Earth-Fault Protection in a Resonant-Earthed System

1. General earth-fault information

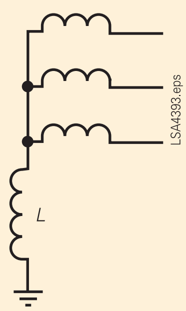
In a resonant-earthed power system an earth fault is not a short-circuit, but an abnormal operating state. It must be signalled and corrected as quickly as possible. The way in which the earth fault is identified depends on the configuration of the network. In a radial system, sensitive earth-fault direction measurement with sine φ measurement is used; in a meshed system the transient earth-fault measurement is preferred.

In the case of an earth fault with no resistance, e.g. in phase L3, the voltage $U_{L3\text{-}E}$ drops to zero and the voltages $U_{L2\text{-}E}$ and $U_{L1\text{-}E}$ increase to the $\sqrt{3}$-fold value. A displacement voltage $U_{E\text{-}N}$ accumulates. This is also referred to as zero-sequence voltage (U_0). Under normal operating conditions it has the value of the phase-to-earth voltage.

The capacitive earth-fault current at the fault location is compensated by the inductive current from the Petersen coil so that the active current at the fault location is very small. A residual resistive current remains and is determined by the ohmic part of the coil. It is in the order of magnitude of 3 % of the capacitive coil current. The $U_{E\text{-}N}$ voltage is evaluated for signalling the earth fault.

The U_0 voltage can be calculated from the phase voltages or it can be detected via the voltage transformer open delta winding (e–n delta). This winding generally has a greater ratio in the region of factor $\sqrt{3}$. In the case of an earth fault, the measuring-circuit voltage is thus approximately 100 V. A voltage relay for earth-fault detection is set at 25 – 30 V, and a time delay of 5 s is appropriate. This functionality is included in line protection relays 7SJ5.., 7SJ6.., 7SA5.. and 7SA6 depending on the configuration chosen. If the relays are equipped with three transformer inputs a phase-selective earth-fault alarm can also be produced. $U \leq 40$ V serves as the criterion for recognizing the defective phase and $U \geq 75$ V for the fault-free phase.

Fig. 1 Transient earth-fault relay 7SN60



- Earth fault = No short-circuit
- Operation continues
- Earth fault must be signaled and corrected as quickly as possible
- Earth-fault location with watt-metric earth-fault direction measurement or transient earth-fault relay

Fig. 2 Resonant-earthed system

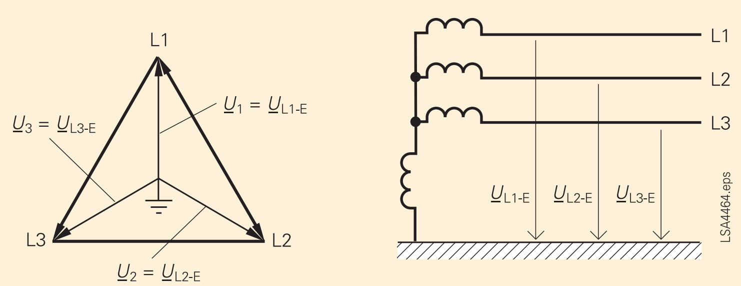


Fig. 3 Voltages in normal operation

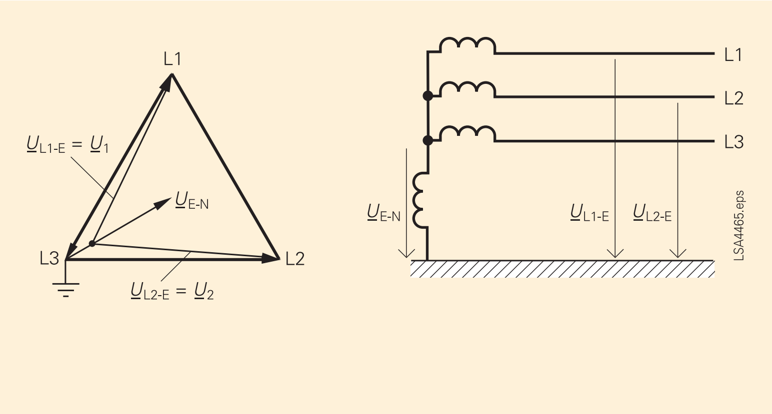


Fig. 4 Voltages for earth fault L3

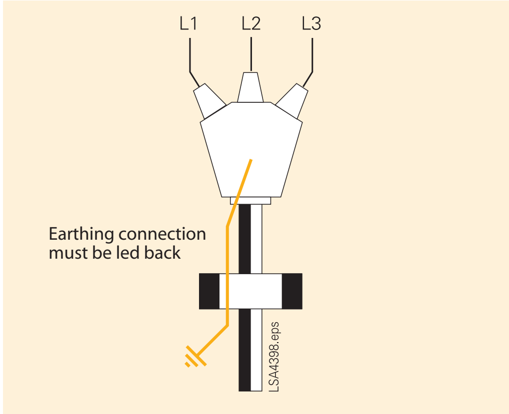


Fig. 7 Core-balance current transformer

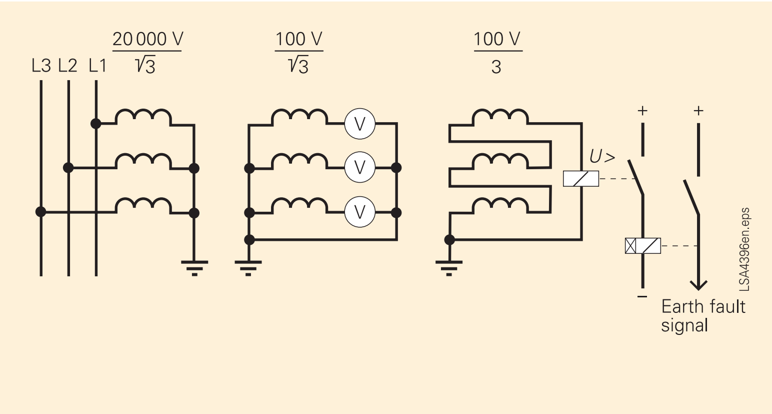


Fig. 5 Voltage transformer with open delta winding

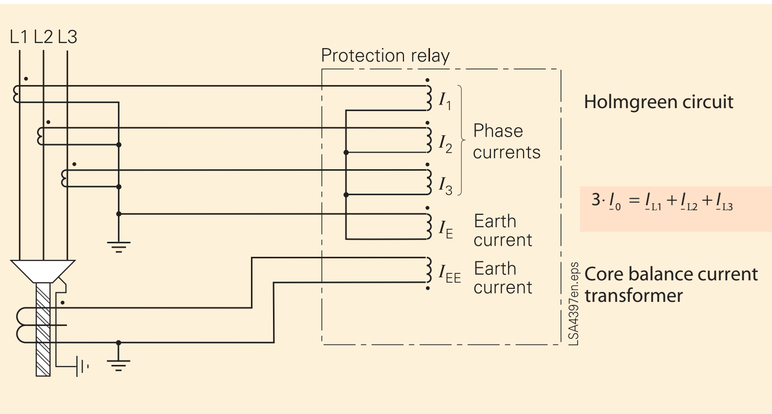


Fig. 6 Connection of currents

Two methods can be used to measure the flowing earth current.

The *Holmgreen-circuit* adds the three phase currents (by means of appropriate connection of the current transformers) and thus provides the earth current. However, because each transformer has a fault, this measurement method is not suitable for the small residual resistive currents in a resonant-earthed system. The second method, the *core-balance current transformer* is available for such cases. This delivers definitely better values for earth-fault detection. It is important to ensure that it is assembled with precision. In the case of cut-strip wound transformers it is essential that the core surfaces lie directly on top of each other. It is also critically important that the cable screen earthing is led back through the transformer so that the sum of the phase currents can actually be measured.

■ 2. *Watt-metric earth-fault direction detection with cos φ measurement.*

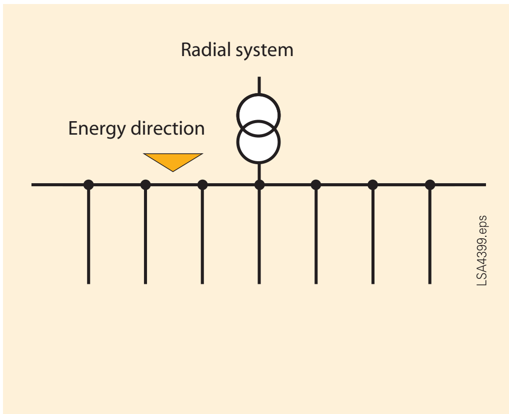


Fig. 8 Radial system

Watt-metric earth-fault direction measurement is only appropriate in the radial system. If it is used in a meshed system, meaningful results can only be expected after switching over to radial lines.

Capacitive currents			
Overhead line	20 kV	~	0.05 A/km
	110 kV	~	0.30 A/km
Cable	10 kV	~	1.5 A/km
	20 kV	~	3.0 A/km
	110 kV	~	20.0 A/km

The network's capacitive current can be estimated by using the table or values given in cable manuals. Alternatively, the value can be read from the coil.

<u>Example:</u>

Current
Petersen coil with a rated current of 200 A, momentarily adjusted to 180 A.
We can assume a capacitive earth-fault current of 180 A. If we estimate the residual resistive proportion at 3 %, 5.40 A is the result. This is transformed by the core-balance current transformer at 60:1, and 90 mA consequently arrive at the protection relay. The pickup value should then be set at approximately 50 mA. In the case of an earth fault only the healthy parts of the system continue to provide an earth-fault current; therefore the pickup value must always be lower than the maximum earth-fault current.

Voltage settings:
Attention must be paid to the voltage settings as follows:

- Displacement voltage: value in the case of earth fault: $100\ \text{V}/\sqrt{3}$
- Measured voltage at the open delta winding (e-n winding): value in the case of earth fault: 100 V
- Threefold zero-sequence voltage $3U_0$: value in the case of earth fault: $100\ \text{V}\cdot\sqrt{3}$.

For connection to the e-n winding, a pickup value of $U_{e-n}> = 25$ V is usual. For setting tripping values for the (calculated) displacement voltage, $25\ \text{V}/\sqrt{3}$ is recommended. The proposed pickup value for $3U_0$ is $25\ \text{V}\cdot\sqrt{3}$.

Earth-fault report time delay: $t = 5$ s

Voltage setting for phase-selective earth-fault detection:
Affected phase $U \leq 40$ V
Healthy phases $U \geq 75$ V

Type of measurement
Cos phi

Earth-fault detection
Signal only (disconnection following an earth fault is not usual)

Fig. 9 shows an example of how watt-metric indication of the earth-fault direction detection could look in a specific case. It is important to note that

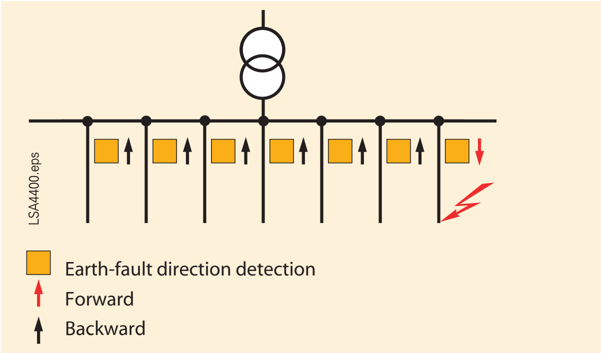


Fig. 9 Earth fault in radial network

not all the unaffected circuits (or in the worst case scenario none of them) indicate backward. If the active component of the partial current being delivered to the earth-fault location is lower than the limit value set, no direction indication occurs. However, because of the voltage ratios, the earth fault is recognized by all relays and the general earth-fault signal is given. For remote reporting the message "earth fault" <u>must</u> be transmitted once from the galvanically connected system. From the individual feeders it is advisable only to transmit the message "earth fault forward". If the feeder with "earth-fault forward" message is disconnected, the earth-fault message will be cleared.

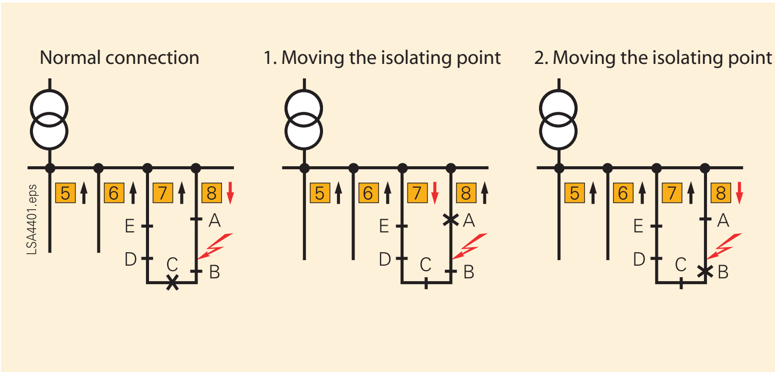


Fig. 10 Searching for the earth fault in a ring system

If the line affected by the earth fault is an open ring with several sectioning points, it is possible to identify the earth faulted section by moving the isolating point.

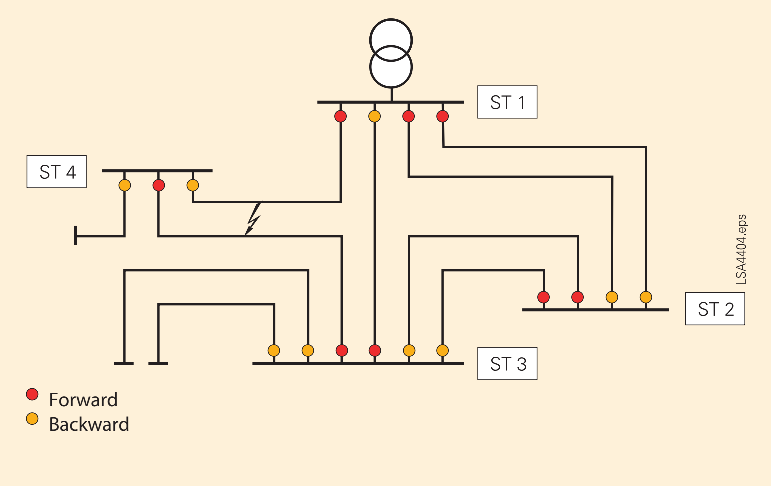


Fig. 11 Transient earth-fault relay indications

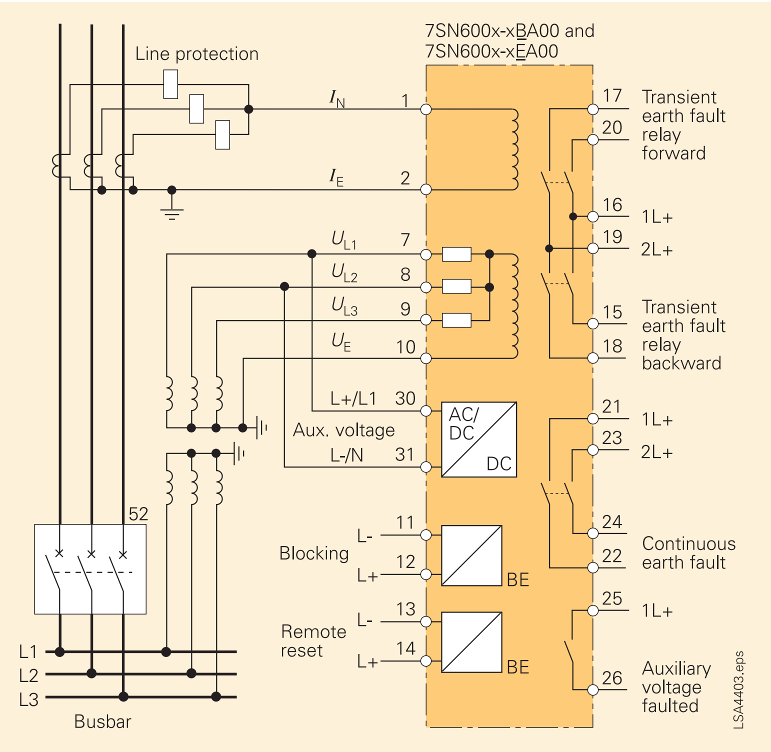


Fig. 12 Transient earth-fault relay connection

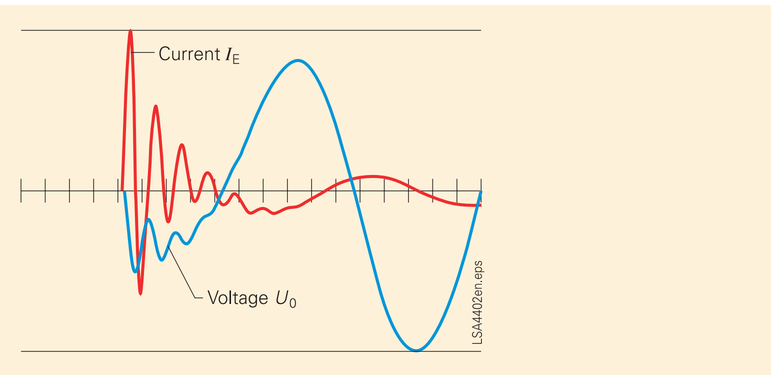


Fig. 13 Transients in an earth fault

Example in Fig. 10:
Normally the isolating point is situated at C. An earth fault has occurred and relay 8 has reported "forward". If the isolating point is now moved from C to A, which can be done (by load disconnection switches) with no interruption to supply, the relay 7 indicates "forward". The section A – C is thus affected by the earth fault. If the isolating point is now moved to B, the relay 8 once again indicates "forward". Thus section A – B is clearly affected by the earth fault.

3. Earth-fault direction detection with the transient earth-fault relay 7SN60

If the system is meshed, no clear direction indication can be obtained with watt-metric relays. The current direction in the case of an earth fault cannot be definitely detected. Good locating results are achieved using transiente earth-fault relays. These relays work with the charge-reversal process, which occurs with the earth fault. The capacity of the phase affected by the earth fault is discharged to earth and the healthy phases are charged up to the higher voltage value. This charge-reversal produces a large current, amounting to a multiplication (threefold or fourfold) of the capacitive current. The transient earth-fault relays are thus always connected to the Holmgreen-circuit. It is important to be aware that the charge-reversal process only occurs when the earth fault appears, i.e. just once. Repeat measurements following switching therefore have no meaning and lead to confusion.
In order to identify the circuit affected by the earth fault in a meshed system, an indication is required from both ends of the line. Both relays must indicate in a "forward direction". It is therefore advisable to transfer the signals from the transient earth-fault relay onto an image of the system. It is then possible to decide quickly where the earth fault is located.

In Fig. 11, the fault is located in the middle line from ST 4 to ST 3, since here both relays are indicating "forward".

4. Summary

Operation can be continued when an earth fault occurs in a resonant-earthed power system. The fault can be located as described above. The operator should quickly separate the fault location from the system. Thus a double fault (which – as a short-circuit – would cause a supply interruption) can be avoided.