FAST SELECTIVE EARTH FAULT LOCALIZATION USING THE NEW FAST PULSE DETECTION METHOD

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ABSTRACT

Secure and reliable earth fault localization is a challenge for today's protection engineers. New standards, regulations and grid expansion lead to increased demands on grid operation management especially for fault localization. As a result new methods and techniques for fast earth fault localization and detection are required. The earth fault localization should be performed as quick as possible and under the condition, that the fault current at the fault location will not be significantly increased, to avoid additional damages and hazards for human life and health.
One of the most used methods for earth fault localization is the traditional pulse detection method. This detection method is widespread because the implementation is simple and only a current measurement is needed. With the installation of more than one relay along a line a simple in-depth localization of the earth fault is possible.
In this paper a new and fast fault localization method based on a thyristor-controlled high-power-current-injection (HPCI) will be presented. Compared with traditional pulse detection, this method has a lot of advantages, which will be described in this paper.

INTRODUCTION

The "resonant earthing" 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], [2], [3] and [9]. 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 during normal operation level is mainly due to the reduced capacitance unbalance of the cables. Furthermore, the cables have smaller dielectric 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 of the "resonant grounding" 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, this improves the power quality. Problems arise for the selective detection and localization of earth faults, because the fault current is low. The conventional relays are designed only for non-intermittent low ohmic earth faults and for non-meshed grids.
In [3] and [4] 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 1 kOhm
- Parallel lines with asymmetrical serial impedances in the phases
- Restriking 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].

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:

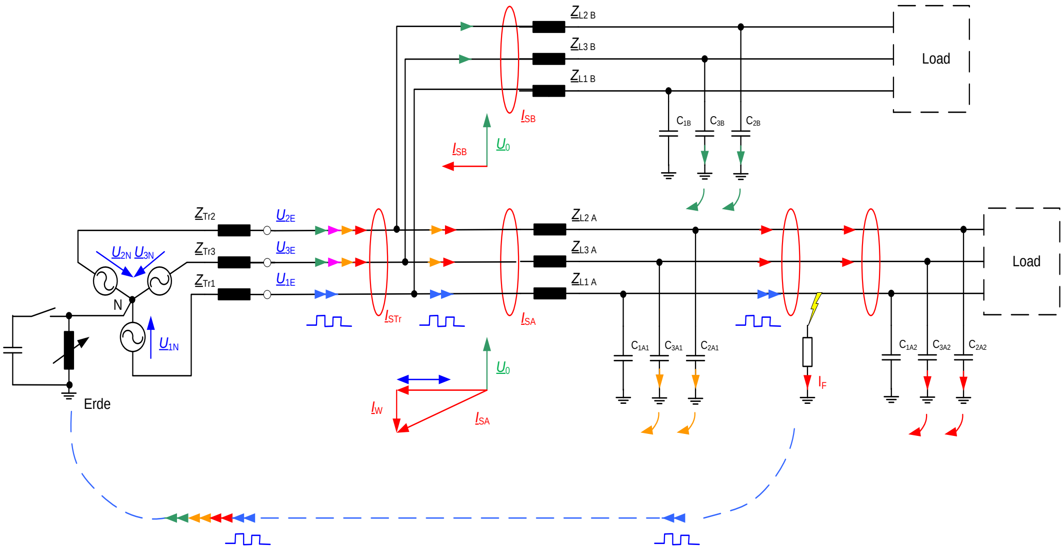

Fig. 1. Compensated network with the standard pulse method

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.

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

a) 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.

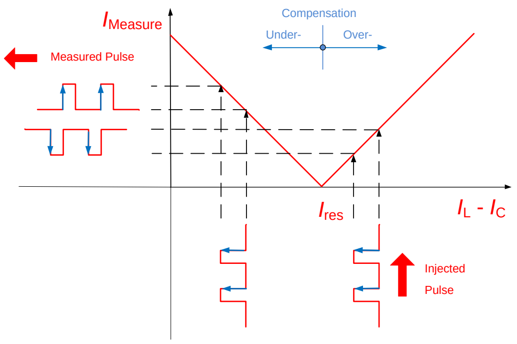

Fig. 2 Asymmetric pulses for the case of high ohmic earth faults at the fault location as function of the compensation

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. 2, for example switch on of the capacitor for 1.0 second and followed by a pause of 1.5 seconds.

b) 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.

c) 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. 3. 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.

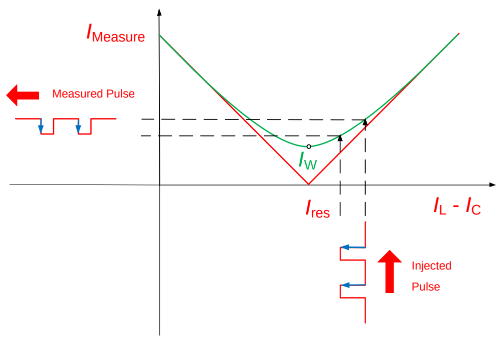

Fig. 3. Reduced amplification of the pulse near to the resonant-point due to wattmetric current

d) 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. 4.

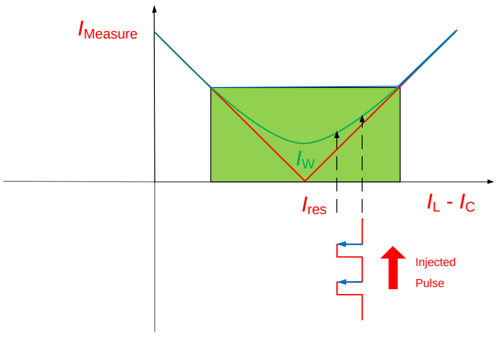

Fig. 4. Hiding of the pulse due to harmonics in the zero-sequence current

e) 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.

f) No change of the network-configuration during the measurement

g) The fault must be more or less constant for about 25 s to detect usually 7 pulses out of 10 pulses

h) **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 split 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.

INJECTION OF FREQUENCIES IN THE ZERO-SEQUENCE-SYSTEM

In [5], [6] and [7] the injection of frequencies in the zero-sequence system in order to improve the control of Petersen Coils in case of very symmetrical networks, respectively for networks with not negligible crosstalk from load-current to the zero-sequence system, was presented.
The current injection is designed to generate different pulses in the zero-sequence-system of the healthy network. The following Fig. 5 shows one possible pattern of pulses for the current injection.

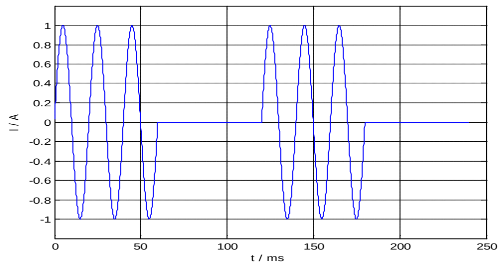

Fig. 5. Sample pulse pattern for control operation

For the control operation of the Petersen Coil the frequencies unequal to 50 Hz in the zero-sequence current and zero-sequence voltage are used for the parameter estimation of the zero-sequence system of the healthy network [5]. The injection is only active in the healthy network and it is blocked during an earth fault.

FAST PULSE METHOD

To generate fast pulses for the earth fault localization the same concept of the previous chapter can be used. The difference is that the current injection has to be done during the earth fault and with a much higher current. Normally the injected current should be in the range of 1 A to 5A on the primary side.
A cost optimized version of a **H**igh-**P**ower-**C**urrent-**I**njection (HPCI) is shown in Fig. 6. The HPCI is using directly the power available at the Power-Auxiliary-Winding (PAW) of the Petersen-Coil.

During the healthy state of the network Th1 and Th2 are switched off and Th3 and L1 are used for the control of the Petersen Coil, as explained above.
In case of an earth fault Th3 is switched off immediately and the parallel switching of Th1 and Th2 is used to generate the requested pulse pattern. The injected current is limited by the coils L1 and L2. An additional modulation of the injected current is available via the ignition point of the thyristors.

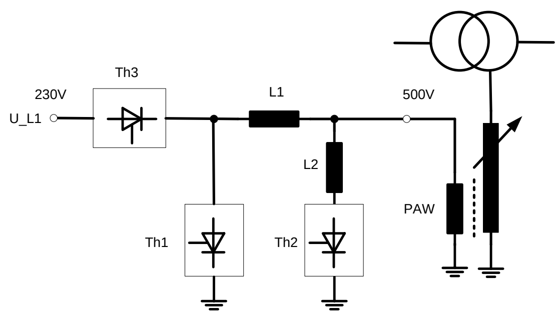

*Fig. 6. Cost-optimized **H**igh-**P**ower-**C**urrent-**I**njection for*
- Fast Pulse Method
- tuning of the Petersen-Coil in healthy very symmetrical network
- tuning of the Petersen-Coil in healthy networks with crosstalk from load current to the zero-sequence voltage

Fig. 7 presents a real High-Power-Current-Injection for a 20 kV-network and a maximum current injection current of 2 A on the primary side.

Fig. 7. Realized thyristor controlled High-Power-Current-Injection (HPCI)

One additional advantage of this concept is that also the necessary pulses for the standard pulse-method can be generated. Using special pulse patterns and their corresponding filters, it is possible to detect the pulses in the zero-sequence current. Due to the evaluation of frequencies unequal to 50 Hz it is not more necessary to make an overcompensation of the network.

Extensive simulations and real field tests have shown that with this method the following main advantages can be fulfilled:

- Results of localization available within a second
- No over-compensation required
- No influences through the 50 Hz wattmetric current
- Reduced influences through crosstalk from the load current to the zero-sequence-system
- Reduced influences through harmonics in the fault current
- Directional earth fault localization in rings without voltage measurement
- Reduced demands on the angular accuracy of the current transformer

This type of generator can also be used for "mobile" earth fault localization with the procedure presented in [10]. This method is based on additional tracing current injection with a non-grid-frequency and detection over a magnetic-field sensor in close vicinity of the line.

FIELD TESTS

During very extensive field tests in the 20-kV-network of the utility KELAG [12], [13] the fast pulse method was tested with different impedances at the fault location. The fault-impedance of the 20-kV-network with a capacitive current of 115A was varied between 0 Ω and 10 kΩ.

Fig. 8. Field test with 10m OHL-conductor lying on ground, 20kV-network, Ice = 115 A, 30 A overcompensation

Using only the current measurements the fast pulse-method worked up to a fault-impedance of 100 Ω over the whole tuning-range of the Peterson-coil of 20 A to 205 A. Up to an impedance of 300 Ω the method is working, if the detuning is less than 30 A.

The directional signalisation of the fast pulse method using only the current measurement was successfully verified.

Using the zero-sequence-voltage as additional information it was verified, that the fast-pulse-method worked up to 10 kΩ and that it is more or less independent of the detuning.

Due to the use of pseudo-random-binary signals (PRBS) of the injected current and the use of corresponding matched filters, the unwanted operation of the fast-pulse-method can be reduced dramatically, especially compared to the standard pulse-method. The tests confirmed the reliability of these methods for stationary earth faults and for OHL lying on ground.

One of the results of these field tests was that the fast-pulse-method is not working during restriking earth faults. The influence of the injected current is too small compared to the restriking current-spikes. But for the case of restriking earthfaults the qui-method [4] respectively the new qui3-method provide very good results.

CONCLUSION

In this contribution we have discussed the different effects reducing the applicability of the traditional pulse method based on the r.m.s measurement of the zero-sequence current.

To solve these problems a new thyristor controlled pulse-generator was presented to generate well defined short pulses. In the next step this generator was combined with the existing current injection for the control of Petersen Coils. The applied generator is very cost-effective.

Extensive simulations and real field tests have shown that the disadvantages of the traditional pulse generator can be removed. By using this new version, the time for a reliable identification of the segment with the earth fault can be reduced dramatically.

REFERENCES

[1] DIN VDE 0228, *Maßnahmen zur Beeinflussung von Fernmeldeanlagen durch Starkstromanlagen*, 1987.

[2] Druml G., Kugi A., Parr B. *Control of Petersen Coils*, Proceedings XI. International Symposium on Theoretical Electrical Engineering, 2001, Linz

[3] Druml G., Seifert O., Fickert L.: *New Improvements for Transient Relays*, Seminar: Methods and techniques for earth fault detection, indication and location, Aalto University Espoo, Finland, 2010

[4] Druml G., Seifert O., Marketz M.: *Directional Detection of Restriking Earthfaults in Compensated Networks*, CIRED2011, paper 612, Frankfurt, 2011

[5] Druml, G, Seifert, O., Kugi, A.: *New Method to Control Petersen Coils by Injection of Two Frequencies*, CIRED2005, Turin, 2005

[6] Druml, G, Steger, S., Seifert, O., Kugi, A.: *Operational experiences with the new method to control petersen coils by injection of two frequencies*, CIRED2007, Wien, 2007

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

[8] Northcote-Green J., Wilson R., *Control and Automation of Electrical Power Distribution Systems*, Taylor & Francis, Boca Raton, 2007

[9] Poll J., *Löschung von Erdschlusslichtbögen*, Elektrizitätswirtschaft, Jg.83 (1984), Heft 7, pp 322-327, VWEW-Verlag, Frankfurt am Main

[10] Raunig, C., Fickert, L., Obkircher, C., Achleitner, G., *Mobile earth fault localization by tracing current injection*, PQ2010, Kuressaare, 2010

[11] Willheim R., Waters M., Neutral Grounding in High-Voltage Transmission, Elsevier Publishing Company, London, 1956

[12] Tengg C., Schoaß K., Schmaranz R., Marketz M., Druml G.: *Neue Erdschluss-Ortungsverfahren im Praxis-Test*, STE2011,Erfurt, 2011

[13] Tengg C., Schoaß K., Druml G., Schmaranz R., Marketz M., Fickert L.: *Evaluation of new earthfault localization methods by earth fault experiments*, CIRED 2013, Stockholm, 2013