WHY DOES THE EARTH FAULT DETECTION METHOD BASED ON 3RD HARMONIC WORK IN LARGE MESHED 110-KV-NETWORKS

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ABSTRACT

Due to today´s increased demands on grid operation management, new methods for earth fault localization and detection are needed. The fault localization should be performed as quickly as possible and under the condition, that the fault current at the fault location will not be significantly increased.

Up to now, the 3rd harmonic was never used as a directional earth fault indicator, as the 3rd harmonic does,more or less, not exist in the line-line voltage of a healthy network.

In today´s meshed compensated 110-kV-networks with increased length, only the transient relays work correctly. But these relays give a signalization only during the beginning of an earth fault. They are not able to give correct information after a change of the network-configuration.

One effect that was observed in the past was, that the harmonics in the line-line voltages are changing during an earth fault. In this paper the advantages of the use of the 3rd harmonics will be presented.

INTRODUCTION

In Fig. 1 the distribution of compensated networks in Germany is shown.

The distribution in Austria and Switzerland is similar to Germany. The advantage of compensated networks is, that the customers can be supplied continuously during a single line to earth fault. Detailed information of Pros and Cons of compensated networks can be found in [4] and [5].

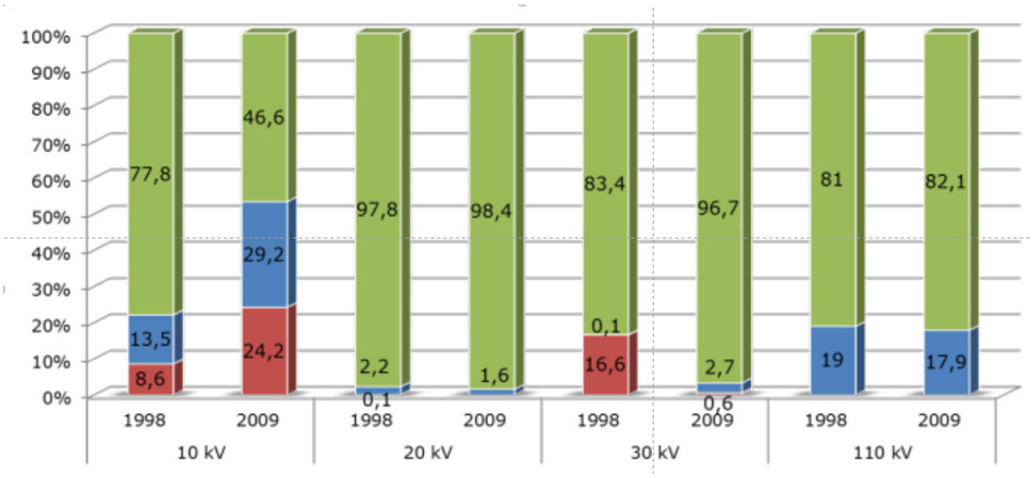

Fig. 1 Neutral Point Treatment in Germany [4]: green: Petersen-Coil; blue:solid grounded; red: isolated

BASIC OF THE EARTHFAULT

To explain the behaviour of a single-line earth fault in more detail, the scheme of a substation (Fig. 2) with three feeders (A, B and C) and an earth fault in line 1 of feeder A will be used [1].

With the beginning of the transient earth-fault, two different processes can be superposed [1]. The following two processes are starting at the same time, but with different duration:

- discharge of the faulty line over the earth
- charging of the two healthy lines over the earth

The two processes end in the stationary state of the earth fault, which is shown in Fig. 2

Stationary state of the earth fault

In an isolated network the whole capacitive currents of all healthy feeders flow via the fault location. In the faulty feeder, the sum of these currents flows in the opposite direction.

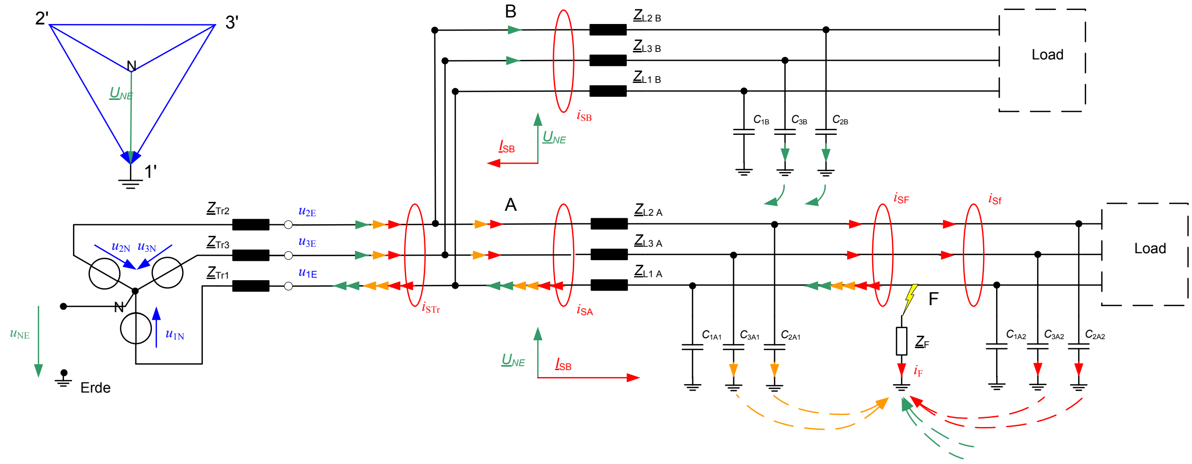

Fig. 2 Single-line-earthfault (SLE) in feeder A of the isolated network

The zero-sequence currents in healthy feeders are capacitive and, due to the change of direction, in the faulty feeder inductive. The reference for the decision if inductive or resp. capacitive depends on the relation of the current to the zero-sequence voltage $\underline{U}_{0\_50}$.

As a result, the relays identify feeders with a capacitive zero-sequence current $\underline{I}_{0\_50}$ as healthy and feeders with an inductive current $\underline{I}_{0\_50}$ as faulty.

For compensated networks the situation is different. In this case, the 50 Hz current through the Petersen-Coil superposes and reduces the capacitive current over the fault location. In a well-tuned network the 50 Hz capacitive current over the fault location is completely compensated.

Using a Petersen-Coil, the fundamental current over the fault location can be reduced to the small wattmetric part, which is usually in the range of 2 % to 3 % of the whole capacitive line-to-ground current of the network. After few periods the transient load current of the healthy phases is damped out completely, and the capacitive current via the fault location is compensated more or less completely from the inductive current of the Petersen-Coil. In a well-tuned network without harmonics, only the wattmetric part flows over the fault location.

The requirements for the directional identification of the faulty line are different for isolated and compensated networks, according to Fig. 3.

Fig. 3 shows, that the directional cos(φ)-method is very sensitive to angle errors between zero-sequence-current and zero-sequence-voltage. The wattmetric part of the zero-sequence-current is only in the range of 2 % to 3 % and a virtual wattmetric current can be generated by amplitude or phase errors of the ICTs. An angle error can also be generated by the inaccuracy of the IVTs. In meshed networks an additional circulating current, due to phase splitting, can generate a virtual wattmetric current. These virtual currents often lead to an over- or under-functionality of the cos(φ)- method.

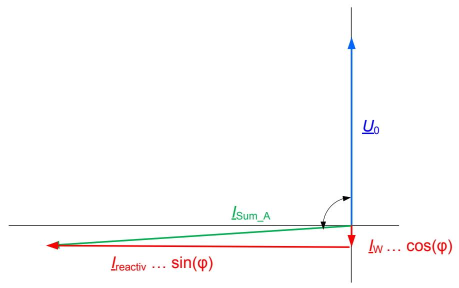

Fig. 3 Directional identification of the faulty feeder at 50 Hz
cos(φ) … wattmetric method for compensated networks
sin(φ) … for isolated networks

On the opposite side, the requirements to the angle error between the zero-sequence-components $\underline{U}_{0\_50}$ and $\underline{I}_{0\_50}$ are strongly reduced in isolated networks. For the directional decision an angle error of ± 45 ° is acceptable.
The following chapter describes measures which can be taken, in order to create, for the purpose of the directional earth-fault identification, the same behaviour in the compensated network as in the isolated network.

EARTHFAULT DETECTION BASED ON 5th HARMONIC

Principle

Due to nonlinear loads and nonlinearities of the distribution transformers, there are harmonics in the load current. This harmonic currents flow via the impedances of the supplying transformers and generate a harmonic distortion of the line-line voltages. In this case the bus bar is the point of common coupling (PCC) for the harmonics.

For compensated networks a simplification can be assumed for the 5th harmonic: For the 5th harmonic, the impedance of the Petersen-Coil increases by the factor 5 and the impedance of the line-ground capacities decreases by the factor 1/5. Therefore the Petersen-Coil can be neglected for the 5th harmonics-method:

The network for the 5th harmonics shows the behaviour of an isolated network.

As a result, the requirements for the ICT and IVT are strongly reduced.

For homogenous networks this behaviour helps to simplify the directional earthfault identification. But in mixed networks major problems arise through series resonances.

Series resonance effects

Up to now, the series inductivity of the lines were neglected. Compared with cables, OHL have a large zero-sequence series inductivity. On the other hand, OHLs have a very small capacity to ground, compared with cables.

In homogenous networks the serial resonance frequency is higher than 250 Hz and the directional earthfault detection works well, see Fig. 4

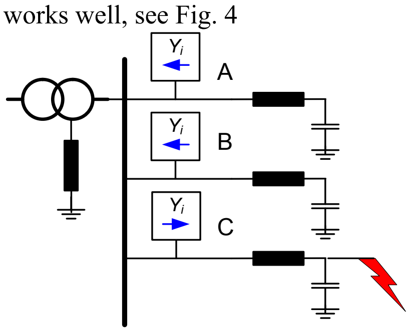

Fig. 4 Directions of 5th harmonic, if the series resonance frequency is below the 5th harmonics

If one feeder of the OHL network is extended by a very large cable-network, as depicted in Fig. 5, this capacity makes more or less a short to ground.

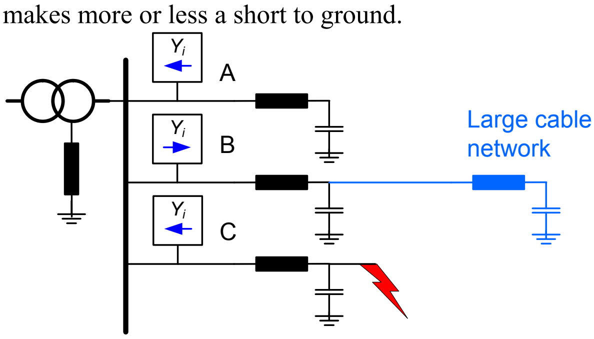

Fig. 5 Direction of 5th harmonic, if the series resonance frequency is higher than the 5th harmonics

From the bus bar, the relay now sees an inductive current and interprets this feeder now as the faulty one. On the bus bar, Kirchhoff's law must be fulfilled and one of the other feeders must also change the direction. This change can be only on the faulty feeder. Now we have, due to the series resonance in feeder B, the worse situation that the healthy feeder B is identified as faulty feeder. In addition the faulty feeder is identified to be healthy.

The same behavior occurs with relays in the field near to the boundary of large networks. The problem occurs especially in suburbs of large cities, where the last distance to the customer uses OHLs. If the SLE-fault occurs near to the end of the feeder, the series inductivity of the feeder from relay to the bus bar with the large cable network in the city can be below 250 Hz. In this case the directional information is incorrect, as shown in Fig. 6.

This behaviour, according to Fig. 6, is to be found also very often in the 110-kV-networks, especially if the feeder supplies very long valleys with branching. Usually small substations are installed at the nodes with relays for the faster directional earthfault identification.

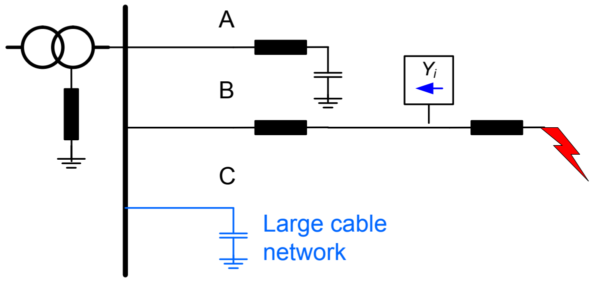

Fig. 6 Direction of 5th harmonic in distributed relays, if the series resonance frequency of feeder and base network is higher than the 5th harmonics

Change of the harmonics during earthfault

Under healthy conditions, the positive-, negative- and zero-sequence systems are more or less decoupled.

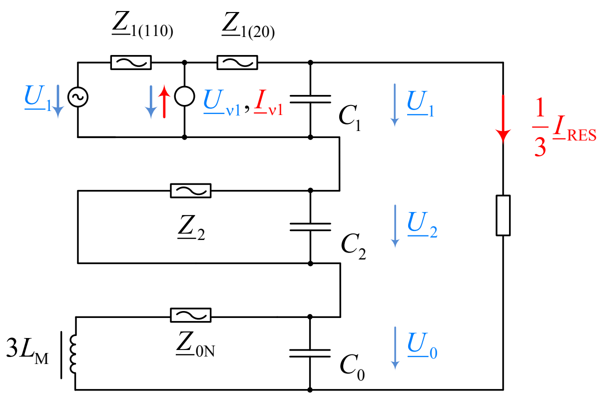

Fig. 7 Simplified equivalent circuit in symmetrical-components considering the 110-kV-network in case of a single-phase earth fault [6]

In case of a SLE-fault the three symmetrical systems have to be connected at the fault location, as depicted in Fig. 7 [3] [6]:

A complete new formulation of the algorithm, presented in [2] [6], uses **harmonic current sources** and takes into account also the 110-kV-network. This model is shown in Fig. 7. Using this formulation the results of simulation correspond to the measurement of the healthy state and the SLE-fault state. The harmonics in the line-earth voltages are shown for the healthy state in Fig. 8 and for the SLE-fault state in Fig. 9. The changes of the harmonics due to the SLE-fault are remarkable and not neglectable.

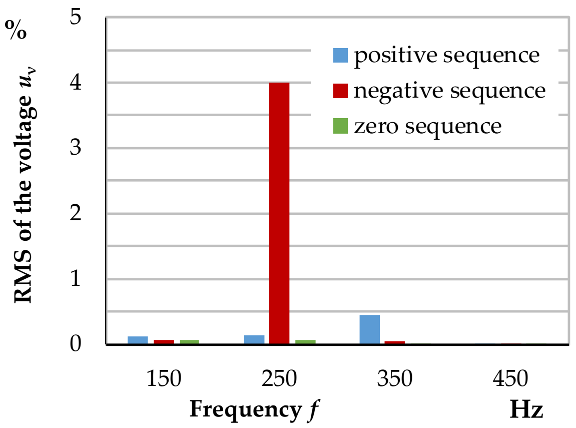

Fig. 8 Measured phase to earth voltage at the bus bar before earth fault [6]

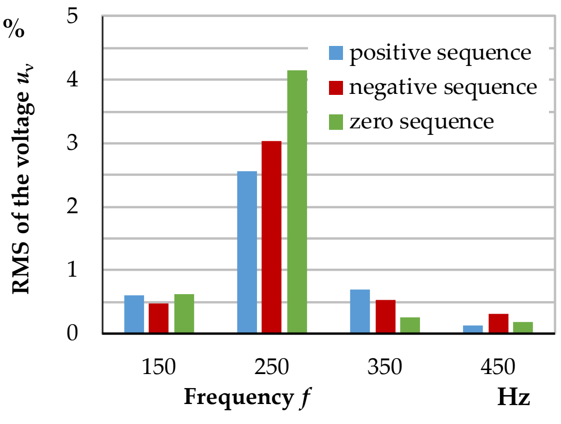

Fig. 9 Measured phase to earth voltage at the bus bar during earth fault [6]

It is also remarkable that, due to the solid earthfault, there is an increase of the 3rd harmonics. Up to now we have learned, that 3rd harmonics in the distribution network do not exist, due to distribution transformers which are connected to the network as Dy transformers. These delta-winding makes a short of harmonics, which are integer multiples of 3. But, due the impedances in the distribution transformers and the line length to the distribution transformer, the short is not perfect, as shown in Fig. 9.

A second reason for the increase of the 3rd harmonics are increasing harmonic single-phase loads in the LV-area. A single phase load on the LV-side generates the corresponding currents only in two limbs on the primary side. This can also result in 3rd harmonics on the primary side, if there are 3rd harmonics on the LV-level.

EARTHFAULT DETECTION BASED ON 3rd HARMONIC

110-kV-networks

The major part of the compensated 110-kV-network in Germany, Austria and Switzerland is realized with over-head-lines.

Extensive field-tests have shown, that overhead lines falling on meadows cannot be represented as a constant linear impedance in the range of some 100 Ω.

As it can be seen from Fig. 10 there are a number of arcs from the line to ground. The field test has shown, that the soil under one arc melted and changed to higher impedance. Therefore the arc distinguished at this location and new arcs ignite, additionally to the existing, on another site. This results in a non-constant impedance over the time at the fault location. The impedance depends also from the tuning and it has its highest value at the 50 Hz resonance point.

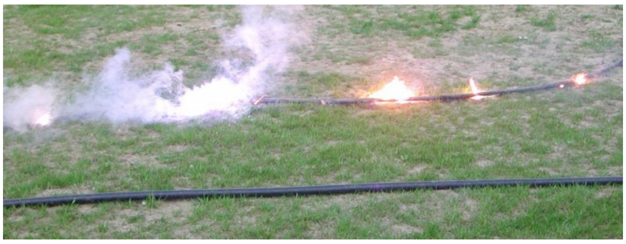

Fig. 10 Over-head-line on meadow

In the 110-kV-network the contact of OHL to meadow is one of the most common causes of earth-faults.

A look to the phase-voltage of the faulty phase shows, that it is a restriking fault. The simplest approximation of this voltage is a rectangular voltage with the average over a half period of the burning voltage of the arc. But a rectangular voltage implies a 3rd harmonic voltage and a 3rd harmonic current in the faulty phase.

With this OHL on meadow we have an additional harmonic generator at the fault location. This harmonic generator is independent of the load current in the 110-kV-network.

The currents of this harmonic generator must flow to the next substation and can be compensated only behind the relays.

Advantages of the 3rd harmonic method compared to the 5th harmonic method

The major improvement is, that the frequency of the 3rd harmonic is much closer to 50 Hz.
Therefore the possible distance from the relay to the large cable network according to Fig. 6 increases.
The probability of a wrong directional decision decreases.

Experience

In Austria the 3rd harmonic method is in practical use since several years very successfully.

The following earthfault directional results were compared in the 110-kV-network:

- transient evaluation with qu2 algorithm
- evaluation of intermittent earthfaults with the qui2 algorithm
- wattmetric method (not usable, due to the meshed 110-kV-network)
- 5th harmonic method
- 3rd harmonic method

Result of comparison: qu2, qui2 and the 3rd harmonics were delivering the most reliable results.

The new earth-fault directional relay implements several algorithms. All these algorithms are working parallel and a priorization of the different earth-fault methods is nowadays state of the art. Fig. 11 shows an example of such a relay.

Fig. 11 SPRECON-EDIR includes the 3rd harmonics method

SUMMARY

In the 110-kV-networks the cos(φ) method is not working, due to the small wattmetric component and the meshed design of the 110-kV-network.The transient relays based on qu2 and qui2 are working without problems also in a meshed situation.

For the stationary evaluation, up to now, only the 5th harmonic evaluation was an alternative to the cos(φ) method. The 3rd harmonic was always out of scope, because the 3rd harmonic is more or less not existing in the positive sequence system due to the Dy distribution transformers.

In this paper it was shown, that the 3rd harmonic is dramatically increasing during a single-line-earthfault, especially if an OHL is falling on a meadow.

In this case, the 3rd harmonic method can be used for the evaluation of the directional earthfault identification as a stationary method. The advantage of this method is, that the influence of series resonances is reduced and larger networks can be handled.

Experiences over several years have confirmed the usability of the 3rd harmonic method in large 110-kV-networks.

Now a relative robust stationary method exists to identify the faulty feeder.

REFERENCES

[1] Druml G., 2013, "Innovative Methoden zur Erd-schlussortung und Petersen-Spulen Regelung", Thesis at the Institute of Electrical Power System in Graz, Austria

[2] Frowein K., 2015, “Beschreibung von Ober-schwingungsquellen für die Berechnung des Erd-schluss-Reststromes bei Resonanz-Sternpunkt-erdung”, diploma thesis, TU Dresden, Dresden.

[3] Frowein K., Schmidt U., Druml G., Schegner P., 2017, "New model for the calculation of harmonics in the residual earthfault current of medium voltage systems", *Proceedings CIRED 2017 conference*, paper 1062

[4] Melzer H., et al: 2012, *Die aktuelle Situation der Sternpunktbehandlung in Netzen bis 110 kV (D-A-CH)*, *ETG-Fachbericht 132*, VDE Verlag GmbH, Berlin Offenbach, Germany

[5] Schegner P.; Schmidt U.; Frowein K., 2017, *Influences on the Neutral Point Treatment Caused by Changing General Requirements and New Network Concepts*, *ETG-Fachbericht 151*, VDE Verlag GmbH, Berlin Offenbach, Germany

[6] Schmidt U.; Frowein K.; Druml G., Schegner P., 2016, *Proceedings PQ2016 conference in Tallinn*