NEW ADAPTIVE ALGORITHM FOR DETECTING LOW- AND HIGH OHMIC FAULTS IN MESHED NETWORKS

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ABSTRACT

Statistics show that the major portion of grid faults are earth faults. Conventional relays are designed only for low ohmic earth faults under stationary conditions and for non meshed systems. They can handle neither high ohmic earth faults, which occur especially in rural networks with overhead lines, nor intermittent earth faults in compensated cable networks. Additionally all algorithms are very sensitive to real and virtual crosstalks from the load current to the zero-sequence-system, which occur in every meshed system. As a consequence, very often the earth fault is not recognized or the wrong feeder is selected to be healthy.

In the paper the reasons for the crosstalk from the load current to the zero-sequence-system, the influence even to transient relays and the benefits of the new adaptive algorithm are explained in detail.

The theoretical explanation is completed with the presentation of real field results from a very large meshed distribution network.

INTRODUCTION

In many countries of the EC the "resonant grounding" is one of the most important options in electrical network design to obtain the optimal power supply quality. The first main advantage of this treatment of the neutral point is the fact, that in most cases the system is self-healing, as the arc distinguishes without any intervention of the protection system[1]. The second main advantage is the possibility of continuing the network operation during a sustained earth fault. As a consequence, the number of interruptions of the power supply for the customer is reduced. But with this improved power quality problems arise for the selective detection of earth faults. The conventional relays are designed only for non-intermittend low ohmic earth faults and for non meshed grids.

With the new adaptive algorithm directional earth fault detection from low ohmic up to some kOhm is possible in non-meshed and meshed networks.

Up to now the preferred fields of application for transient relays in the medium voltage were large unmeshed cable networks. With the new adaptive algorithm the relay is also applicable for rural networks, where the probability of a high ohmic earth fault is much higher.

This new adaptive algorithm is now also able to suppress crosstalk from the load current to the zero-sequence-system. Therefore transient relays with this new adaptive algorithm can be used successfully in meshed networks with non negligible crosstalk.

The algorithm can also be used for the detection of restriking earth faults in compensated cable networks and intermittent earth faults in isolated networks.

BASICS OF THE EARTHFAULT

To explain the behavior of a single line earth fault, two different processes can be superposed [3], [6], [9]. 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 are ending in the stationary state of the earth fault. The explanation of the two processes will be made by using a network with three feeders (A, B and C) and an earth fault in line 1 of feeder A according to *Fig. 1*.

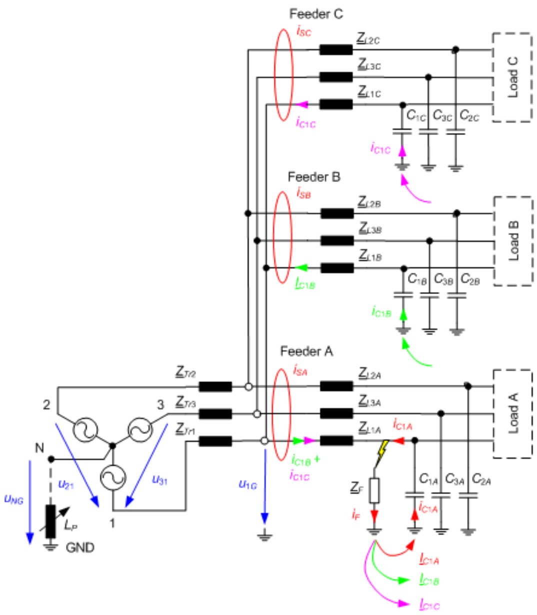

Fig. 1: Discharge of the faulty line over the earth

Discharge of the faulty line over the earth

The lines can be considered as a distributed lattice network, consisting of a complex serial impedance $\underline{Z}_{LXX}$ and a line-to-ground capacitance $\underline{C}_{XX}$ .The greatest probability for the first ignition is near the maximum of the line-to-ground voltage u_{1G}. At this time the line has about the maximum charge. The discharge of the lattice network of line 1 will start at the fault location and will propagate in both directions to the ends of line 1. A reflection of the waves occurs at the end of the line respectively at every change of the image impedance of the line. These reflections can be detected in form of oscillations at a high frequency in the zero-sequence current and in the zero-sequence voltage. The oscillation frequency essentially depends on the serial impedance and the line-to-ground capacity which are, in a first approximation, proportional to the length of the line. The frequency is higher for small networks and it is lower for large networks.

Charge of the two healthy lines over the earth

As a result of the discharge of the faulty line the triangle of the line-to-ground voltages is destroyed. As the supply-transformer is still delivering a symmetrical three phase system, the two healthy lines will be charged to the line-to-line voltage. This charging process for the network with three feeders is shown in detail in *Fig. 2* .

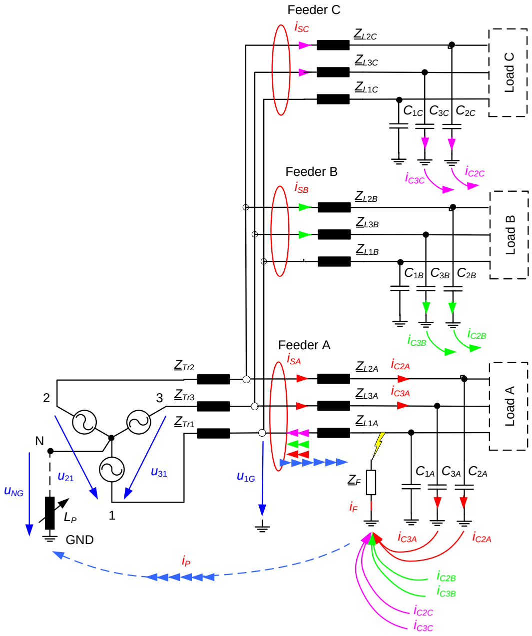

Fig. 2: Charge of the healthy lines over the earth

The distribution transformers respectively the loads are comparatively high ohmic and can be neglected in the first approximation. The influence of the Petersen-Coil can also be ignored, as the impedance of the Petersen-Coil is much higher than the leakage inductance of the transformer.

QU-ALGORITHM

The following considerations are based on the transient definition of the zero-sequence-system according to the space-vector-theory [5].

For example, for the healthy feeder B or C, as shown in *Fig. 3*, of our sample-network the charging can be described with equation (1).

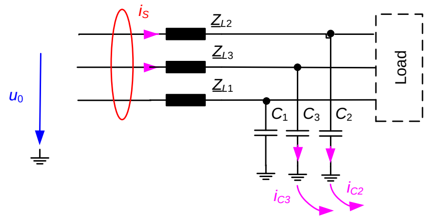

Fig. 3: Charge of one healthy feeder

$$u_0(t) = u_0(t_0) + \frac{1}{C_{eq}} \int_{t_0}^{t} i_S(\tau)\ d\tau \qquad (1)$$

$$u_0(t) = u_0(t_0) + \frac{q_S(t)}{C_{eq}} \qquad (2)$$

Starting the integration at a point where $u_0(t_0) = 0$ results in:

$$u_0(t) = \frac{q_S(t)}{C_{eq}} \qquad (3)$$

Drawing a diagram of this relation, with q_0 on the ordinate and the zero-sequence voltage u_0 on the abscissa results in a straight line with the gradient C_{eq}, which is the equivalent zero-sequence capacitance of the feeder. Subsequently, this diagram shown in *Fig. 4* will be referred to as qu-diagram.

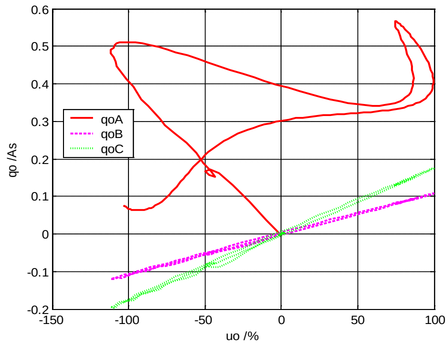

Fig. 4: qu-diagram of the three feeders in case of a low ohmic fault in feeder A

In the case of a faulty feeder this relation is no more valid. The sum of the charging currents of all healthy feeders flows out from the faulty feeder, it starts with a negative gradient and in compensated networks it is not a straight line. The last statement can be used as additional information for the earthfault detection.

The advantages of the qu-algorithm are:

- Simple evaluation
- No high speed sample rate is necessary. A sample rate of about 2 kHz is sufficient
- Influence of the discharge is reduced due to the integration of i_0
- The integration and evaluation can be done over a half period
- The integration of i_0 over a larger range before the trigger-point enables the detection also of high ohmic earth faults up to some kOhm

- on-line versions of the least squares algorithm [8] and pattern recognition algorithms (e.g. [4]) improve the computational efficiency

The disadvantages of the standard qu-algorithm are:

- Sensitive to analog-digital-converter saturations, as the straight line is modified to a curve
- Sensitive to not negligible phase-splitting
- Sensitive to crosstalk from parallel systems

The first disadvantage is only relevant in case of integration over the complete half period of u_0 and in combination with testing of the feature "straight line" of healthy lines.

The sensitivity against phase-splitting is a general problem of all relays, especially for cos(phi) relays. Using *Fig. 5* the reason of phase splitting in a healthy meshed network will be explained.

Phase-splitting

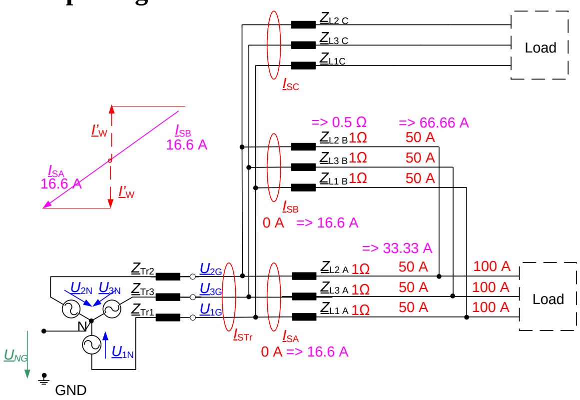

Fig. 5: Phase-splitting in the healthy network

In a symmetrical situation the load current in each phase will be splitted symmetrical to the feeders A and B. In this situation the measured sum-current ($\underline{I}_S = 3\,\underline{I}_0$) at the substation will be zero. Due to unbalances in the serial impedances of the lines the distribution of the load current will change. In the example the current in phase 2 is changing from 50 A to 33.3 A respectively to 66.6 A.

Now the sum-currents of the feeders in the substation are no longer zero. In our example the sum-current increases up to 16.6 A and the directions in the two feeders are opposite.

We can find this behavior in any loop, in parallel lines and in meshed networks.

The size of the phase-splitting current depends on:

- load current
- point of load on the loop
- physical arrangement of the asymmetry of the serial impedances [2]
- number of meshes

The asymmetry of a line may be caused for example by the kind of laying the cables, as shown in *Fig. 6* a (for further details the reader is referred to [5],[10],[11]). If the cables are laid in a triangle (see *Fig. 6* b) the mutual coupling of the three phases and therefore the serial impedance is obviously the same.

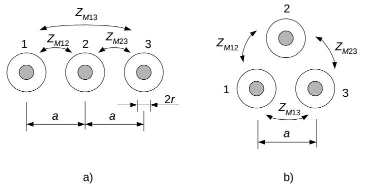

Fig. 6: a) Single conductor cables in parallel
b) Single conductor cables in triangle

A similar situation can be found for overhead lines where an improvement can be made, by transposing the phases.

One possible way to compensate this influence in loops is to measure the currents in all feeders and to add the currents of the feeders, which are switched to a loop. But this version needs a very high number of current measurements and, in addition, always the actual information, which feeders are switched to a loop. The requirements to such a SCADA System would be enormous.

Crosstalk from parallel systems

Systems switched to a loop are also very sensitive to the magnetic coupling of galvanic isolated parallel systems.

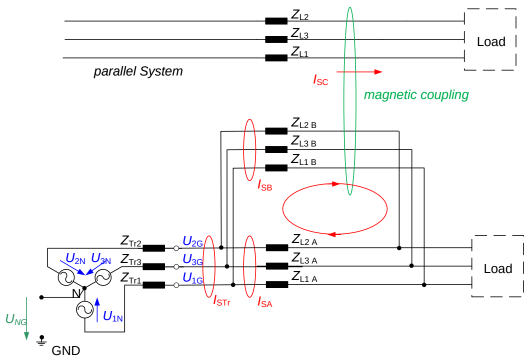

Fig. 7: Magnetic coupling of parallel systems

The influence of the parallel system may be negligible under normal operation, due to the small distances between the three phases. But in case of an earth fault in the parallel system, the currents through the three wires are no more symmetrical, also in healthy feeders (see *Fig. 2*). The asymmetric loading currents can be in the range of 100 A. Therefore the magnetic coupling must be taken into account.

A worse situation arises in case of a cross-country-fault in the parallel system.

Also a phase-splitting in the parallel system can be the reason for a crosstalk.

QU2-ALGORITHM AS A SOLUTION

With the assumption of no change of the crosstalk from a neighbor system and no change of load in the own system during the few periods of interest, a linearization around the working point combined with a nonlinear filtering solves the major problem.

For the explanation real measurements of an earthfault in the 16.7 Hz 110 kV network of the railway will be used. The network has about 1200 A capacitive current and is compensated with several distributed Petersen-Coils.

In the following figures the first channel shows the zero-sequence voltage in the substation.

The next two channels are the sum-currents of two parallel lines with a high current due to phase splitting. These two currents are more or less opposite. These currents include also the smaller zero-sequence currents due to the natural asymmetry of the network.

The last two channels show two independent feeders.

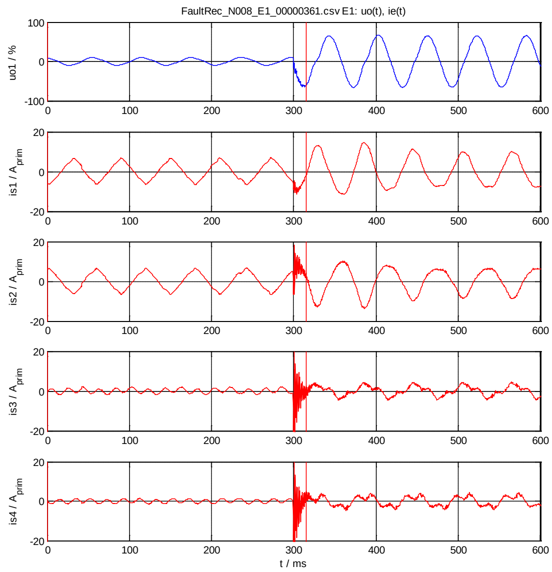

Fig. 8: Zero-sequence-voltage and -currents of four feeders with phase-splitting in feeder 1 and 2

Fig. 8 shows, that the change of currents in the feeders 1 and 2 due to the earthfault is very small.

In *Fig. 9* the corresponding standard qu-diagrams are shown. Comparing to *Fig. 4* or [3], a clear decision, which feeder is the faulty feeder and which are the healthy feeders is not easy, respectively impossible.

As long as the natural asymmetry of the net, represented by u_0, is very small, a linearization around the working point

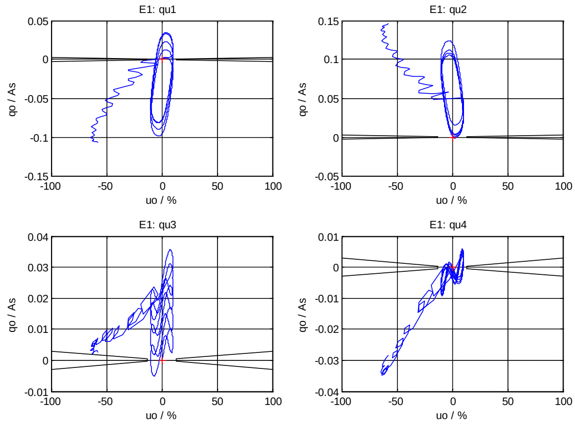

Fig. 9: Standard qu-diagram for the four feeders without correct identification of the faulty feeder

results in relative small inaccuracy of the equivalent model. *Fig. 10* shows the result of the linearization. The first periods are zero and the following periods up to the earthfault have only small variations due to variations in the load.

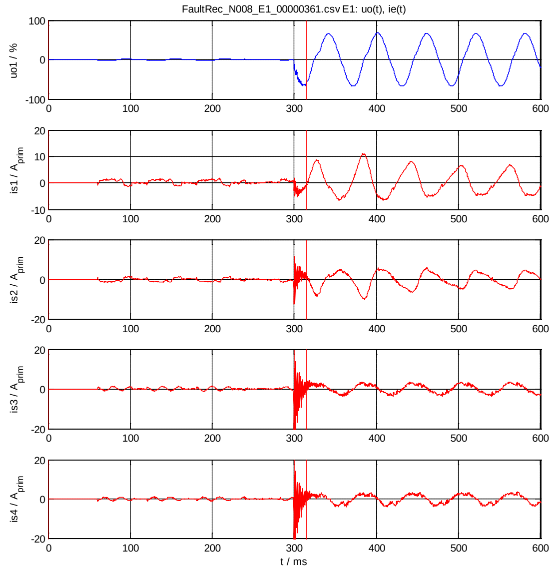

Fig. 10: Currents after linearization at working-point with strong reduction of the phase-splitting in feeder 1 and feeder 2

With an adaptive nonlinear filtering from the first period up to the earthfault, also these values can be reduced.

The parameter of the adaptive filter has an effect on the maximal detectable high ohmic earthfault.
On the other side, the saturation of analog-digital-converter and currents of cross-country faults are also modifying the filter-parameters.

The results of the adaptive nonlinear filtering of the low-ohmic earthfault are shown in *Fig. 11*

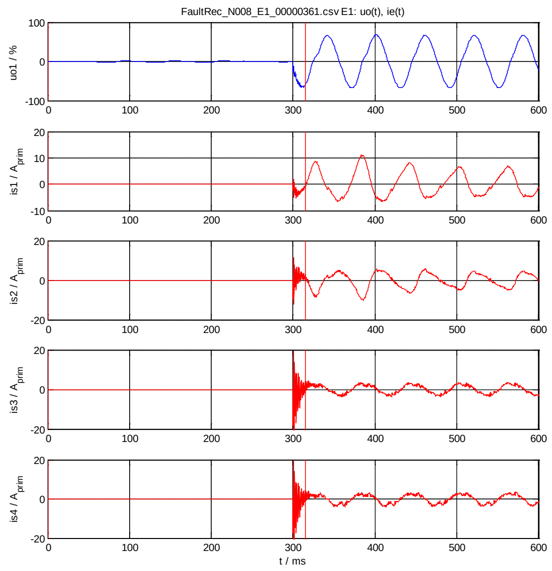

Fig. 11: Zero-sequence- voltage and -currents after adaptive nonlinear filtering. Influence of crosstalk, phase-splitting is reduced and prefault values are set to zero.

In *Fig. 12* the results of this qu-algorithm with additional nonlinear adaptive filtering are shown. Now it is no more a problem to identify the feeder 2 as the faulty feeder.

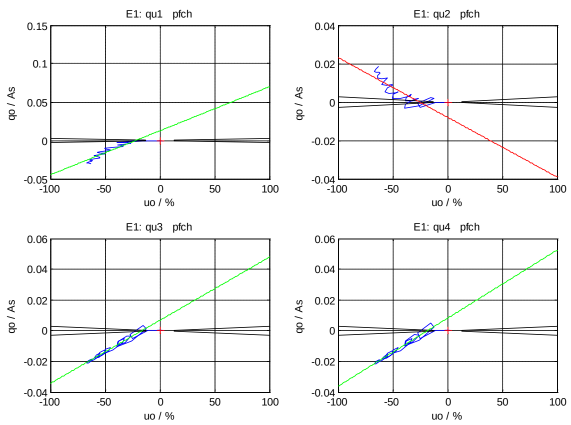

Fig. 12: qu2-diagram with correct identification of the faulty feeder 2

CONCLUSION

In this contribution we have discussed the basics of an earth-fault and the effects of phase-splitting on the behavior of the transients in the zero-sequence system.

To see the limits of conventional transient relays and the standard qu-algorithm, we have elaborated different situations, which may occur in every real-world looped ore meshed network.

According to these requirements we have presented a new algorithm.
Real measurements show the effectiveness of this new concept for transient relays, based on the qu2 algorithm.

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