ELECTRICAL-ENGINEERING.ACADEMY

# How does the harmonic method work?

**Welcome** dear friends of protection, control and electrical engineering to today's second part of the selective earth fault location by means of harmonic methods. In the first part we clarified what the whole thing is actually good for and also looked at the connection of the protection function. Today, we will look at the theoretical principle of operation and derive the resulting practical findings.

Let us briefly summarize the findings from our previous paper. We had said that with the transient method one of the best tools for selective earth fault location in meshed networks is available. There is the major limitation that no search circuits are possible for pending earth faults, since only the onset moment of the fault can ever be evaluated. If the network is quite simple and ideally arranged radially, the transient method can be supplemented with the classical wattmetric method. However, the wattmetric earth fault location method quickly reaches its limits in more complex and meshed network topologies; we had mentioned here effects such as angular errors of the transformers and phase splitting as possible causes of faults. In addition, the wattmetric method requires the use of cable transformers for current measurement and is therefore not suitable for air-insulated power systems from 110 kV upwards. Nevertheless, in practice there is also a lot of wattmetric protection with design in Holmgreen circuit. Here, however, the required measuring accuracy is often not given and erroneous directional indications can be the result. Unless a sufficiently large watt residual current booster is used, which can significantly reduce the influence of Holmgreen angular errors.

The much better method is the harmonic method presented today. Let us remind ourselves again of the connection: Each feeder has an earth fault relay, which permanently monitors its own feeder for earth fault excitation and earth fault direction. We record the secondary measured variables required for this in the classic way via current and voltage transformers. The common secondary zero-sequence voltage is required at each feeder relay, which is usually obtained via the delta windings of the three voltage transformers connected in open delta. For this purpose, a ring line is established at the da-dn circuit of the voltage transformers and connected to the protection relays in the feeders. Furthermore, we need the zero-sequence current, which we detect via suitable cable conversion transformers in each of the feeders.

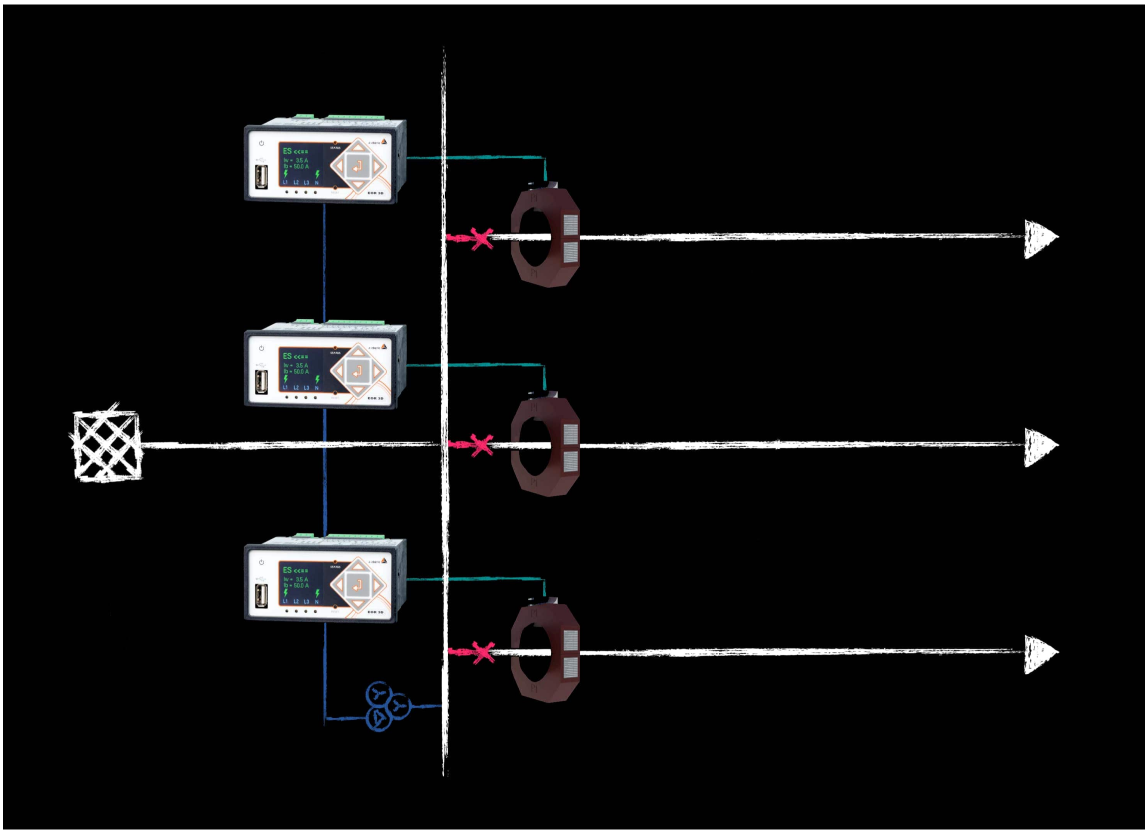

Figure 1: Secondary basic connection of the current and voltage transformers

At this point, we had noted that both the harmonic method and the wattmetric ground-fault location method use the same measurement setup, with the additional note that for the harmonic method, the Holmgreen circuit is also allowed.

Now, in order to make us understand the operation of the harmonic method, it is first necessary to take a closer look at the current conditions in quenched networks and the operation of the wattmetric cos-phi method. In a network with earth fault compensation, at least one star point of a transformer or star point former is grounded via an earth fault quenching coil. The inductance of existing quenching coils is matched to the earth capacitance of the network in order to compensate almost completely for the capacitive earth fault current in the event of an earth fault. This results in an energetic relief at the fault location and allows much larger networks to be operated below the quenching limit.

The usual overcompensation in Germany means: The inductive current of the Petersen coil is slightly larger than the capacitive earth fault current of the network. This deviation is called the degree of detuning V and is usually in the order of about 5 %.

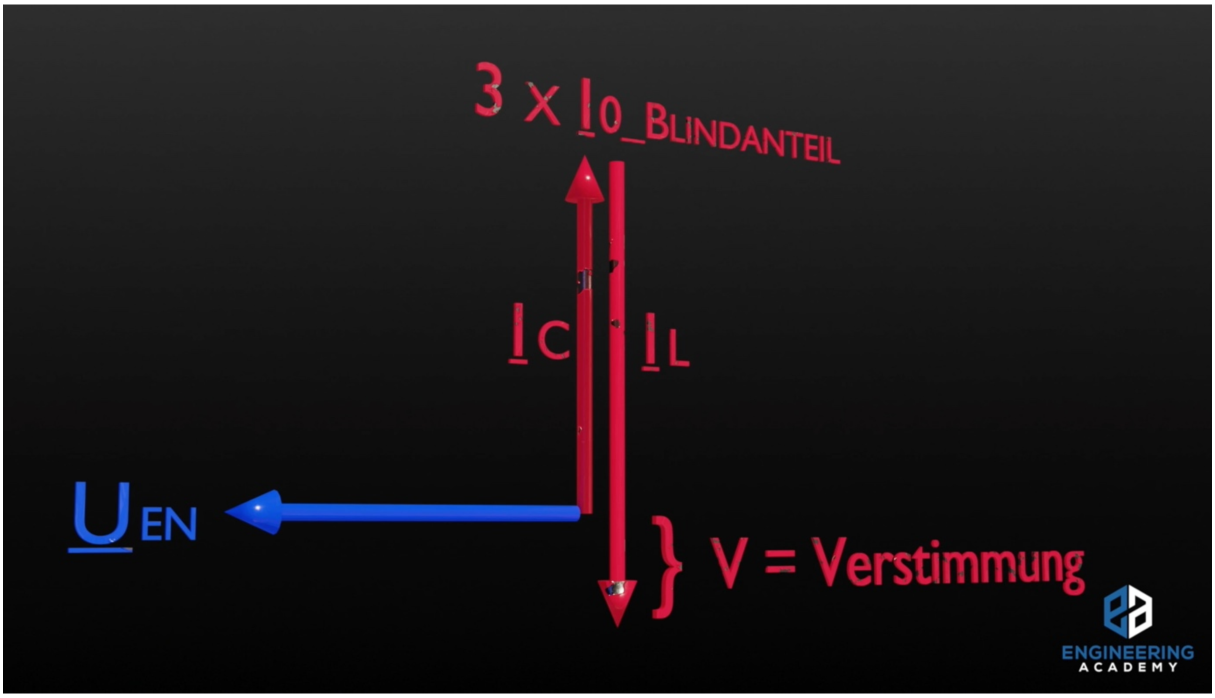


Figure 2: Degree of detuning V with overcompensation

Overcompensation offers a practical advantage: If cable or line sections are switched away, resonance operation is prevented because the detuning level cannot drop in the direction of full compensation but continues to rise. The background here is simply that we always try to avoid full compensation in order to avoid resonance.

With the cos-phi method, the magnitude and direction of the active current component in the residual earth fault current are now evaluated. The great advantage is that the active current is largely independent of the degree of detuning of the suppression coil. It amounts to about 3 % of the capacitive earth fault current in cable networks and about 6 to 10 % in overhead line networks.

Let us first take a look at the general composition of the residual earth fault current. The residual earth fault current resulting from the compensation consists of an uncompensated active current component, uncompensated components of the reactive current depending on the operating point of the quenching coil, as well as harmonic components, which are not shown here for reasons of clarity.

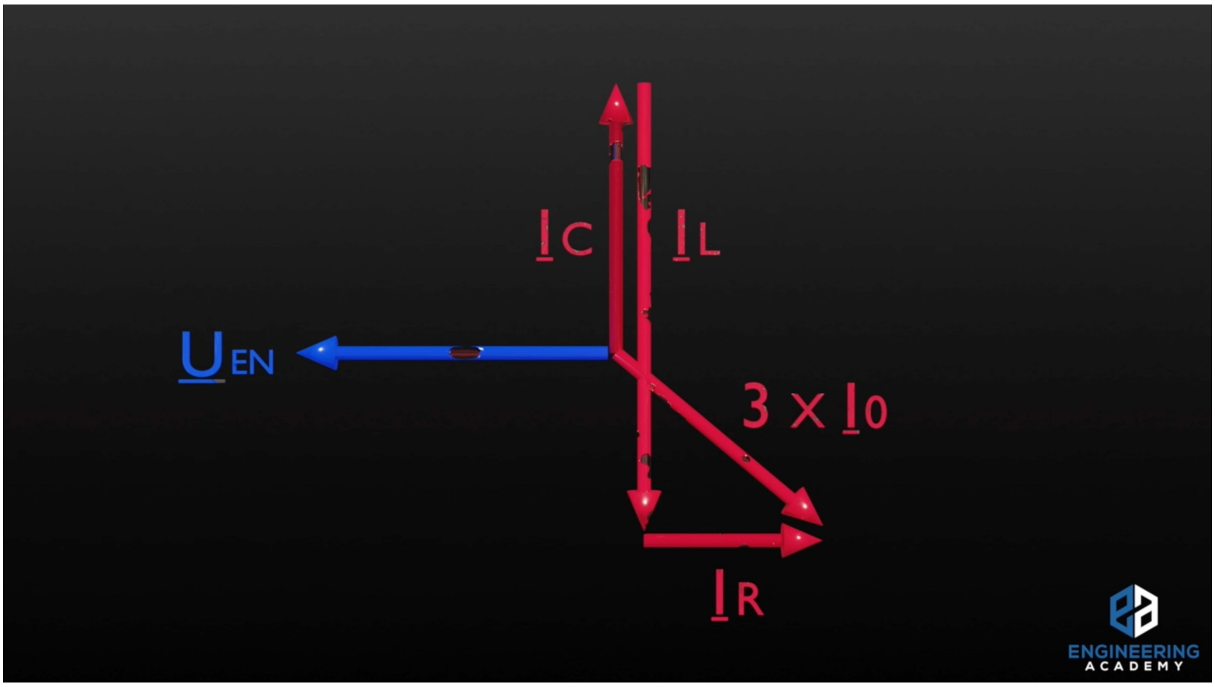


Figure 3: Composition of the residual earth fault current & position with respect to the zero-sequence voltage

If a network is overcompensated, the angle of the residual earth fault current is usually in the range from -10° to -80°, i.e. in the 4th quadrant, if we specify beforehand that the zero-sequence voltage is at 180° and that we are in the feeder affected by the earth fault. In case of undercompensation, the residual earth fault current can be found in the first quadrant.

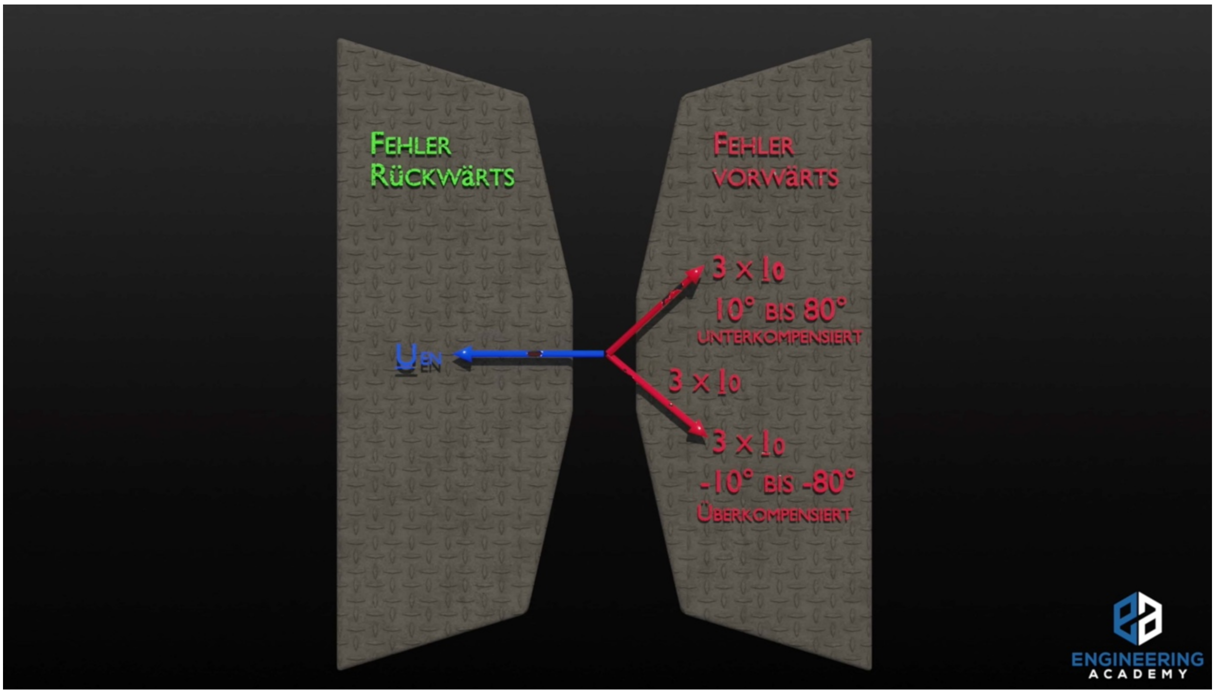


Figure 4: Position of residual current for under- & overcompensation

As already mentioned, the wattmetric method requires a very high angular accuracy, since the active current causes only small pointer rotations at larger degrees of detuning. In particular, angular errors with a positive direction of rotation can make "healthy" feeders appear faulty, since a shift occurs in the direction of the tripping range. The use of accurate cable conversion converters is recommended here in any case.

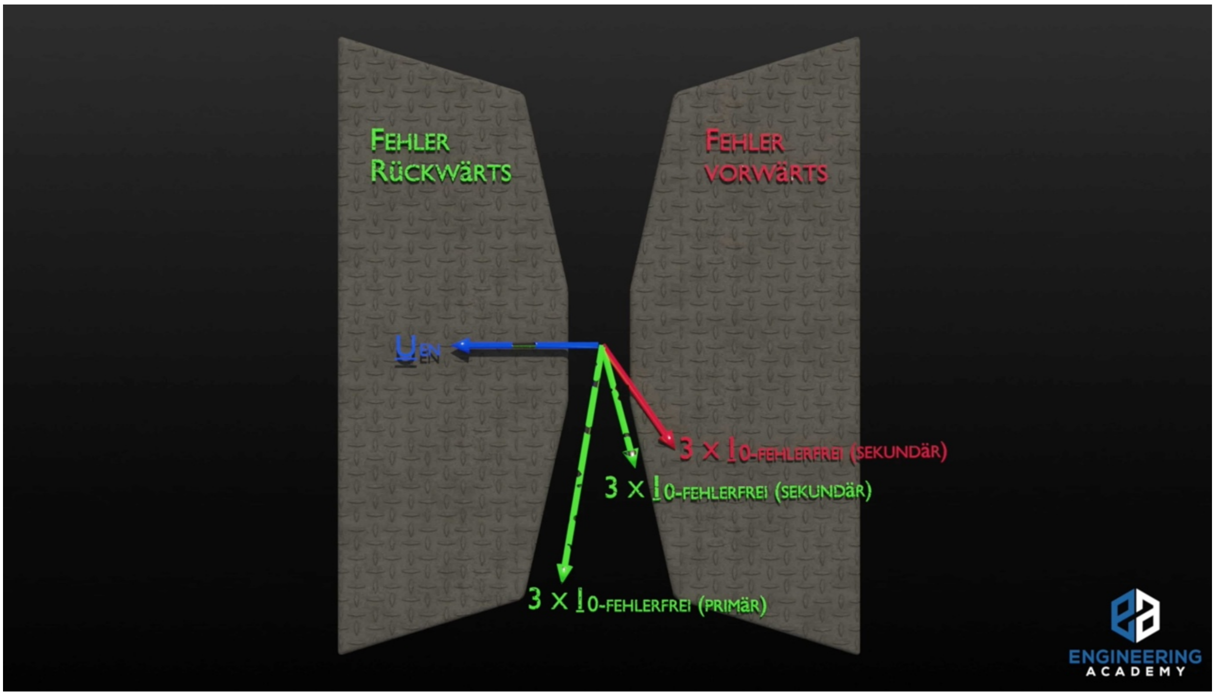


Figure 5: Angular error in the limit range

Now, why can the harmonic process also be operated inexpensively and practically via Holmgreen circuit, even if there is no residual wattage current increase, and in general, how does the harmonic process work? To be able to answer these questions, let's have a look at the following figure and thus at the basic structure of the harmonic process.

The earth fault relays in the figure are able to filter the currents and voltages specifically to a specifiable frequency on the basis of the Fourier transform. In our example, these are the 250 Hz components of current and voltage.

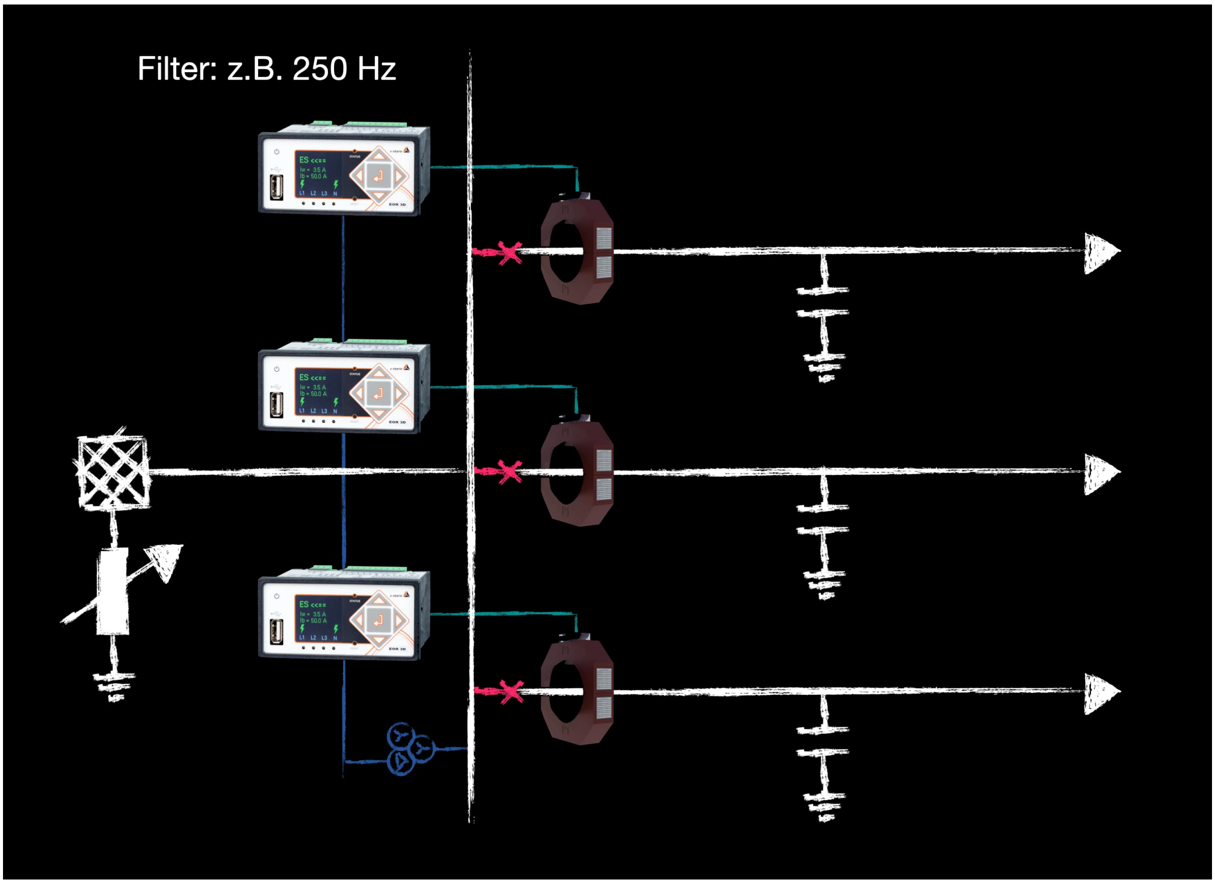


Figure 6: Secondary structure of protection system for harmonic processes

The 250 Hz components are now used instead of the fundamental fundamental currents and voltages to monitor the characteristics of the characteristic. The capacitive earth fault current is calculated from the product of the nominal voltage, square root of 3, omega and the conductor-to-earth capacitance of the total network.

$$I_{CE} = U_n \sqrt{3}\ \omega\ C_E$$

When looking at the factors of this equation, it is noticeable: These are mainly constant quantities. The voltage can be assumed to be largely constant and there is not much room for negotiation for root 3 either. If we further assume that no switching operations take place, the conductor-to-earth capacitance of the network can also be assumed to be approximately constant. So all that is left is the small omega and this is where all the magic takes place. Omega is the angular frequency and is calculated from the product of 2 Pi f. Thus, the capacitive zero-sequence current is frequency dependent. This is because the zero reactance of the conductor-to-earth capacitances drops to one-fifth in the 250 Hz range, making it more conductive for larger frequency ranges. As we know, this results in:

$$Xc = 1 / ( j \omega C )$$

If the frequency increases by a factor of 5, the reactance drops analogously to one fifth and the current goes up accordingly. Of course, the magnitude of the 250 Hz current must be related to its actually existing components. The magnitude of the harmonic component in the sum zero-sequence current can therefore be calculated as follows:

$$I_{fx} = I_{CE} \frac{f_{fx}}{f_{50\,Hz}} \frac{U_{LL\_fx}}{100}$$

We multiply the capacitive earth fault current by the harmonic frequency used and the percentage of harmonic present in the conductor-to-conductor voltage and divide the result by a factor of 5000.

The genius now is that we always have a maximally detuned system and the blind components can no longer compensate each other. Because what we haven't even addressed yet is the fact that the reactance of the Petersen coil in the world of the

250 Hz level also changes by a factor of 5, more precisely it increases by a factor of 5.

Strictly speaking, we are no longer dealing with a compensated network at the 250 Hz level, but with an isolated network.

Let's make a numerical example to illustrate the advantage of the harmonic method, and assume a quenched medium-voltage system with 100 A capacitive ground-fault current, an attenuation of 3%, and a 250 Hz component of 4%.

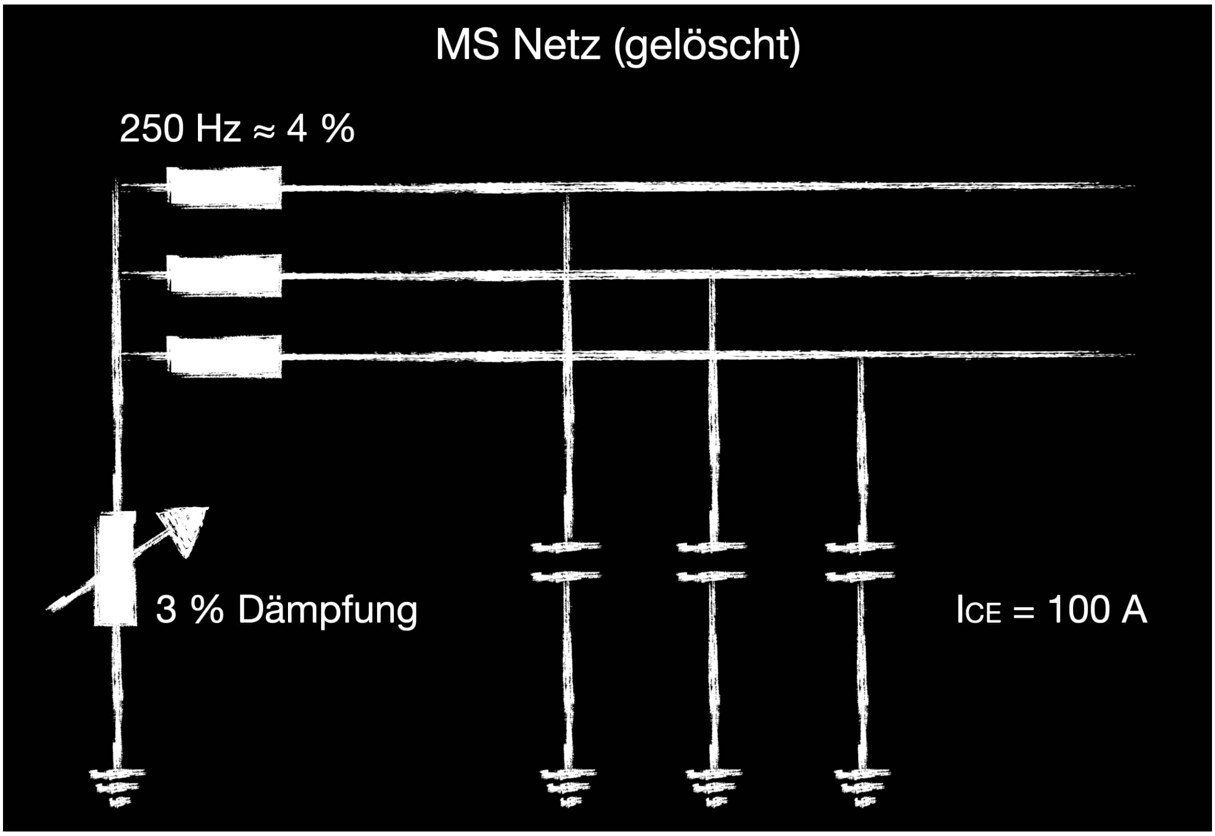


Figure 7: Compensated medium-voltage grid as a numerical example

The 50 Hz portion of the residual watt current, which is used for the cos-phi method, is approximately 3 A. With a cable conversion transformer with a 60 / 1 A transformation ratio, we only have a secondary residual wattage current of 5 mA, which is too small to be safely evaluated. We cannot use the capacitive component in the compensated network, because it is non-binding and dependent on the operating point of the coil.

The capacitive 250 Hz component, on the other hand, is a whopping 20 A. The coil current of about 105 A appears in the 250 Hz world only with about 840 mA and is therefore no longer significant. A resulting capacitive 250 Hz current of 19.16 A remains. This means that after translation to the secondary side, an impressive 320 mA is available. This is of course a considerable difference and provides suitable excitation conditions for the ground fault direction protection.

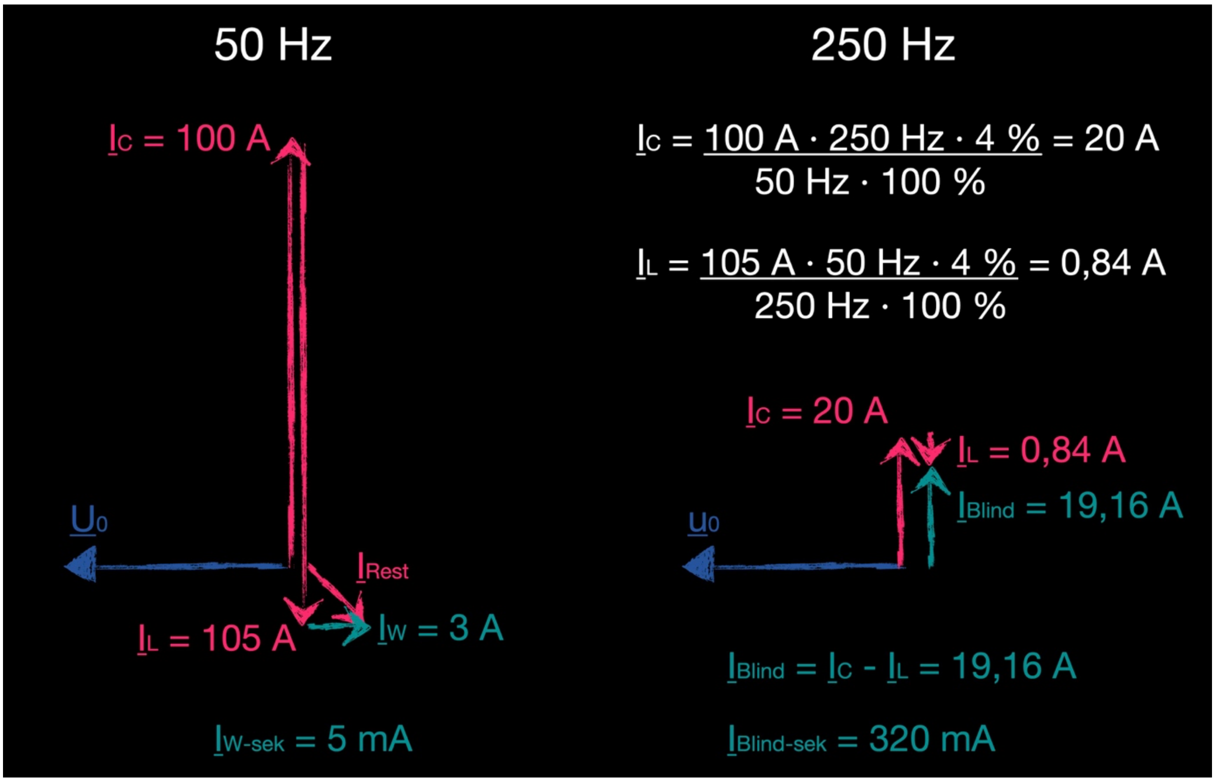

Figure 8: Calculation of current components for 50 and 250 Hz

For the evaluation of the measuring signals, the characteristic of the sin-phi method is used, since not the active but the reactive component in the zero system is monitored.

So let's summarize the operation of the harmonic method in one sentence: The harmonic method is a reactive power direction protection in the zero-sequence system, which refers exclusively to a filtered harmonic frequency of the measured current and voltage signals.

What else is important to say? The sensitivity of the harmonic method is quite good; it allows to detect earth faults with fault resistances of up to 4 kΩ. The cos-phi method, on the other hand, only gets reliable results up to a maximum of 2 kΩ. Then we had said that the requirements regarding the angular errors are lower and due to the sufficiently large currents, the Holmgreen circuit is also used.

However, a prerequisite for the application of the harmonic method is that sufficiently high harmonics are permanently present in the system. Here it is recommended to carry out long-term measurements over a period of about 2 to 3 weeks and to see which odd harmonics are bindingly present. This can be done, for example, very conveniently and reliably with a PQ box from the company A. Eberle from Nuremberg.


Figure 9: PQ-Box 200 of the company A. Eberle GmbH & Co. KG

In general, don't worry, odd harmonics are actually present all the time, even if there are few or even no non-linear loads in the customer's system.

In practice, one often tries to find a compromise between a sufficiently high current and a minimum frequency with regard to the harmonics used, since frequencies that are too high can have a negative effect when additional inductive network components are connected. The following applies here: The greater the harmonic selected, the less mains can be switched in. In practice, frequencies in the range of 150 to 350 Hz are used, depending on the existing network topology. The EOR-3D earth fault locating relay from A. Eberle has a freely selectable frequency range from 0 to 500 Hz and is supplied with a default setting of 217 Hz.


Figure 10: Earth fault locating relay EOR 3D of the company A. Eberle GmbH & Co. KG

As we can see, the harmonic method is a technically very reliable complement for the transient method and should always be considered in good ground fault engineering.

**Kind regards, your EEA-TEAM**