Info Letter No. 6

Detection of transient earth faults

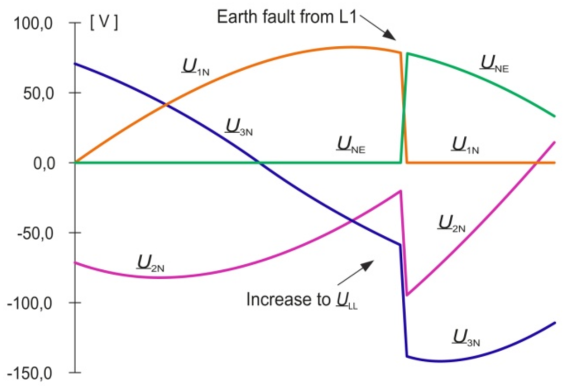
When there is an earth fault in a conductor, at the start of the earth fault three events occur at the same time.

- The voltage $\underline{U}_{1E}$ (phase-earth) of the conductor affected by the earth fault collapses, with a saturated earth fault $\underline{U}_{1E}$ goes to zero
- the zero sequence voltage $\underline{U}_{NE}$ rises abruptly from the operating value (a few volts) to a higher value;

  with a saturated earth fault $\underline{U}_{NE} = \frac{\underline{U}_{primary}}{\sqrt{3}}$
- the capacitance C_{LE} (phase-earth) of the faulty conductor is discharged while the charge state of the capacitances C_{LE} of the two fault-free conductors is also abruptly changed (recharged) (up to $\underline{U}_{LL}$) by the simultaneously varying voltage $\underline{U}_{1E}$

Zero sequence voltage:

The zero sequence voltage $\underline{U}_{NE}$ occurs regardless of the location of the earth fault in the entire electrically connected network in nearly the same way and has the same waveform and frequency as the line voltage. The zero sequence voltage $\underline{U}_{NE}$ is present as long as the earth fault persists.



Filgure 01 *Voltage waveform before and after an earth fault*

Discharge of C_{LE} of the earthed conductor

When there is an earth fault in a conductor, the capacitance C_{LE} of all the lines of the electrically connected network discharge across the earth fault to earth. This process occurs only once immediately after the start of the earth fault and is completed in a short time.

The timing of this discharge current is dependent on the data of the conductor. The ratio of the ohmic resistance to the inductance of the conductor determines the properties of the resonant circuit consisting of these elements. If the inductance is relatively small, the discharge current is an aperiodic, steadily decaying DC; with larger inductance values it is a periodic decaying alternating current.

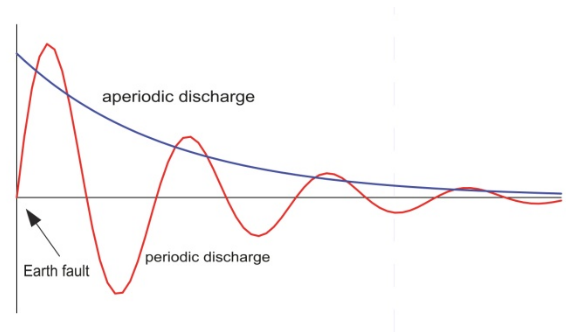


Figure 02 *Typical patterns of the discharge current*

The amplitude of this current surge is dependent on the time of occurrence of the earth fault. If this coincides with the maximum of the half-wave of $\underline{U}_{LN}$, the initial amplitude of the current surge also reaches the maximum and it goes to zero if the fault occurs during the zero crossover.

Discharge of C_{LE} of the fault-free conductor

With the capacitances C_{LE} of all fault-free conductors, the rapidly changed voltage $\underline{U}_{LN}$ (maximum $\underline{U}_{LL}$) starting at the beginning of the earth fault, causes the sudden change of the charge state of C_{LE} and thus also a settling process. All currents flow through the point of failure to the earth and therefore every conductor has the same direction.

Ignition oscillation

The currents flowing at the charge and discharge of the capacitance C_{LE} add up (overlap). This process occurs only once at the beginning of each earth fault, is generally ended after 0.5 s ... 3 s and is called the ignition oscillation. When there is a transient earth fault this current impulse has in extreme cases a duration of less than a half-wave.

The frequencies of the ignition oscillations are different. The empirical values lie between 800 Hz and 2000 Hz for overhead networks, and several hundred Hertz for cable networks.

Earth fault current

With a persistent earth fault an alternating current with the network frequency, which leads the voltage $\underline{U}_{LN}$ by 90° (capacitive current), flows after the end of the ignition oscillation through all of the fault-free conductors and is referred to as earth fault current I_E.

Direction of the discharge current

The current surge resulting from the capacitance discharge always flows from all conductors to the earth fault location. The direction of discharge currents along the conductor before the earth fault location is in the opposite direction to the flows along the conductor after the fault point, because all currents flow towards it.

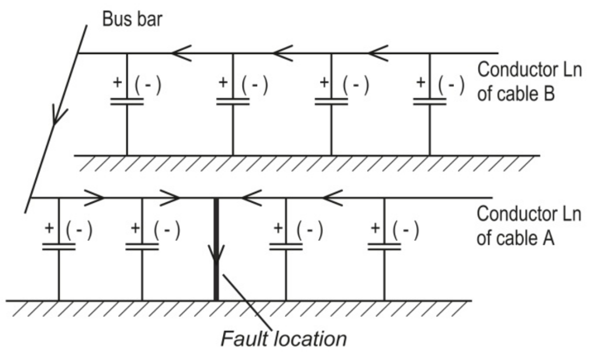


Figure 03 *Direction of the discharge current*

To determine of the location of the fault location in relation to the location of the observer (the direction), one determinant is available; but it is not sufficient on its own for the unambiguous determination of the current flow direction. When using common measurement equipment, the displayed measured value of an alternating current has a positive sign that is always independent of the direction of current flow, so that a second determinant is required for the unambiguous direction determination.

The zero sequence voltage is used as the second determinant. A unique, direct relationship exists between the discharge current and the zero sequence voltage. After the earth fault occurs, the zero sequence voltage changes in direct continuation of the previous course of the voltage $\underline{U}_{LN}$, that has then dropped to zero, so that at least the first half-wave of the discharge current and the associated instantaneous values of the zero sequence voltage always have the same sign (compare Fig. 04).

The current surge that comes from the charge change (recharging) of the two capacitances of the fault-free conductors is a direct consequence of the suddenly changed voltages $\underline{U}_{LN}$. The zero sequence voltage is again in a fixed relationship with these two voltages and thus enables an unambiguous determination of the direction by the comparison of the polarity of the two instantaneous values of the current surge and the zero sequence voltage at the same time, i.e. within a set time frame almost immediately after the beginning of the fault.

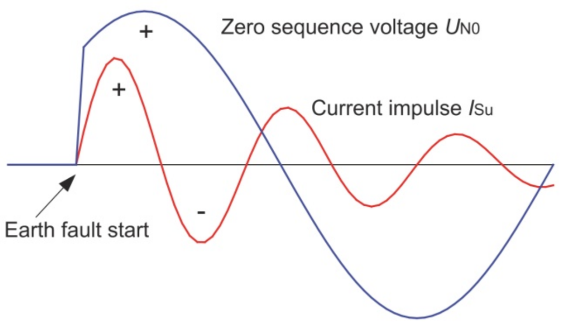


Figure 04 *Zero sequence voltage and current surge*

Location of the earth fault (search direction)

For the direction of the earth-fault current (total current) with respect to the observation location the convention applies that: if at the comparison time, the instantaneous values of the current pulse and the zero sequence voltage have the same polarity, the earth fault is in the direction of the conductor, if the polarities of both values are different, it is in the direction of the busbar.

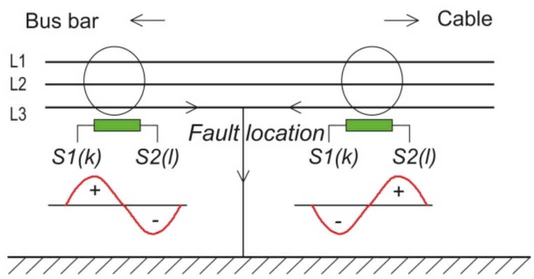


Figure 05 *Determining the location of the earth fault*

While the amplitude and angle (against the x-axis) of the zero sequence voltage is approximately the same throughout the network, the sign of the current surge on the secondary side of the current transformer at terminals k and l depends on the location of the earth fault.

All current transformers are always installed in the direction S1(k) - S2(l) (producer - consumer); the power surge thus flows in all current transformers that are before the earth fault location in the direction S1(k) - S2(l) (from the busbar to the earth fault location) and all current transformers after the earth fault location are in the direction S1(l) - S2(k) (from the conductor to the earth fault location).

The reverse direction of the current flow causes a change in the phase angle of the current of 180° and thus a change in the sign of the instantaneous value of the current surge at the terminals of the current transformer.

Determining the comparison values

The current surge (ignition oscillation) is superimposed on the load currents of the conductors and must therefore be separated from it for evaluation. This separation can be achieved by summing the three phase currents. (Info Letter 05: Summation of Alternating Currents)

The zero sequence voltage is usually measured across the auxiliary winding of the voltage transformer. (Info Letter 06: Zero sequence voltage).

The sign of the product or the result of a comparison of the other two (polarized) values indicates the direction of the earth fault.

Comparison criteria

The comparison assumes specified minimum amplitudes of current and voltage, because a zero sequence voltage caused by asymmetry in the network and short-term current surges can have causes other than an earth fault. Likewise, a comparison is not possible if the earth fault occurs in the region of the zero crossing of the voltage U_{LN}. Experience shows, however, that such cases occur almost never.

To avoid uncertainties due to small amplitudes or noise voltages, the comparison must be somewhat delayed and start a short period of time after the start of ignition oscillation and still be completed well before the end of the first half cycle.

Transient earth fault relay

For adaptation to the respective network data and for assess the earth faults detected, the earth fault relay must have a variety of features.

Sensitivity (minimum value of the amplitude)

The threshold value of the zero sequence voltage and the total current must be adjustable to avoid false positives due to interference.

Minimum duration of the earth fault, signal output delay

It must be possible to trigger an error message, either instantaneous and independent of the duration of the earth fault or only if the duration of the earth fault exceeds a selectable time delay. After an earth fault with a duration shorter than the selected delay time, the neutral output state will be restored automatically.

Message selection conductor/busbar

It must be possible for earth fault messages for the direction of the busbar to be reset or suppressed.

Display of the last transient earth fault

At each new transient earth fault associated with a change in direction of the earth-fault current, the display must also change without the relay being reset first manually or by a signal. (retriggerable)

Display of the first transient earth fault

The message remains displayed after the occurrence of the initial transient earth fault until this message is acknowledged; subsequent transient earth faults will not be reported. (not retriggerable)

Duration of the message, reset

The message must remain until it is cleared by an instruction (manual or external signal) or automatically after a specified time interval.

Author: Helmut Karger

The series will be continued.
We will gladly supply missing Info Letters at any time!

Issue: 03-2013 / I006-1-D-1-001-04