

Info Letter No. 17

Transient relay for high resistance, intermittent and recurrent earth faults (Part 1)

The statistics show that earth faults constitute a large proportion of network faults. Conventional relays are designed only for low resistance faults under steady state conditions. They are not suitable for high resistance faults that occur especially in rural networks with transmission lines, nor for recurrent faults that occur mainly in compensated cable networks. As a result the earth fault is very often not recognized as the cause of the fault or an incorrect cause is identified. This increases the time required to localise the earth fault. On the other hand, effective protection of the network in a deregulated market is becoming increasingly important.

This newsletter introduces a new algorithm for detecting high-resistance earth faults in the range of several Kiloohms and describes its benefits.

BASICS OF EARTH FAULTS

The behaviour of a single-pole earth fault can be described by superimposing three different operations. While all three operations start at the same time, each of them has a different duration.

The three operations are:

- Discharge of the faulty conductor across earth
- Charging the two healthy conductors across earth
- Stationary state of the earth fault

The explanation of the three operations is done using the network shown in Figure 1, with three outputs (A, B and C) and an earth fault in the conductor 1 of output A.

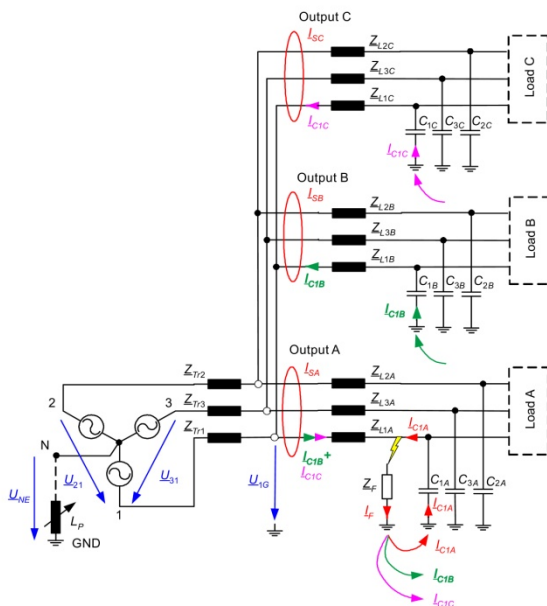


Figure 1 Discharge of the faulty conductor

Discharge of the faulty conductor across earth

The lines can be considered as a distributed network with a complex series impedance Z_{LXX} and a phase-earth capacitance C_{XX} . Most highest probability for the first ignition of the arc is near the maximum of the phase-earth voltage U_{1E} . At this time the load on the conductor is also the largest. The discharge of the conductor 1 begins at the point of failure and spreads like a wave in both directions to the ends of conductor 1. The propagation of the wave to the two healthy conductors is consequently blocked. The effect is also suppressed by a Petersen coil. More often there is a reflection of the wave at the ends of the conductor or at any point with a change of the characteristic impedance, such as in a substation or at a distribution point with a transition from one line to two or more. This reflection can be seen as a high-frequency oscillation in both the zero-voltage and zero-current.

Important parameters for the behaviour of the discharge are:

- Phase-earth capacitance of conductor 1
- Charge state of the phase-earth capacitance before the first ignition of the arc
- Z_L series impedance of conductor 1 in the faulty output and in healthy outputs
- Impedance Z_F at the fault point, which also includes the earth impedance.

The discharge frequency substantially depends on the series impedance and the phase-earth capacitance, which in a first approximation is proportional to the conductor length. The discharge frequency is higher for small networks and lower for large networks. Usually, the discharge frequency is in the range above 10 kHz.

Charging of the two healthy conductors

As a result of the discharge of the faulty conductor, the equilateral voltage triangle is disrupted and the voltage U_{1E} is more or less zero (Fig. 2b).

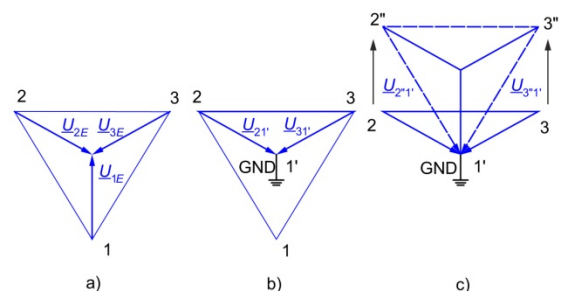


Figure 2 Voltage during the charging process

Since the supply transformer continues to provide a symmetrical three-phase system, the two healthy conductors are charged to the line voltage (Fig. 2c).

In Figure 3, the charging process for a network with three outputs is shown in detail.

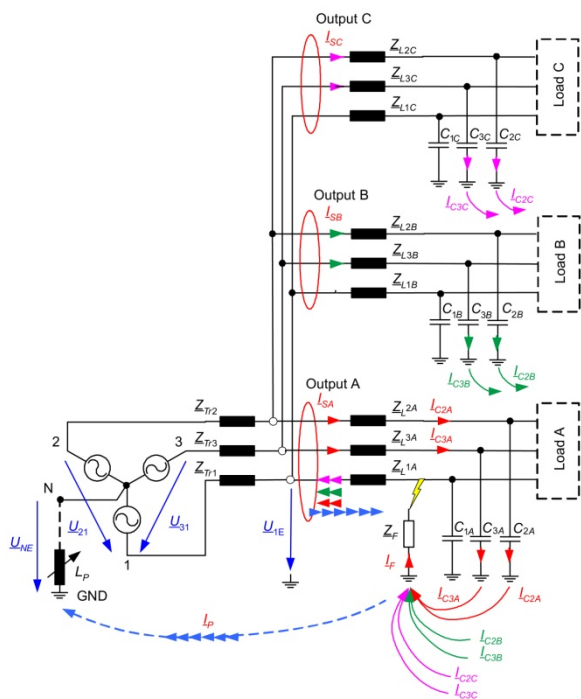


Figure 3 Charging of the two healthy conductors

Important parameters for the behaviour of the charging are:

- Phase-earth capacitance of conductors 2 and 3
- Charge state of the phase-earth capacitance before the first ignition of the arc
- Charging voltage U_{21} and U_{31}
- Leakage inductance of the supply transformer
- Series impedance Z_L of the conductors
- Impedance Z_F at the fault point, including the earth impedance.

As a first approximation, the distribution transformers or the loads can be ignored because they are relatively high resistance. The active load of the consumer is reflected as an additional attenuation of the charge oscillations. If the distribution transformer is operated idle, only its very high impedance main inductance will be active.

The influence of the Petersen coil can be ignored as the inductance of the Petersen coil is considerably higher than the leakage inductance of the transformer.

The equivalent circuit in Figure 4 can be used for the description of the charging process of the two healthy conductors.

For low-resistance earth faults ($Z_f \ll$) the charge oscillations can be approximated by equation (1):

$$f_c = \frac{1}{2\pi} \cdot \sqrt{\frac{1}{L_{eq} C_{eq}}} = \frac{1}{2\pi} \cdot \sqrt{\frac{1}{3 L_{Tr} C_{2E}}} \quad (1)$$

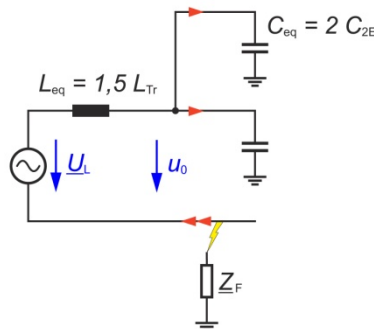


Figure 4 Equivalent circuit for the charging process

The charging frequency f_c is usually in the range from 100 Hz up to several kHz.

With Figure 3, the following statements can be made:

1. Two capacitive currents flow in a healthy output. These currents can be measured as a zero current. The value of the zero current is proportional to the phase-earth capacitance of this output.
2. The sum of the two capacitive charging currents of the healthy output (B and C) must be through the point of failure.
3. The charging current of the faulty output (A) flows through the point of failure and in phase 1 back to the supply transformer. As a result this charging current cannot be determined with the neutral current measurement, The sum of the two currents is zero.
4. The zero current of the fault output is the sum of the currents of all healthy outputs but with the opposite direction. An "inductive" load current is measured instead of capacitive charging current.
5. In a compensated network an overlay of the current is also carried out the Petersen coil. However, the impact is very small at the beginning of the ignition.

Summarising, it can be determined that the relay in the faulty output measures the sum of capacitive output of the healthy outputs and that this current has a reverse direction.

The topic is continued in Part 2 / Info Letter No. 18
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The series will be continued.
 We will gladly supply missing Info Letters at any time!

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