# DIRECTIONAL DETECTION OF RESTRIKING EARTHFAULTS IN COMPENSATED NETWORKS

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## ABSTRACT

*The earth fault signalization and directional detection is one of the most difficult tasks in the area of protection systems.*
*In this paper the behavior of a restriking earth fault in cable networks is investigated in detail. Also the response to restriking earth faults of different conventional earth fault detection algorithms and of the new directional algorithm will be presented.*
*Additionally, the behavior of the algorithms in case of meshed networks, parallel lines, moving of the normally open point in networks operated with open loops will be presented in detail.*
*It will be shown, that with the new algorithm the recognition and the localization of the restriking earth fault in cable networks can be improved dramatically.*

## INTRODUCTION

Conventional earth fault detection relays are designed for low-impedance faults with stationary behavior. They are not designed for restriking earth faults, which especially occur in compensated cable networks.

As a result, the restriking earth fault in cable networks will not be recognized or the healthy feeder will be identified as the faulty one. This dramatically increases the necessary time for the localization of the real earth fault. On the other hand, in deregulated markets, the importance of effective protection of the network increases.

## THE ARC

The arc in compensated networks can be classified as low-current arc. In case of cables the length o f the arc is more or less constant. The evaluation of the behavior of arcs in the real network respectively in the laboratory is very expensive.
Real measurements and research in the past have confirmed that with increasing current via the arc the power conversion, the temperature, the ionization and the conductivity of the arc increases. Additional parameters for the behavior of the arc are the environmental conditions as for example pressure, type of gas, temperature and length of the arc.

At the TU Dresden an arc model was developed, based on the modified Mayr-equation [1][7] and the theorem on the race between dielectric strength.
*Fig. 1* shows the transient recovery voltage $u_e$ after the zero-crossing of the arc-current $i_B$. There is a race between the buildup of dielectric strength of the gap and the recovery voltage imposed by the power system. In case the dielectric strength $u_{z1}$ builds up at a rate faster than the recovery voltage $u_e$, the extinguishing of the arc is successful; otherwise the arc restrikes and the extinguishing becomes unsuccessful as shown with the characteristic $u_{z2}$ .
Independent of this, in cables there will be a restrike, whenever $u_e$ crosses the restriking voltage $u_W$. The restrike voltage $u_W$ is not a constant and depends on the actual environment of the plasma before the extinguishing, various parameters of the cable and the fault geometry.

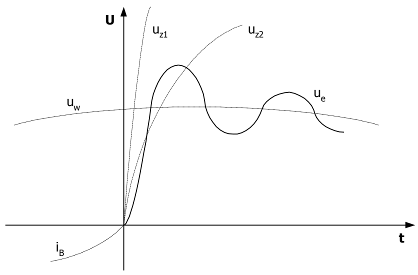


*Fig. 1: Transient recovery voltage $u_e$ and the restrike voltages $u_{z1}$, $u_{z2}$ after the zero-crossing of the arc-current $i_B$*

Due to the thermal capacity and the thermal conductivity, the AC-arc has a thermal inertia, which can be described with a thermal time constant. Therefore the distribution of temperature and conductivity of the arc follows with a time delay. The result is a hysteresis in the u-i-charateristic of the arc, as depicted in *Fig. 2*.

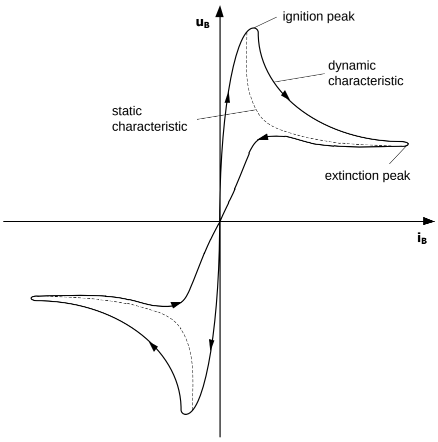


*Fig. 2: u-i-characteristic of the AC-arc*

The research at the TU Dresden is based on the double modified Mayr-equation (1), which is based on both parameters: Converted power and thermal time constant. [8][6][9]

$$\frac{1}{g}\cdot\frac{dg}{dt}=\frac{1}{\tau(g)}\cdot\left(\frac{u\cdot i}{P_{ab}(g)}-1\right) \qquad (1)$$

In a well compensated network the current via the fault location is in the range of few amperes, this means in the range of 2 A … 30 A. The burning voltage of this arc is in the range of 30 V to 60 V [4]. This means, in compensated networks with a well tuned Petersen Coil, the power generation is very low. In case of overhead lines, this enables a complete successful extinguishing of the arc, without any action of a protection system or intervention of personal in the control-room.

In pure cable networks the advantage of the Petersen-Coil is less, but in any case it reduces the current via the fault location dramatically and improves the personal safety.

## RESTRIKING EARTH FAULTS

The following figures are related to a well compensated network according to *Fig. 3* with the following data:

Resonance-point $I_{CEres}$ = 90 A
Active current of the network $I_w$ = 2.5 A
3 feeders: A,B,C
Restriking earth fault in feeder A in phase $L_1$

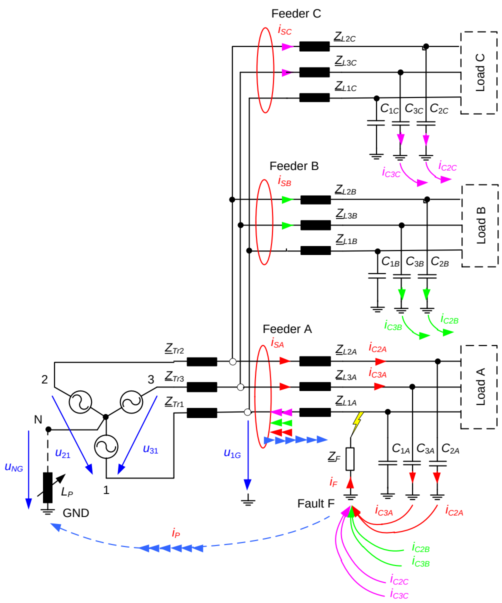


*Fig. 3: Investigated Compensated network*

The measurements were done at the fault location (F) and in the substation at the faulty feeder (A) and at the healthy feeder (B).

*Fig. 4* shows the behavior of a restriking fault: The voltage $u_{L1}$ is not zero during the whole earth fault. The low current arc extinguishes within few milliseconds at the zero-crossing of the current. As the investigated network is a compensated network, the phase voltage $u_{L1}$ increases slowly. The increase of the voltage in a cable network goes up to the restriking voltage, which is in the range between 2 kV and 6 kV in a 20 kV network. This restriking voltage depends on different parameters and is not constant, neither during an earth fault.

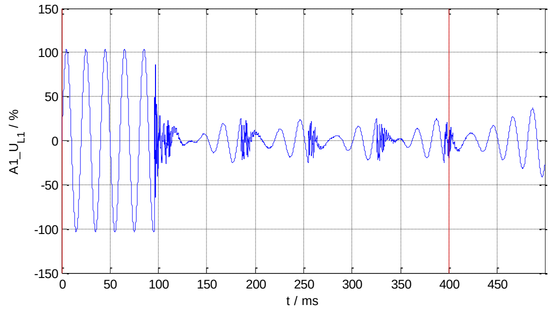


*Fig. 4: Voltage $u_{L1}$ measured at the bus-bar*

As the measurements in SCADA-systems are based on averaged rms values over 200 … 1000 ms, a restriking earth fault will not be recognized as restriking earth fault. This type of fault would be always classified as high impedance earth fault. Later on we will show, that the conventional relays are not working correct with the restriking earth faults. Due to this fact and due to the knowledge, that a high impedance earth fault could only occur in the part of an overhead line, the fault localization by the dispatcher will normally start in a complete wrong area in mixed networks.

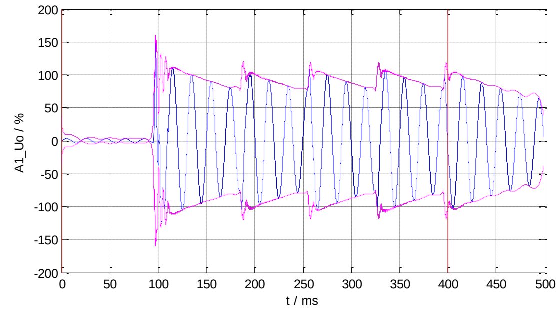


*Fig. 5: Envelope of the voltage $u_0$*

From *Fig. 5* and *Fig. 6* we see the following items:

- Zero-sequence-voltage $u_0$ does not reach 100%
- Between the restrikes, the network is healthy, but with displaced neutral-point
- Zero-sequence-voltage $u_0$ does not fall below the earth fault threshold voltage during the restriking fault
- At the moment of restrike the envelope of $u_0$ increases
- The first direction of the restriking current at the fault location depends on the actual voltage in phase L1 and not on $u_0$

The following figures show the zero-sequence-current at different measurement localizations: Fault location F, healthy feeder B in the substation and the faulty feeder A in the substation.

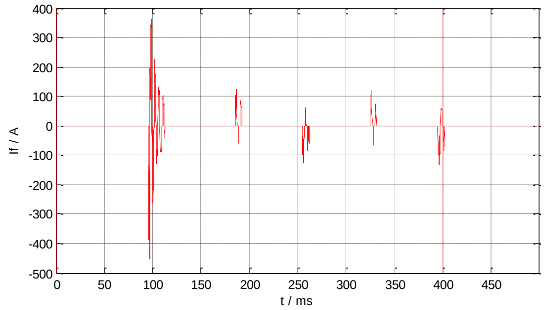


*Fig. 6: Current via the fault location F*

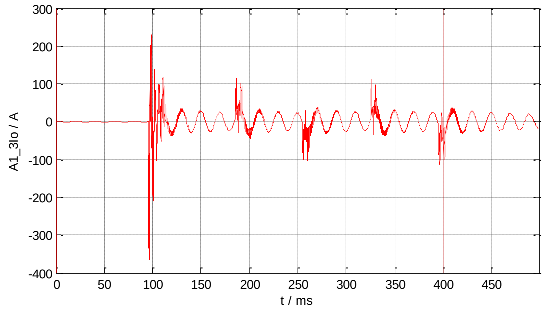


*Fig. 7: Zero-sequence-current $i_{0A}$ measured in the substation at the faulty feeder A*

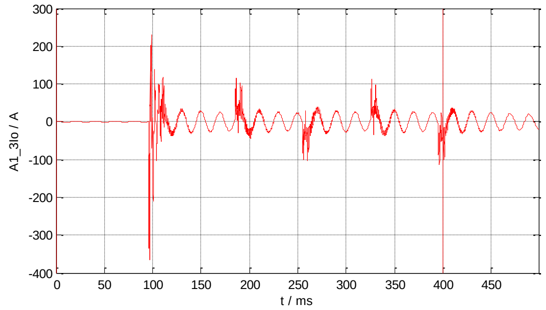


*Fig. 8: Zero-sequence-current $i_{0B}$ measured in the substation at the healthy feeder B*

**Cos(φ) – method ( wattmetric )**

The cos(φ) method is usually based on the 50 Hz DFT respectively FFT transformation [2]. It is important, that these transformations are **assuming** a **stationary state** of the fault, which is not true in case of a restriking earth fault. For the following figures a moving DFT calculation over a time range of 20 ms was used to calculate $\underline{I}_{0x}$ per sample. For each calculated sample the corresponding $\underline{U}_0$ and the projection of $\underline{I}_{0x}$ on $\underline{U}_0$ as $I_W$ for the records from *Fig. 6* up to *Fig. 8* was evaluated. This wattmetric currents $I_W$ are shown in *Fig. 9* up to *Fig. 11*.

For a network with a wattmetric current of about 2.5 A the threshold for the protection relays would be set to about 0.5 A. Using these threshold, the evaluation in *Fig. 9* up to *Fig. 11* shows, that the direction is only depending on the moment of evaluation. The chance to get the correct direction is about 50 %, also in the healthy feeder.

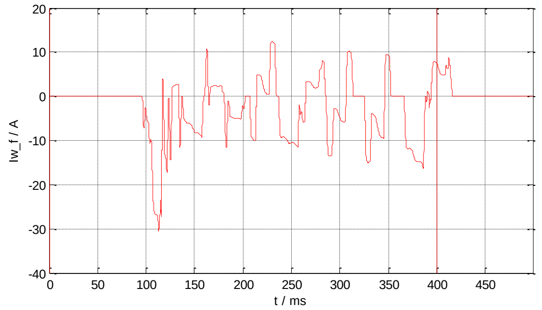


*Fig. 9: 50 Hz - active current at the fault location*

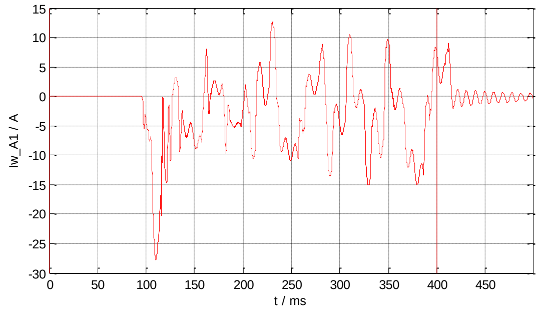


*Fig. 10: Wattmetric component of zero-sequence-current $i_{0A}$ measured at the substation at the faulty feeder A*

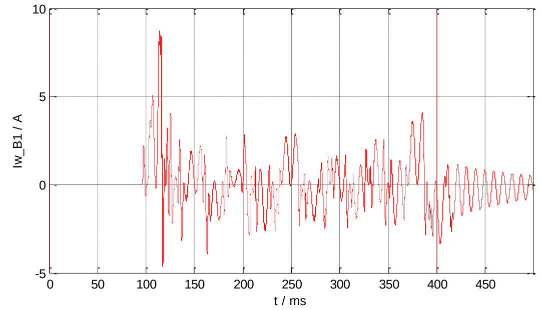


*Fig. 11: Wattmetric component of zero-sequence-current $i_{0B}$ measured at the substation at the healthy feeder B*

**Sin(φ) at 250 Hz ( 5th Harmonics Method)**

The evaluation shows, that this method is working correct. However, further limitations of this method have to be taken into account during earthfault engineering.

Some limitations are for example [3]:

- Serial resonance effects in mixed networks: High serial inductivity of overhead lines in series with the high capacity of cable networks
- Small values of the harmonics in the line-to-line voltages
- Day-time dependence of the harmonic voltages
- Cross-talk of load current to the zero-sequence system in meshed networks

### Pulse Method

The pulse-method is based on different currents via the fault location due to modification of the value of the Petersen-Coil with a sequence in the range of seconds. The influence of the value of the Petersen-Coil on the transient charging-current in case of a restriking earth fault is very small. This small influence cannot be detected using the standard measurements.

### qui Method

The qui-method is the qu2 method [3] evaluated continuously, not only in the range around the beginning of the earth fault.

The qu2 method is based on the definitions according to the space-vector-theory [5]. For example, for the healthy feeder B or C, as shown in *Fig. 3*. of our network, the charging can be described with equation (2) respectively (3).

$$u_0(t) = u_0(t_0) + \frac{1}{C_{eq}} \int_{t_0}^{t} i_S(\tau)\ d\tau \quad (2)$$

$$u_0(t) = u_0(t_0) + \frac{q_S(t)}{C_{eq}} \quad (3)$$

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

$$u_0(t) = \frac{q_S(t)}{C_{eq}} \quad (4)$$

Drawing a diagram of this relation(4), with the charge $q_0$ 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 this feeder.

In restriking feeders this behaviour is only valid during the healthy period between the restrikes, as shown in *Fig. 12* for feeder A.

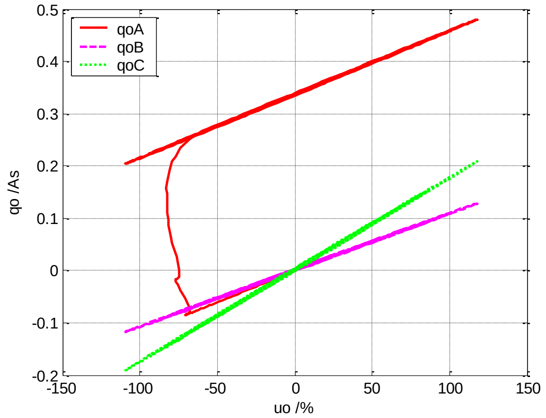


*Fig. 12: qu-diagram of a restriking fault*

## PARALLEL LINES AND MESHED NETWORKS

In the paper [3] the problems of Holmgreen measurements for the zero-sequence-current, parallel lines and meshed networks on stationary earth fault methods and on the qu-methods were presented in detail.
In case of a restriking earth fault, the described influences from [3] are less, as with the qui-algorithm the charging current of the two healthy feeders are evaluated.

In general the requirement for the qui-algorithm can be shortened to the statement: As long as the charging currents are higher than the virtual currents from the cross-talk of the load current to the zero-sequence-system, the qui method is working without problems.

## HARDWARE REALISATION

In the meantime the presented algorithms qu2 and qui are, for example, implemented in the new combined short-circuit and earth fault signalization relay EOR-3D. These algorithms are implemented in parallel to standard earth fault detection algorithms and some other new methods.


*Fig. 13: EOR-3D with implemented qu2 and qui*

## CONCLUSION

This paper shows that the directional signalization of a restriking earth fault is one of the most difficult tasks.

The wattmetric method, which is based on DFT or FFT transformation, is not able to deliver valid directional signalling.
Also the pulse-method as non- directional method cannot be used.
The restriking earth fault can be described as a nonlinear system. Normally the use of methods, which are assuming stationary states, is not possible for nonlinear earthfaults. To get correct directional signalizations, it is necessary to use methods which evaluate the zero-sequence-voltages and zero-sequence-currents during the restrike, for example the qui-method. A further advantage of the qui-method is, that the signalization is also correct during the time of localization of the point of fault by moving the sectioning point.
In order to improve the earth-fault localization it is recommended, to separately display the signalization of transient-relays, relays for directional restriking faults and relays using stationary methods in the control-room.
This enables the dispatcher to make the correct decisions during the localization of the point of earth fault also in case of restriking earth faults. Due to the increase of cable-networks also the number of restriking earth faults is on the rise.

## REFERENCES

[1] Cassie, A. M., 1939, "Arc rupture and circuit severity: a new theory", *CIGRE-Bericht* Nr. 102

[2] Druml G., 2009, "Neue Methoden zur Erdschluss-eingrenzung", *ETG Fachtagung STE2009: Sternpunktsbehandlung in Verteilnetzen – Stand, Herausforderungen, Perspektiven*, Berlin

[3] Druml G., Klein R.W., Seifert O., 2009, "New adaptive algorithm for detecting low- and high ohmic faults in meshed networks", *CIRED*, paper 631

[4] Fiedler H., 1991, "Anwendungsschranken der Resonanzsternpunkterdung in Kabelnetzen", *ELEKTRIE,* Berlin no. 45

[5] Herold G., 2002, Elektrische Energieversorgung III, J. Schlembach Fachverlag, Weil der Stadt, Germany

[6] Höpfner, S; Schegner, P; Seifert, O; Zickler, U, 2007, "Modellierung von frei brennenden Erdschluss-lichtbögen", *ETZ,* no. 3, page. 62-67

[7] Mayr, O., 1943, " Beiträge zur Theorie des statischen und dynamischen Lichtbogens", *Archiv für Elektrotechnik*, vol. 37, no. 12

[8] Schwarz, J ,1972, "Berechnung von Schaltvorgängen mit einer zweifach modifizierten Mayr-Gleichung", *ETZ-A*, vol. 93, no. 7

[9] Zückler, K., 1978, "Untersuchungen zum dynamischen Verhalten von Schalterlichtbögen", *ETZ-A,* vol. 99, no. 9