NEW METHOD FOR IDENTIFICATION AND LOCALISATION OF AN EARTHFAULT IN COMPENSATED NETWORKS

Gernot DRUML
Sprecher Automation -Austria
g.druml@sprecher-automation.com

Oliver SKRBINJEK
Energie Steiermark - Austria
oliver.skrbinjek@e-steiermark.com

Uwe SCHMIDT
University Zittau - Germany
uwe.schmidt@hszg.de

Karla FROWEIN
TU-Dresden - Germany
karla.frowein@tu-dresden.de

Peter SCHEGNER
TU-Dresden - Germany
peter.schegner@ tu-dresden.de

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.

In today´s meshed compensated 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. During the steady state of the earthfault more or less all existing methods cause problems.

The new proposed method is based on injection of a zero-sequence current during an earthfault by tuning the Petersen-Coil. The relays have to use a simple evaluation of the zero-sequence current in the complex plane.

Using this method, an identification of the faulty feeder as well as a distance estimation up to the earthfault location is possible.

This paper will present the first results of this evaluation.

INTRODUCTION

The "resonant grounding" is one of the most important options in electrical network design to obtain the optimal power supply quality and reliability. The main advantages of earth fault compensation are:

- Self-healing of the system without an intervention of protection systems
- Continuing the network operation during a sustained single pole earth-fault
- Improved power quality for the customer
- Reduction of the current via the fault location to 2 % - 3 % of the whole capacitive current

For the suppression of the arc the Petersen coil should be well tuned within limits, which are described in[1][3], [9] and [12] for the different insulation levels. The increasing length of cables in distribution networks leads to the fact, that on the one hand the level of the neutral-to-earth voltage is decreasing and on the other hand the resonance curves become sharper. The reason for the reduction of the neutral-to-earth voltage level is mainly due to the reduced capacitance unbalance of the cables. Furthermore, the cables have smaller losses compared to equivalent overhead lines. This is why the damping of the network is reduced and the resonance curves become sharper.

The second main advantage is the possibility of continuing the network operation during a sustained earth fault [11]. As a consequence this reduces the number of interruptions of the power supply for the customers. But with this improved power quality, problems arise for the selective detection and localization of earth faults. The conventional relays are designed only for non-intermittent low ohmic earth faults and for non-meshed grids.

In [3],[4],[12] and [14] new methods for a transient evaluation of the earth fault are explained in detail. Especially the advantages of the new qu2-algorithm, using the linearization around the working-point with a subsequent adaptive nonlinear filtering in comparison to a conventional transient relay, were elaborated in detail. The comparison was based on the following usual situations:

- High impedance earth faults with impedances above 5 kOhm
- Parallel lines with asymmetrical serial impedances in the phases
- Re-striking earth faults in cable grids
- Ignition of the arc in the falling region of the zero-sequence voltage

The disadvantage of transient relays is that they are evaluating only the transient part of the earth fault. A repetition of the evaluation is impossible. With transient relays it is not possible to repeat a directional evaluation after a reconfiguration of the network, for example after a search using the "switching method"[8].

PULSE METHOD

The pulse detection method according to Fig. 1 is wide-spread in compensated networks because only a simple zero-sequence r.m.s current measurement is needed and the implementation is very simple.

The current injection with a rectangle pulsing r.m.s value can be generated for example by switching a capacity on and off in parallel to the Petersen-Coil [7].

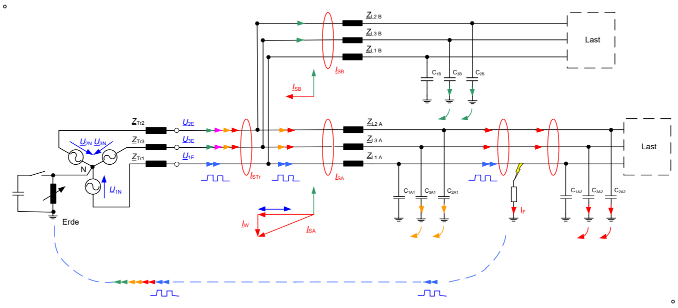

Fig. 1 Compensated network with the standard pulse method

The principle is very old and was used in the past in combination with moving-iron instruments. Therefore the pulse length is in the range of 1s. In case of a low-ohmic earth fault the pulse can be detected only between the pulse-generator and the fault location. Therefore the search strategy is defined as follows:

Start at the location of the pulse-generator and search the first location without pulse. In this case the faulty segment is in-between the location of the last measured pulse and the actual location.

It is also important, that the measurement is based on the r.m.s -value of the zero-sequence current. This principle is shown in more detail in Fig. 2 for the case of an overcompensated network.

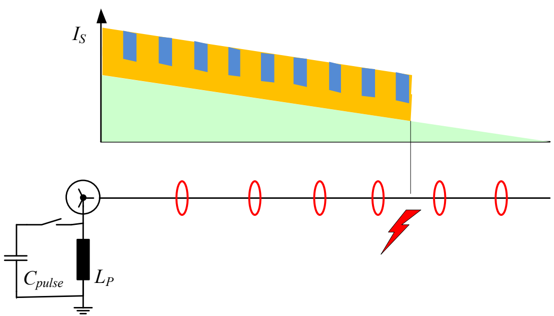

Fig. 2 Principle of the standard pulse method, over-compensated grid

There are some additional requirements for a correct operation of the standard pulse-method:

- **Very low ohmic earth fault**

In case of a higher ohmic earth fault the voltage-drop over the earth-impedance is changing with the change of the current via the fault location. Due to this behaviour also the zero-sequence voltage in the whole network is changing. The further consequence is that also the zero-sequence current in a healthy feeder is changing. Now it is not so easy to distinguish between a faulty feeder and the healthy feeder. The change of the zero-sequence current in a large capacitive current can be larger than the change in the faulty feeder. This problem can be reduced by using an asymmetric pulse length as shown in Fig. 3, for example switch on of the capacitor for 1.0 second and followed by a pause of 1.5 seconds.

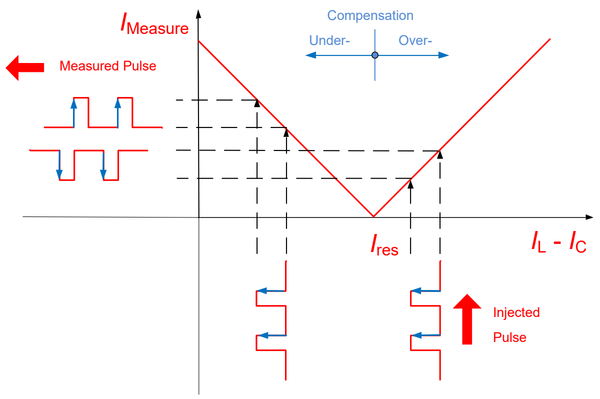

Fig. 3 Asymmetric pulses for the case of high ohmic earth faults at the fault location as function of the compensation

- **The network must be overcompensated**

If this requirement is not full-filled there is a spot on the feeder without an r.m.s-pulse. According to the search strategy a wrong segment will be defined to have the earth fault.

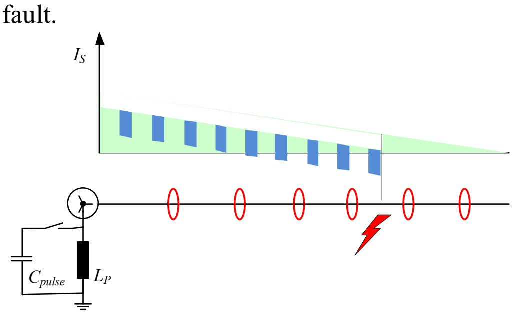

Fig. 4 Blind spot due to wrong compensation

- **Only small wattmetric-current via the fault location**

Due to the wattmetric current the well-known V-curve at the fault location is modified to a hyperbolic curve as shown in Fig. 5. Due to this the amplification of the pulse near to the resonance-point is reduced. To get the correct faulty segment an overcompensation of about double of the wattmetric current as a minimum is required.

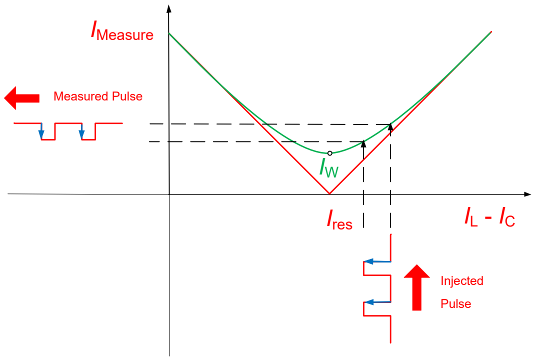

Fig. 5 Reduced amplification of the pulse near to the resonant-point due to wattmetric current

- **Only small harmonics in the zero-sequence current**

As the pulse is measured as r.m.s-value existing harmonics in the zero-sequence currents hide the pulse as shown in Fig. 6.

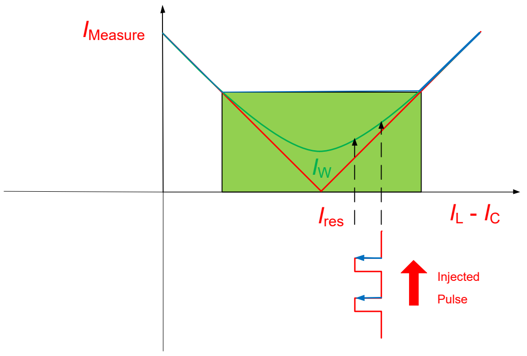

Fig. 6 Hiding of the pulse due to harmonics in the zero-sequence current

- **Only small networks**

Due to the increase of the capacitive currents the current via the fault location is increasing. To fulfil the requirements for the step-voltage and the self-distinguishing of the arc, the current via the fault must be reduced. Therefore the overcompensation cannot be increased to any size.

- **No change of the network-configuration during the measurement**

- **The fault must be more or less constant for about 25 s to detect usually 5 pulses out of 7 pulses**

- **Only earth faults on radial feeders can be identified with r.m.s-pulses. There is no correct indication on loops**

The zero-sequence-current-pulse is splitted into two currents flowing from the pulse-generator to the fault location. Therefore the amplitude at the measurement-points is reduced. As the measurement is done as r.m.s-values no directional information is available. It is not possible to identify the faulty segment on the loop.

As a consequence of the explained problems, it is necessary to improve the standard pulse method for today's networks.

PULSE-METHOD USING THE COMPLEX PLANE

If the zero-sequence current is determined in terms of amplitude and angle, then the transfer characteristic becomes a straight line above the complex plane. The distance to the complex plane corresponds to the active part of the zero-sequence current.

Using a 50 Hz DFT, which is necessary to determine amplitude and angle of $\underline{I}_0$, the filtering is done automatically.

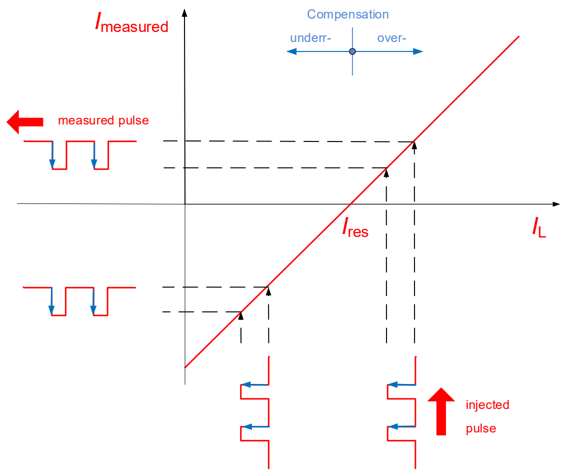

Fig. 7 Reduced amplification of the pulse near to the resonant-point due to wattmetric current

The standard pulse method has no directional information and cannot be used in loops.

With the new method there is additionally a direction information included, regardless of the type of compensation. The reason for the directional information results from the behaviour, that the connecting of the capacitor causes that the capacitive component of $\underline{I}_0$ is increased. It is always a movement in direction of an isolated network.

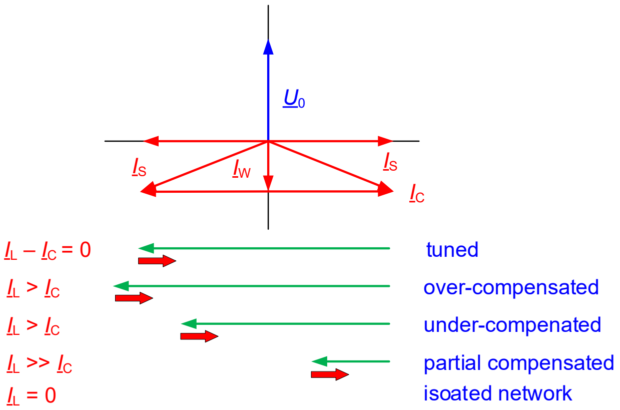

Fig. 8 Direction of the capacitive pulse not depending on the different types of compensation

The standard pulse-indicators can only use the actual measured value of I_0. The sensitivity is therefore in the range of fault-impedances of about 200 Ω. In the new method the $\underline{I}_0$ current is recalculated for a solid earthfault. Therefore the sensitivity of the indicator is **increased up to 5 kΩ earthfaults**.

DIRECTIONAL PULSE-METHOD IN LOOPS

The following figures show the comparison of the signalisation of the pulse indicators using the standard non-directional pulse method (circle) and indicators using the new directional pulse method (arrow). In Fig. 9 the operation mode is open loop and the operation mode in Fig. 10is closed loop.

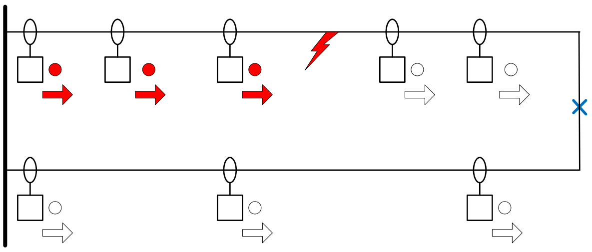

Fig. 9 Open loop configuration

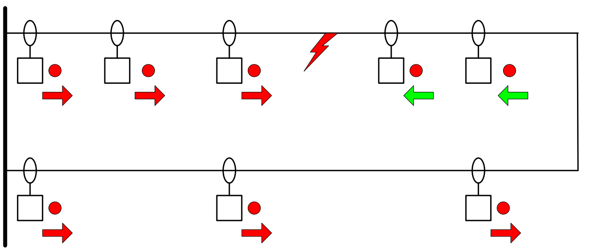

Fig. 10 Closed loop configuration

Fig. 11 Example for an indicator with evaluation of $\underline{I}_0$ in the complex plane

COMPLEXE PULSE-METHOD USING THE PETERSEN COIL

However, injection-based methods require an injection device, installed at the primary substation. In the past the switching of a capacitor in parallel to the Petersen-Coil was used. Today it is possible to use faster thyristors for the switching of parallel inductivities.

But the easiest way is to move the already existing Petersen-Coil during the earthfault. More or less all coils are designed for this operation. The movement can be like one pulse or like a half pulse (movement only in one direction). The necessary movement lies in the range of few A_prim, therefore the time for the necessary movement is in the range of few seconds.

EARTHFAULT DISTANCE ESTIMATION

There exist some algorithms [12], which enable a distance estimation in case of an earthfault. They all need a change of $\underline{I}_0$ in the range of more than 30 A. With tuning the Petersen-Coil no additional power-component is necessary.

Some new pulse-indicators can recognize, that there is an earthfault and start with the supervision of $\underline{I}_0$. They are able to detect the minimum required change of $\underline{I}_0$ for distance estimation and trigger this new function.

SUMMARY

In this contribution we have discussed the different effects reducing the applicability of the standard pulse method based on the r.m.s measurement of the zero-sequence current.
The new proposed method, based on injection of a signal, includes the following features:

- **Directional identification** of the faulty feeder during the steady state of the earthfault
- Works **also in loop configuration** of the feeders
- Works for fault impedances up to 10 kΩ
- Is **repeatable** during the steady state operation
- **No overcompensation** of the network is required
- **Works also with decentralized Petersen-Coils**

- Estimation of the distance of the single-line fault distance during the steady state of the earthfault

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