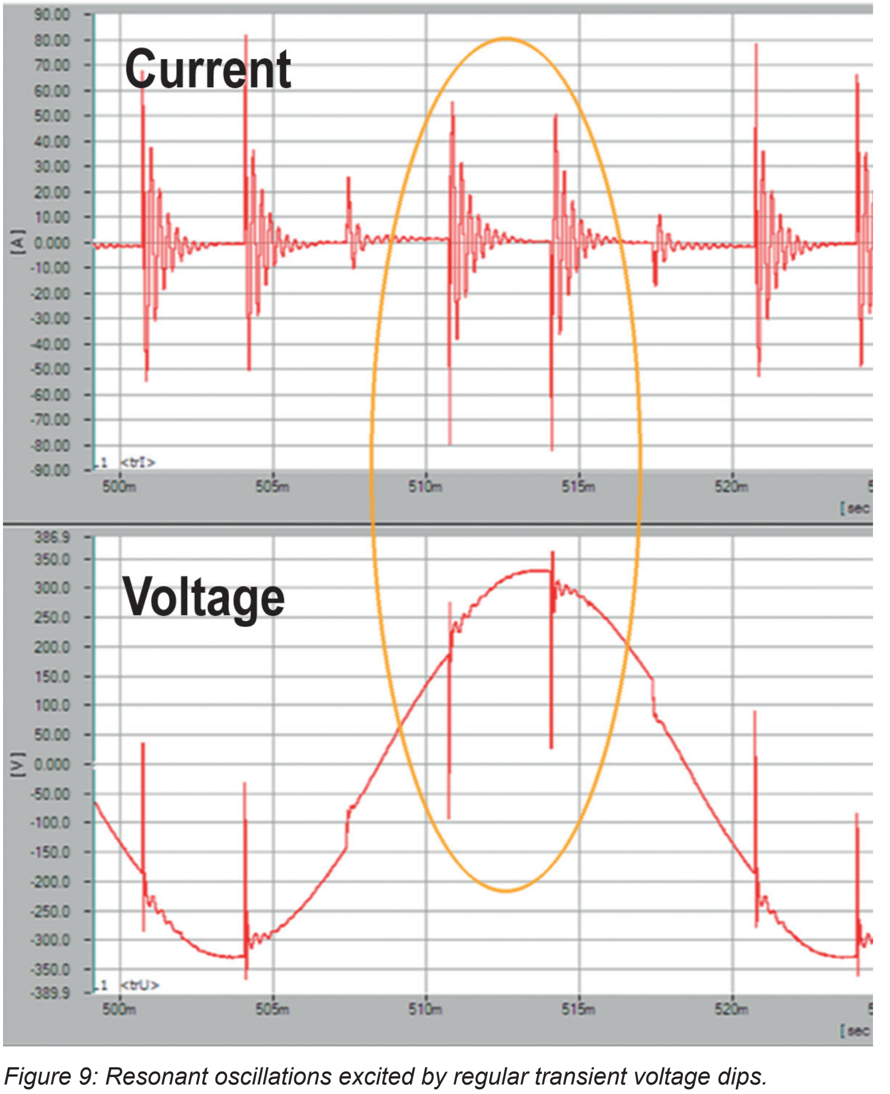

Figure 9: Resonant oscillations excited by regular transient voltage dips.

inverters used, consequence: Danger of their failure (production stop)
- Overvoltages (voltage rises) and thus flashovers onto windings of motors or transformers
- Destruction of power supplies
- "Buzzing" or "droning" of electrical equipment
- Coupling of interference signals (interference voltages) into data connections
- (data lines), consequence: e.g. electromagnetic interference of the company Intranet
- Uncontrolled activation (tripping) of protective devices (fuses...)
- "Shutdown" of generator governors in a stand-alone electrical network

In this context, the use of reactive power compensation systems without detuning is particularly critical. The missing choke precipitates a resonance situation, because at any frequency a parallel resonance occurs between the PFC system and the feeding transformer (depending on the transformer size and the connected PFC capacity). In this respect, especially in networks with existing harmonic loads (i.e. now in virtually all networks), one should urgently refrain from using such systems. Due to the constant change and expansion of the supply networks, PFC systems without detuning, even after many years of trouble-free operation, can suddenly become sources of resonance. This occurs both through changed constellations of inductive and capacitive elements in the network and through the occurrence of other harmonic profiles. It is irrelevant whether the harmonic levels are generated by the system itself (i.e. "home-made") or by the upstream network (the MS level). Ultimately, capacitors without detuning pose a potential safety risk and therefore must be rigorously decommissioned, and if necessary, replaced by capacitors with detuning. Figure 10 shows a resonance caused by PFC without detuning.

The fact that these resonance phenomena were not as pronounced a few years ago is mainly due to the fact that the share of non-linear users industrial firms has risen sharply in recent years. Mostly (linear) damping loads such as "rigid" three-phase asynchronous motors, furnaces or "run-of-the-mill" incandescent lamps were in operation. These aforementioned users are predominantly ohmic-inductive loads which, due to their impedance characteristics, have an inherent damping effect on potential resonance.

These damping loads have, however, been successively replaced by power electronic controlled equipment (drives...). In order to increase energy efficiency and optimize processes (e.g. variable motor speed), existing motors were very often supplemented with an "upstream" frequency converter, or entire drive systems were completely replaced.

Frequency inverters themselves often lead to resonance situations in the network. This is because inverter units largely contain EMC filters (EMC = electromagnetic compatibility), which in turn have unattenuated and thus "resonance-promoting" capacitors (which can be connected between the phases and to earth/PE).

The EMC filters fulfill the purpose of complying with applicable EMC directives. Only through compliance with these directives is an inverter allowed to be operated in the customer's network at all. In this way, the clock frequency or ripple current and additionally interfering signals in the megahertz range, inevitably occurring when the inverter is switched/clocked, are filtered. As a result, it is not possible to easily do without these "small" filters.

Furthermore, in a voltage-sourced inverter (U inverter – 'U' refers to a capacitive intermediate circuit), the intermediate circuit capacitor (energy storage between input rectifier and inverter) will also prove to be a "troublemaker". Depending on the design of the DC link capacitor (capacitance) and any additional converter circuits, such as chokes on the DC (DC link) and/or AC side (network side), this capacitance may also contribute to a resonance position. Although the DC link capacitor is formally located on the DC side of the inverter, it is always directly connected to the AC grid when the input rectifier diodes are conducting. In this manner, it is possible for it to influence the supply network.

In addition, transformers are also becoming more and more energy-efficient (with lower losses and thus a lower active component), which further reduces damping in the network and increases the tendency to oscillate accordingly.

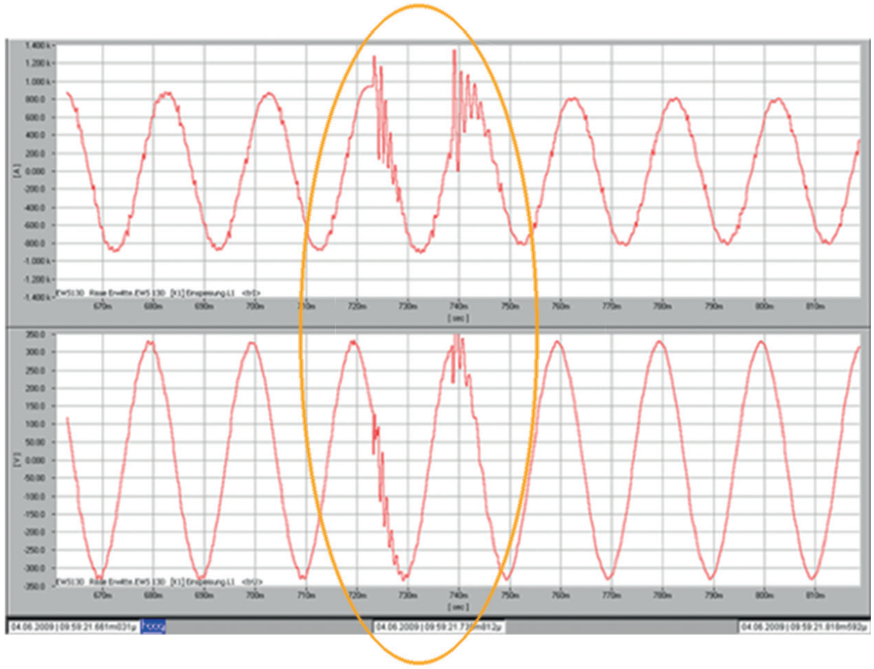

Figure 10: Resonance in the current (above) and in the voltage (below) caused by a PFC system without detuning.

Estimated determination of resonance frequency

The resulting capacitive power in the network and the feeding transformer can be used to approximately determine the frequency at which the maximum impedance - i.e. the resonance point - is formed:

$$f_{res.} \approx f_N * \sqrt{\frac{S_K}{Q_C}}$$

$f_{res.}$ = Resonant frequency in Hz
f_N = Rated frequency in Hz (50 Hz)
S_K = Transformer short-circuit power in kVA (rated power / uk)
Q_C = Capacitive power (total) in kvar

Typically, as already indicated, resonance points only occur in a frequency range above 1000 Hz (20th harmonic). Stand-alone electrical networks can be an exception if the connected users are only supplied with energy via a distributed generator.
Due to the generally lower short-circuit power of a generator, a pole point in a "pure" stand-alone electrical network can also form at a frequency lower than 1000 Hz. For the sake of completeness, it should be mentioned that resonance below 1000 Hz can also occur in the transformer network (i.e. with a normal network connection) if, for example, a vast number of inverters with EMC filters are installed. This requires a relatively large amount of capacitive power.

The following applies: The weaker the network, the lower the resonant frequency (at a certain/defined capacitive power).

Safeguarding resonance points in the network

Consistently safeguarding resonance points in the network, from initial planning, through construction, right down to general operation and any subsequent expansions. Ideally, any resonance points should already be identified in the planning phase of a new network/network section by means of appropriate calculations and simulations.

However, if one considers here which constellations can result from the distribution of capacitive and inductive elements in a larger network, it is relatively difficult in advance to conceive of each individual resonance point that may form. In particular, unfavourable resonant circuits that did not previously exist can be formed by the subsequent addition of operating resources that were not part of the original planning phase. In this context, for example, the input circuit (EMC filter) of a newly connected inverter can cause an existing pole point to be shifted by the additional capacitance of the EMC filter capacitors to a frequency at which a harmonic current is generated which then triggers a resonant oscillation.

It is also possible that pole points are already known in advance, but these are considered non-critical, as they lie in the HF range (HF = high frequency), for example, in which no direct harmonic currents are to be expected. However, if the network range is expanded at a later date with equipment that causes/feeds higher-frequency currents (e.g. in the form of converter clock frequency currents) precisely in this frequency band, previously classified as safe, serious problems will arise in the short or long term as a result of the virtually sudden occurrence of resonance.

It is therefore difficult to ensure that a network area is consistently protected with respect to possible resonance points, from initial planning, through construction, right down to general operation and any subsequent expansions. However, certain measures should already be taken, particularly with regard to the design of the equipment used, in order to prevent possible resonance formation, e.g. targeted use of properly applied chokes on the network and intermediate circuit side (DC side) of the inverters. If problems occur in a network section, caused by insufficient voltage quality, a comprehensive network measurement should initially generally be carried out. The findings obtained from the measurement data can be used to design appropriate filter measures to eliminate the existing problems or to reduce the distortion of the supply voltage to a tolerable level.
In order to be able to identify a pole or resonance point as such, special criteria must be applied. As it is not always possible to directly determine from the measurement data whether the disturbance variables present are directly load- or resonance-related levels. As identified in the measurement report, important indicators include visibly increased current and voltage levels in the higher frequency range (order range) of the spectra (see Figure 11).

Due to the fact that, for example, clock frequency induced currents of frequency converters have a distribution profile similar to a resonance, or converters with so-called slim intermediate circuits cause harmonic currents in the frequency range above 1000 Hz (> 20th order), further criteria must be taken into account to determine network resonance. In particular, attention should be paid to the so-called interharmonic (non-integer multiples of the fundamental oscillation) currents and voltage levels in the range of a possible resonance point. If interharmonics occur and these also have a more or less quadratic function, this strongly indicates an existing pole point in the network.

In addition, one must always pay necessary attention to the curves (instantaneous value curves) of current and voltage, since a resonance may only be sporadically excited to oscillate and may already have completely decayed after a few milliseconds or microseconds (i.e. no longer visible). As a consequence, the pole point in the spectrum is unfortunately not directly identifiable.

These aspects indicate that it can be relatively difficult to identify resonance in a network. However, with the necessary experience and some intuition, it is indeed possible.

Effective combating of resonance

If a resonance point is discovered, one could possibly initially be of the opinion that the situation can be cleared up with a normal passive harmonic filter (LC "suction circuit"), i.e. the resonance can be eliminated. This is a fallacious conclusion, however. The LC series circuit proven for "classic" harmonic filtering would not attenuate or eliminate the pole point underlying the resonance, but merely shift it to a higher frequency (see Fig. 12).

The essentially critical pole point in the network thus continues to exist, only at a different, higher frequency (higher order). Yet even at this "new" frequency, the pole point can be excited to oscillate by a corresponding harmonic current or a switching action in the network, so that the fundamental problem recurs.

Even with a conventional current-controlled active filter, resonance points cannot usually be effectively eliminated. Their use should be carefully examined if there are plans to use such an active filter in a network prone to resonance.

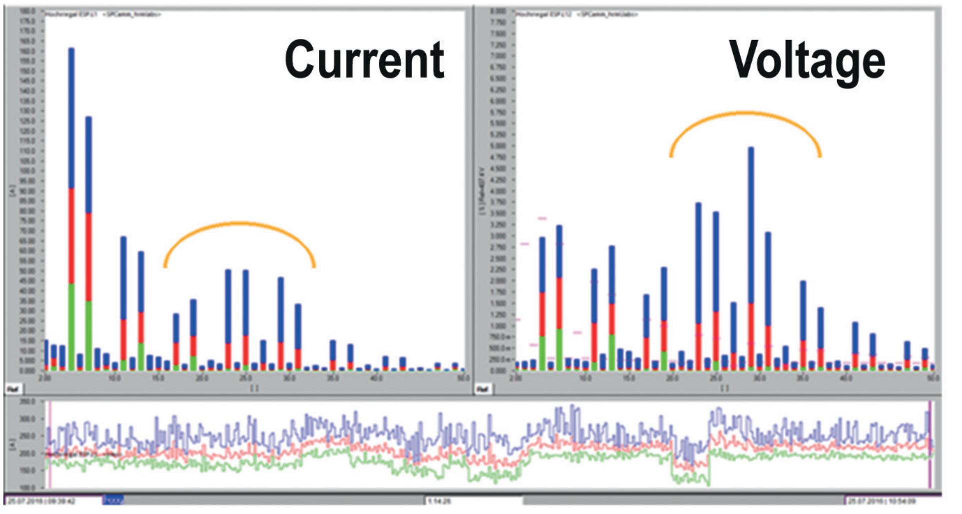

Figure 11: Frequency spectrum with critical current (left) and voltage levels (right).

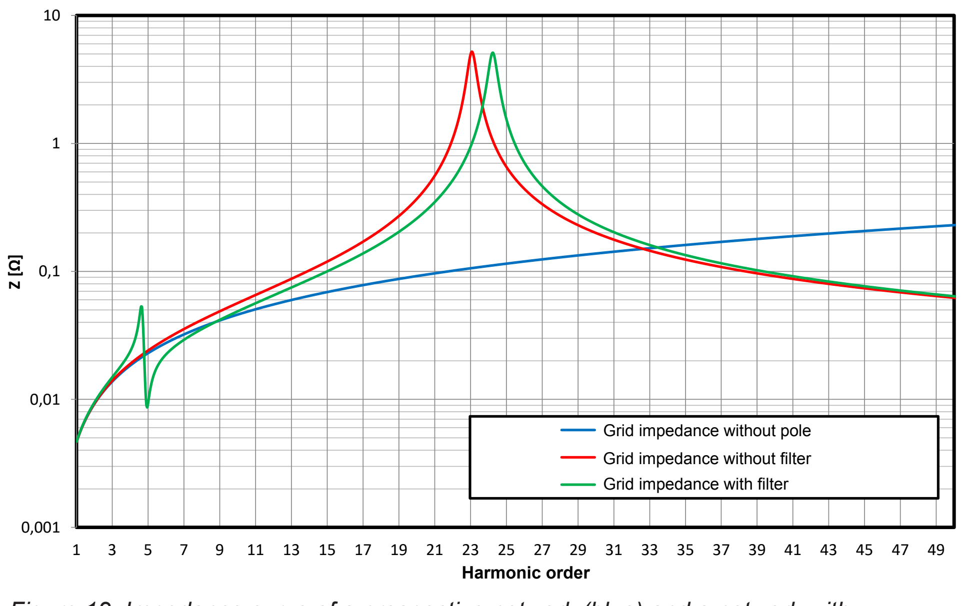

Figure 12: Impedance curve of a prospective network (blue) and a network with distinct pole (red). The interesting green vector indicates the ineffective filtering by a passive filter system. The pole point is only shifted but not eliminated.

Why? Because practically every active filter, comparable to a normal frequency converter, contains a passive output filter (clock frequency filter) (an LC structure), which itself can contribute to resonance formation in the network. The output filter is necessary to limit the ripple current generated by the clocking of the active rectifier to a "healthy" level. In addition, due to their technical functional design, active filters may represent "actively exciting sources" for resonance oscillations. As already briefly explained at the beginning of this article, an active filter is a variable current source that feeds a filter current into the network which is 180°

out of phase with the measured load current, in order to ideally "extinguish" it completely at the filter connection point (so that it no longer flows over the transformer and can therefore no longer cause a voltage drop in the network). However, if the 17th harmonic (850 Hz in the 50 Hz network), for example, indicates that a pole point exists, and the active filter feeds a filter current into the network precisely at this order, the existing pole point is excited to oscillate or a resonance that may already exists is amplified in terms of the interference amplitude. Thus, the introduction of a system to combat harmonics can have the opposite, detrimental effect.

Therefore, the control algorithm or the protection concept of the active filter must absolutely allow resonance points to be reliably detected and, as a precautionary measure, should not allow any harmonic current to be fed into the network at the corresponding order(s).
But this also means that for a relatively wide frequency range, there may be no filter effect emanating from the active filter. Consequently, a pronounced pole point will persist in the network.

Special voltage-guided active filters are also now available on the market with which resonance points can indeed be damped. Such systems behave like an ohmic resistor in the network, resulting in the required damping effect. However, in terms of results, they only cover a limited frequency range and are not as effective as passive damping filters. Furthermore, of course, this type of active filter is also connected to clock frequency current, which flows into the network in a certain order of magnitude (depending on the design of the passive output filter) and can in turn lead to higher-frequency distortions.

These considerations consequently show that active network filters – especially with regard to resonance – always come with certain limitations. This is not the case with passive resonance damping filters.

If one considers the resonance rather from the classical physical point of view, using the example of a pendulum and thus mechanical oscillation, this enables the formulation of a useful solution. If such a pendulum is set in motion, it would continue to oscillate continuously under ideal circumstances without the influence of external forces. However, such a process does not exist in reality, since the oscillation gradually decays due to existing friction forces - at least under the premise that no further energy is added from outside. In this case we also speak of damped oscillation. From this it can be deduced that every oscillating system, by introducing "suitable" damping, can either be made to decay or at least to reduce its "deflection" (amplitude). Thus also if such a system is excited by a frequency corresponding to its natural frequency, which would result in the amplitude of the oscillation assuming its maximum value. In this context, we also speak of resonance frequency, which in turn can be reduced or completely suppressed by introducing a damping element. If this principle is transferred from a mechanical system to an electrically vibrating system, a damping component of this type can be realized by means of a damped high-pass filter. This does not merely shift the frequency range of the pole point (like a tuned "suction circuit"), rather it dampens the resonance point relatively strongly – depending on the design. As can be seen in Figure 13, there are no more critical increases in the impedance characteristic curve after damping.

Due to the much lower impedance in the frequency range in which the pole point occurs, harmonic currents that are still present no longer result in a greatly increased voltage level. Especially from this point of view, a passive resonance filter proves to be advantageous compared to an active network filter. Due to its mode of action, no resonance is excited and broadband, as well as seamless, filtering is guaranteed. Especially in the higher kHz range, existing resonance points are reliably eliminated. Ultimately, the electromagnetic oscillation energy of the resonance is converted into heat in the damping resistance of the high-pass structure, thus making a decisive contribution to the damping of the resonance. The secret is to design the high-pass resistor in such a way that, with the lowest possible fundamental oscillation losses (losses are associated with heat that has to be dissipated from the installation site and which also generates costs), a sufficiently high damping is present, which ultimately ensures that the system can no longer fall into "uncontrolled" oscillations. In most cases, this does not require very much filter power, as the excitation currents have much lower amplitudes than the resulting resonance currents themselves (which are many multiples of the current that triggered them). A "small" (somewhat less powerful) filter is thus often sufficient to significantly reduce high disruption levels and significantly pacify the network.

Immediate shutdown of all PFC systems without detuning

Network resonance and resulting problems in the network (with connected users) continue to be "egregiously" underestimated and often not even recognized. The recent past shows in fact that nowadays, due to the increased use of modern power electronic controlled loads, practically every network

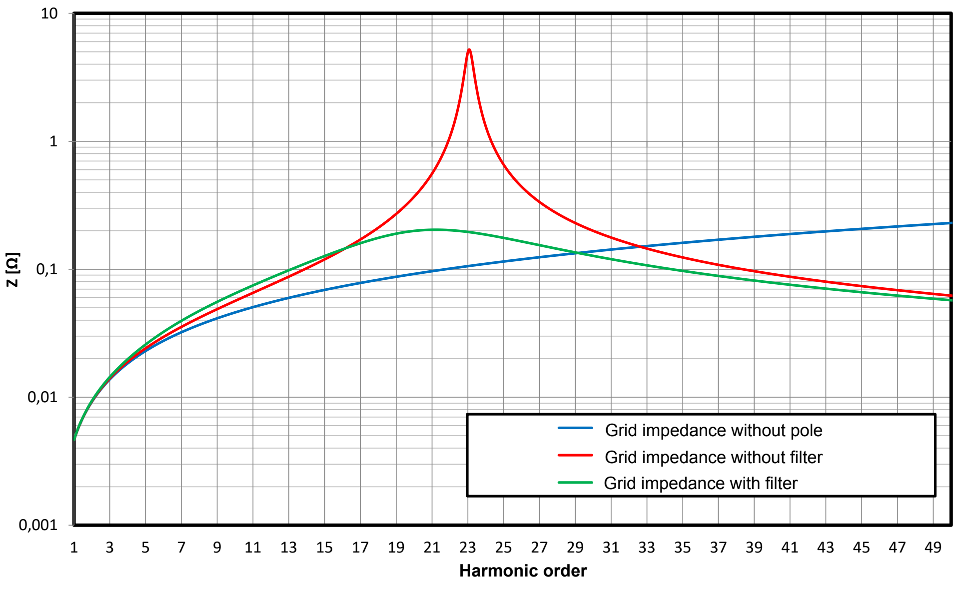

Figure 13: Impedance curve of a prospective network (blue) and a network with a pronounced pole point (red). The green vector indicates the effective attenuation of the pole point with the help of a "resonance damping filter".

has – at least – one pole point (resonance point). The often ill-conceived use of PFC systems without detuning, as well as the excitation of previously unknown resonance points by active filter systems, can suddenly have serious ramifications in a smoothly operating network section. Starting with the disruption of individual processes, right down to damage of operating equipment.

In order to reduce the risk of resonance, only detuned PFC systems may be installed. This principle applies in general. Even if the existing operating equipment in the network area has no capacitive elements and/or no increased harmonic loads. As previously described, resonance can also occur at much later points in time. For example, if the capacitive or inductive properties of the network area are altered by the introduction of additional electrical equipment. Furthermore, by expanding the network and connecting further non-linear loads (harmonic generators), a resonance-exciting current not previously present in that form can suddenly flow in critical harmonic orders. Or already existing resonant oscillation will occur in a more pronounced way (with higher amplitudes), because at dedicated orders simply more harmonic current flows, inevitably resulting in higher voltage levels. If there are already PFC systems without detuning in the respective network section, these must be switched off immediately and either detuned subsequently (if necessary and possible) or replaced by an appropriate new detuned system.

Irrespective of whether PFC systems are present in the network area, a damping filter should be installed as a preventive measure. For example as a transformer fixed compensation. In addition to the resonance damping, this can then provide the inductive power requirement of the transformer. On the one hand, already existing but not yet detected resonance points can be eliminated. On the other hand, this ensures protection against the possible occurrence of future resonance.

Due to the often difficult and protracted troubleshooting into the causes of network resonance and its effects, the additional financial burdens for measurement, stress analyses and evaluations must not be neglected, not to mention the directly associated production downtime and downtime costs.

Therefore, an investment in a damping component to avoid resonance at an early stage can be regarded as useful. Especially if one considers the costs that an increasingly probable occurrence of resonance may entail over the course of time. If there is already a PFC system with detuning in the network area or a new one is to be installed, the damping element can already be integrated into the system here as a simple extension. This minimizes additional costs and installation overhead.

If there is suspicion of resonance – but even in the case of general problems which may be due to insufficient voltage quality – a comprehensive power quality analysis should be carried out as the first measure. These can be used to determine potential resonance points. In addition, a passive damping filter for the corresponding network can be properly designed on the basis of the measured data, in combination with important parameters relating to the network, such as network topology, network short-circuit power and any other boundary conditions (space available on site...). Such a passive filter is practically the only effective way to combat a resonance point without restriction (broadband), regardless of the frequency at which it would ultimately manifest itself.

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