EARTH FAULT DISTANCE LOCALIZATION IN INDUCTIVE EARTHED NETWORKS BY MEANS OF DISTANCE PROTECTION RELAYS

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ABSTRACT

Earth fault location in inductive earthed networks is often limited to know at which feeder the earth fault is present. In order to reduce the time to locate the fault point it is desirable to get an information about the fault distance. With conventional distance protection devices it is usually not possible to calculate the fault distance satisfyingly.

The contribution describes a method, which improves the conditions for a more exact fault calculation, in theory and shows the first practical application in an existing 20 kV network under normal operation conditions: A field test which started at the beginning of January 2011 should give more detailed information for a possible further use in the future.

Goal have been reached if the calculated fault distance would indicate the fault position within one third of the total length of the feeder.

INTRODUCTION

In electrical networks with inductive earthing of the neutral the localization of the earth fault point doesn't work without additional provisions: The low value of the natural residual fault current especially in case of a higher ohmic fault resistance will not be sufficient to pick-up a distance protection device. Further it is not possible to receive a fault distance calculation.

Usually the earth fault protection and detecting equipment in inductive earth networks can be realized by means of various methods which are available on the market, e.g. sensitive directed earth fault protection, detection on fifth harmonic, pulse-method. The outgoing feeders in a substation have protection devices according the chosen method. If the chosen method works properly the system operator gets only the information at *which* outgoing feeder the earth fault is present. Now he has to start with change-over switchings (commutations) in the grid in order to locate the earth fault position.

Some utilities use distance protection devices at the outgoing feeders in the substation for protection of phase-phase- and cross-country-faults. In case of a fault usually they are able to send a fault distance value to the system operator e.g. the primary reactance Xprim (in Ω) or the distance (in km). Due to the experience in cases of phase-phase-faults the calculated fault distance is very close to the fault position in the grid (± 10 %).

As stated above the localization of the earth fault point by means of a distance protection device is not possible without additional provisions. In order to reduce the time to localize the earth fault position it is desirable to receive a *fault distance value* in this case also. It would be convenient if the new method will require only small modifications of the already installed distance protection device e.g. firmware update.

PRINCIPLES OF THE EARTH FAULT DISTANCE LOCALIZATION

The principle is based on the injection of an additional ohmic current (also called "pilot current") in the neutral of the network. Therefore an ohmic resistor is connected in parallel with the reactor (Petersen coil) for the inductive grounding:

If an earth fault occurs after a defined time (e.g. 3 s) the additional resistance will be inserted automatically for a short time (e.g. 0,3 s). During that period and the resistor is switched on the distance protection device gets the possibility to registry an earth fault with a measurable current and distance calculation will be triggered. In order to get an usable, improved value of the fault distance, a distance relay with a modified algorithm for the fault distance calculation must be used, as stated in the chapter below.

FAULT DISTANCE CALCULATION

Conventional

Normally the fault distance will be calculated according the following scheme:

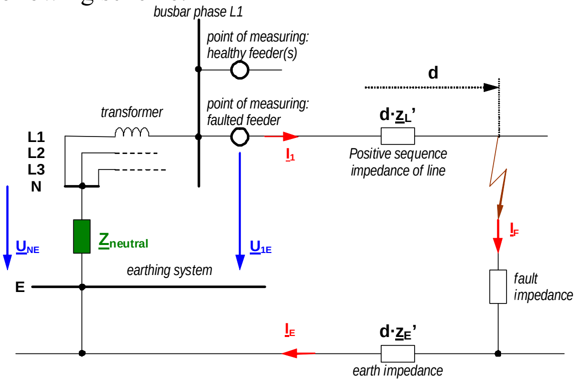


fig. 1 loop and measuring values for the calculation of the fault distance

Measured fault impedance $\underline{Z}_{\mathrm{Dist}}$ of the distance relay:

$$\underline{Z}_{Dist} = \frac{\underline{U}_{1E}}{\underline{I}_1 + \underline{k}_0 \cdot \underline{I}_E} \qquad (1)$$

and therefore

$$X_{Dist} = \mathrm{Im}\left\{\frac{\underline{U}_{1E}}{\underline{I}_1 + \underline{k}_0 \cdot \underline{I}_E}\right\} = x'_L \cdot d \quad \Rightarrow \quad d \qquad (2),$$

with

d … fault distance

and

$\underline{k}_0 = \frac{\underline{Z}_E}{\underline{Z}_L}$ … residual (or neutral) compensation factor (3)

Modified

In practice there are some additional influences in the measuring loop, such as line-earth capacity, earth impedance (resistance) of the substation and fault impedance (resistance). Usually they will be neglected, see formula (1). So the calculation of the fault distance can not give a correct value.

Recent studies at the Institute of Electrical Power Systems of the University of Technology Graz, Austria, resulted in a modified method for calculating the fault distance [1], [2]:

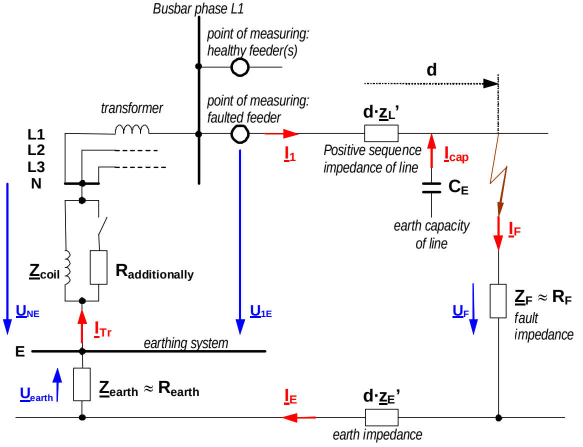


fig. 2 completed loop and measuring value for the calculation of the fault distance

If the earth resistance of the substation

$$\underline{Z}_{earth} \approx R_{earth} \qquad (4)$$

as well as the line-to-earth capacities of the line are known, it is possible to eliminate their influence:

$$\underline{Z}_{Dist} = \frac{\underline{U}_{1E} - \underline{I}_{Tr} \cdot \underline{Z}_{earth} - \underline{I}_F \cdot \underline{Z}_F}{\underline{I}_1 + \underline{k}_0 \cdot \underline{I}_E} \quad . \qquad (5)$$

where:

$\underline{I}_{Tr}$ … current of the earthing system (6)

$$\underline{Z}_F \approx R_F = \mathrm{Re}\left\{\frac{\underline{U}_{1E}}{\underline{I}_E}\right\} \quad \ldots \quad \text{fault resistance} \qquad (7)$$

$$\underline{I}_F = \underline{I}_E - j\,3 \cdot \underline{U}_{NE} \cdot \omega \cdot C_E \ldots \quad \text{fault current} \qquad (8)$$

and therefore:

$$X_{Dist} = \mathrm{Im}\,\{\underline{Z}_{Dist}\} = x'_L \cdot d \quad \Rightarrow \quad d \qquad (9)$$

In substations the impedance of the earthing system is usually low; in consequence the term $\underline{I}_{Tr} \cdot \underline{Z}_{earth}$ is neglectable. Due to formula (5) the fault current $\underline{I}_F$ is not equal to the measured current of the relay $\underline{I}_E$, as given in the simplified model, see formula (1). Now there are two possibilities to find $\underline{I}_F$:

1. Determination by means of formula (8) with using the residual current and the line-to earth capacitance of the faulted feeder. Disadvantage: this correction is valid exactly for one condition only .
2. Obtaining the diagram of the symmetrical component network (fig. 3) it can be stated that the fault current $\underline{I}_F$ is represented by the negative sequence current through the relay $\underline{I}^2_R$:

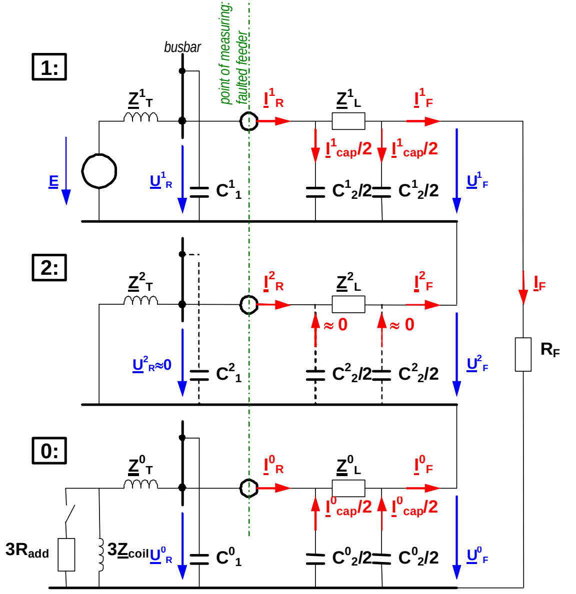


fig. 3 component network of a grid according

where:

Index 1 …	healthy feeder
Index 2 …	earth faulted feeder
Index F …	fault
Index R …	relay
R_F …	fault resistance
$\underline{Z}^{1,2,0}_T$ …	component impedances of network and transformer
$\underline{Z}^{1,2,0}_L$ …	series component impedances of line
$C^{1,2,0}_1$, $C^{1,2,0}_2$ …	shunt component impedances of line

Due to the fact that the component voltage in the negative sequence system is ≈ 0 the shunt currents through the capacities in the negative sequence system can be neglected. This is the reason why the negative sequence current trough the relay $\underline{I}^2_R$ is corresponding with the fault current $\underline{I}_F$ without any disturbing influences.

PRACTICAL REALIZATION

The method described above was tested with simulations and with secondary injection of test values in the laboratory. An implementation in existing distance protection devices, which are available on the market, was not done.

EVN Netz GmbH decided to test the effectiveness of this method in practice, applying it in one of their 20-kV-grids. It was postulated as a basic condition that no simulations or similar should be used. Therefore it was necessary to find manufacturers who where willing to modify the fault distance calculation algorithm in their existing relays according the formulas stated above. Indeed, there were three manufactures found who realized this modified algorithm in their distance protection devices.

With this relays two further steps were done:

1. earth fault test,
2. field test under normal operation conditions.

1ST STEP: EARTH FAULT TEST

The earth fault test was realized in a given 20-kV-network supplied by one 110/20-kV-transformer. It was one of the preconditions that no interruption of supply may occur during the tests.

The 20 kV test grid is operated with inductive grounding of the neutral. For the duration of the test the additional resistor (60 Ω) and a circuit breaker were connected in parallel with the existing reactor.

In order to test the method under different conditions the selected earth fault points were set in branches of the grid with different ratio of cable to overhead line. The three manufacturers prepared one modified test relay each.

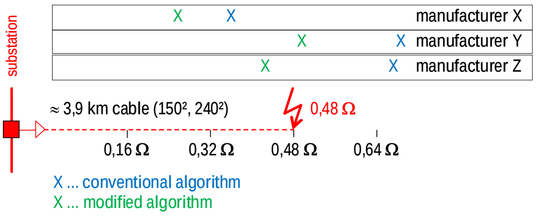
Test #1:

Kind of fault: metallic connection conductor – sheat

Fault resistance: „0“ Ω

Fault current (measured at fault point): ≈ 200 A

Test results: in the table given below the “x” mark the value of the indicated fault distance



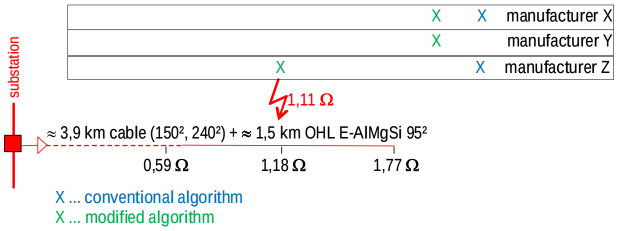
Test #2:

Kind of fault: one conductor connected with earthing system of pole of OHL

Fault resistance: ≈ 60 Ω

Fault current (measured at fault point): ≈ 40 A

Test results: in the table given below the “x” mark the value of the indicated fault distance



Test #3:

Kind of fault: tree

Fault resistance: ≈ ? Ω

Test results: due to the high resistance of the test tree the neutral displacement voltage was much less than the adjusted value of 2,3 kV for triggering the 20-kV-resistor. Therefore the pilot current was only appr. 2,5 Aeff and no fault calculation could occur.

Conclusions of the earth fault test

In general the measured fault distances with the improved algorithm were better than with the conventional method. So this was the reason that EVN decided to continue with a field test.

2ND STEP: FIELD TEST

Preparation

Selection of the test grid:

The service area of the distribution grids of EVN also includes some well known regions with difficult atmospheric conditions such as lightning, rime, heavy snow etc. In such a region a 20-kV-grid was selected for realizing the field test.

Test setup:

Additional resistor and circuit breaker in the neutral were built up as shown in the principle diagram according .

Three feeders were equipped with distance relays with modified algorithm for the fault calculation. These relays were supplied of the same manufacturers who participated at the earth field test. In every test feeder one relay of each manufacturer was implemented. Additionally a digital fault recorder with increased sample rate for busbar voltages and all currents of the involved feeders, the power transformer, neutral transformer, reactor and neutral resistor was installed. With its records each earth fault can be analyzed independent of the fault records of the protection devices.

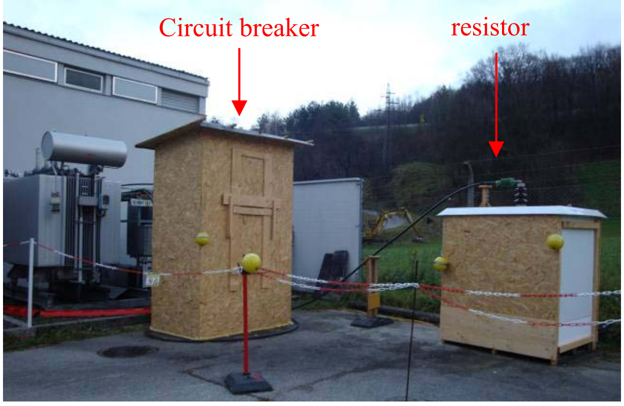


fig. 4 circuit breaker and additional resistor in the neutral of the test grid (both in housing)

Aim

Basically the field test should bring a lot of information and experiences in order to decide if this method could be applied to grids with standard operation in the next future. It would be a success for this method, if the calculated fault distance would indicate the fault position within one third of the total length of the feeder. With this information the system operator and the service personal would be able to locate the real fault position much earlier than now.

Progress

The field test started at the beginning of January 2011. Until the dead line for submitting this paper it is to regret that no earth fault occurred; therefore no indication of the fault distance and an analysis was possible.
Hopefully first results could be presented at CIRED 2011.

Further particulars

Size of the pilot current:

Basically for the pilot current there are two limits existing:

- Upper limit:
  In inductive earthed networks the fault current will be minimized at the fault location. Because of the additional resistor in parallel with the Petersen coil the pilot current generates an additional component of the fault current and therefore increased touch voltages on the earthing impedances. This higher touch voltages must not exceed the limits given in the relevant standards! Note, that the pilot current is active for only a short time (e.g. 0,3 s).
- Lower limit:
  The lower limit is given with the minimum pick-up level of the distance devices even in cases with long fault distances.

For the field test a resistor with 60 Ω was chosen; therefore the maximum pilot current is ≈ 200 A at a system voltage of 20 kV. The analysis of the fault records will show whether this selected resistance is suitable.

Influence of the load current:

It is legitimate that many consideration about protection neglect the influence of the load current, but in this special case it is necessary to obtain the coherence between load current, pilot current and pick-up current of overcurrent protection in the network.
As shown in fig. 5 the load current will add with the fault current in that phase, where the earth fault is present:

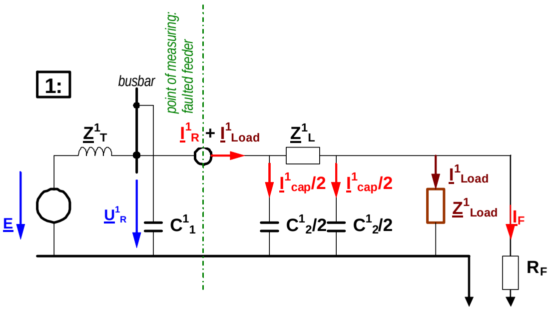


fig. 5 detail of the positive sequence system with load ($\underline{Z}^1_{Load}$)

In other words: the pilot current, which increases the fault current, and the load current will add and the modulus of their geometric sum must be less than the pick-up current of protection devices in the network in order to avoid unexpected disconnections.
In practice it must be possible to find suitable settings which consider this circumstance.

ACKNOWLEDGMENT

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