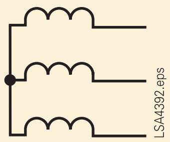
Earth-Fault Protection in Systems with Isolated Star Point

■ 1. General earth-fault information

In a system with isolated star point 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 system. In a radial system, sensitive earth-fault direction detection with sine φ measurement is the method; in a meshed system the transient earth-fault relay 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 $U_{E\text{-}N}$ appears. This is also referred to a zero-sequence voltage (U_0). In normal operation it has the value of the phase-to-earth voltage. A purely capacitive earth-fault current flows at the fault location. This can create very unstable arcs. In general, isolated systems operate up to a capacitive earth-fault current of 50 A. The $U_{E\text{-}N}$ 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 V – 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 provided. $U \leq 40$ V serves as the criterion for recognizing the defective phase and $U \geq 75$ V for the fault-free phases.

Fig. 1 Transient earth-fault relay 7SN60



- Earth fault = no short-circuit
- Operation continues during single earth fault
- Earth fault must be signaled and corrected as quickly as possible
- Earth-fault location with wattmetric earth-fault direction measurement or transient earth-fault relay

Fig. 2 Isolated system

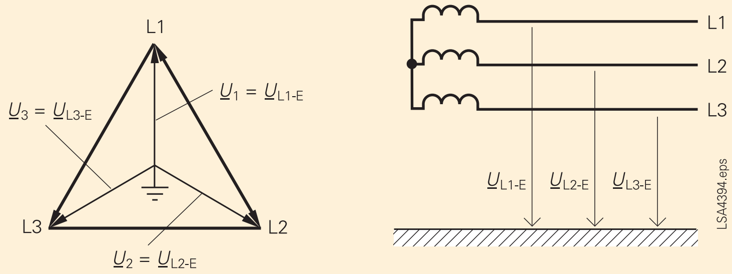


Fig. 3 Voltages in normal operation

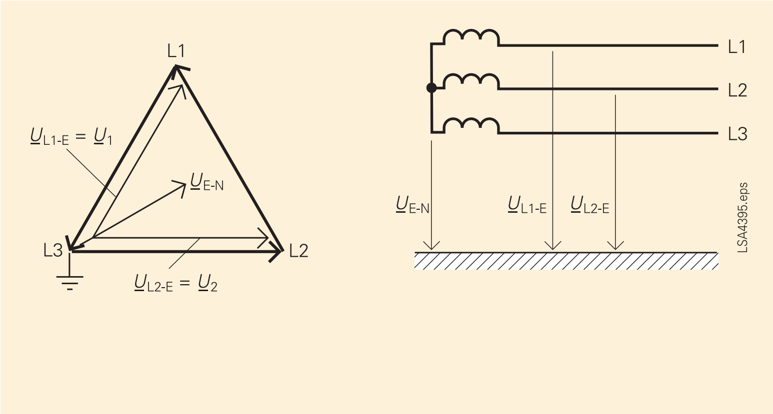


Fig. 4 Voltages for earth fault in phase L3

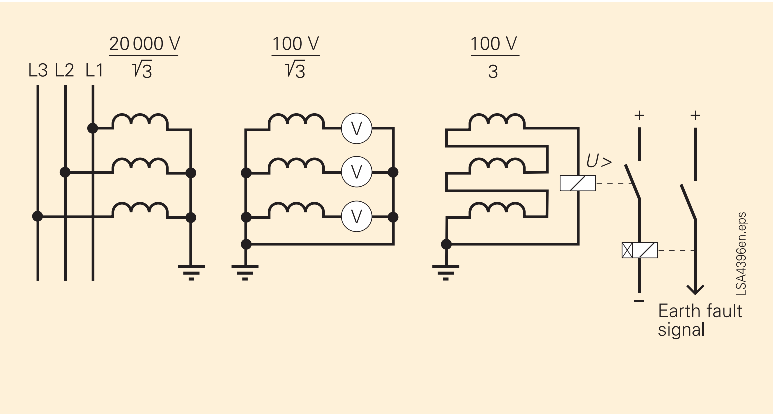


Fig. 5 Voltage transformer with open delta winding

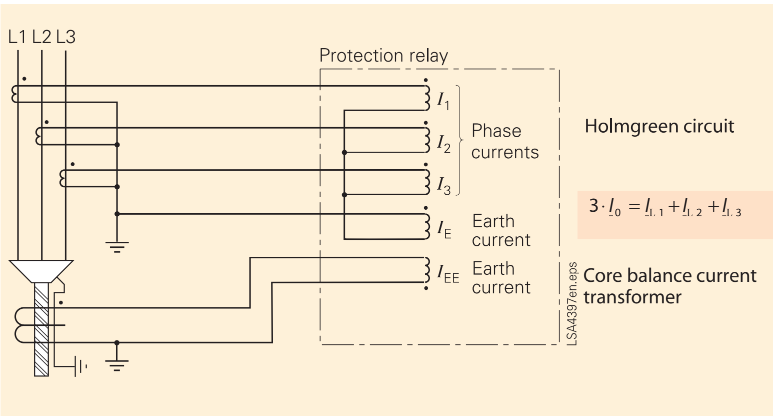


Fig. 6 Connection of currents

Two methods can be used to measure the 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 always an error of measurement, this method for measuring the earth current is only suitable in systems with higher earth-fault currents (> 40 A) and

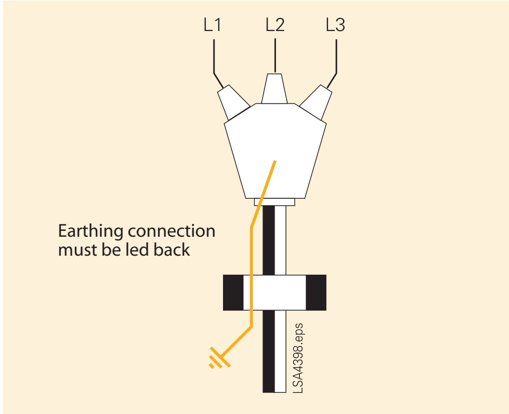


Fig. 7 Core-balance current transformer

a not excessively high ratio of the transformers (<150/1 or 150/5). The second method, measurement with a *core-balance current transformer*, can be used for smaller earth currents. It delivers better values for sensitive earth-fault detection. It is important to ensure that the transformer 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 earthing connection of the cable screen earthing is led back through the transformer so that the sum of the phase currents can actually be measured (see Fig. 6 and 7).

■ 2. *Sensitive earth-fault direction detection with sine φ measurement*

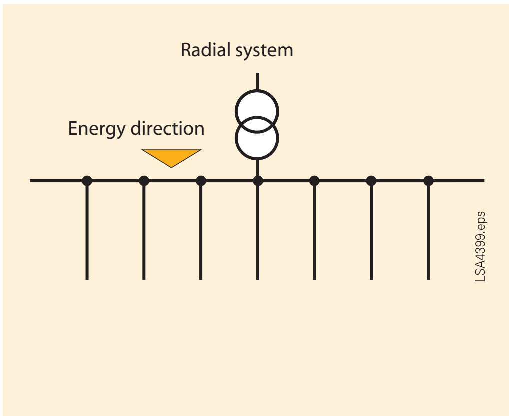


Fig. 8 Radial system

Earth-fault direction measurement is only applicable 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 system capacitive current can be estimated by using the table or values given in cable manuals.

Example to determine I_E

Current
30 km 10 kV cable, 1.5 A/km
I_E = 1.5 A / km · 30 km = 45 A

Holmgreen-circuit, ratio of the main current transformer 200/1
Earth current at the protection relay 225 mA
Setting I_E> 150 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. In an exact calculation the value of the longest line section plus a safety margin must be subtracted from the maximum.

Voltage settings:

Attention must be paid to the voltage settings as follows:

- Displacement voltage: value in the case of earth fault: 100 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 V· $\sqrt{3}$.

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

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
Sine phi

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

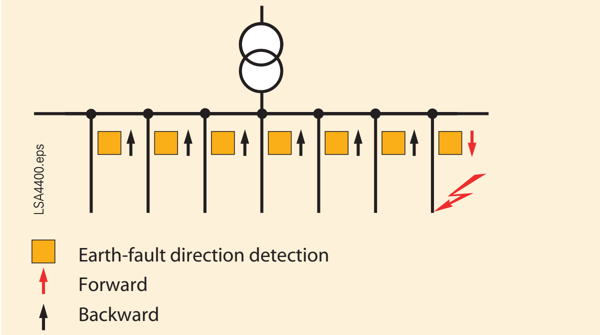


Fig. 9 Earth fault in radial system

Fig. 9 shows an example of how the indication of earth-fault direction detection could look in a specific case. It is important to note that not all the unaffected circuits (or in the worst case scenario none of them) indicate backward. If 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" must 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.

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.

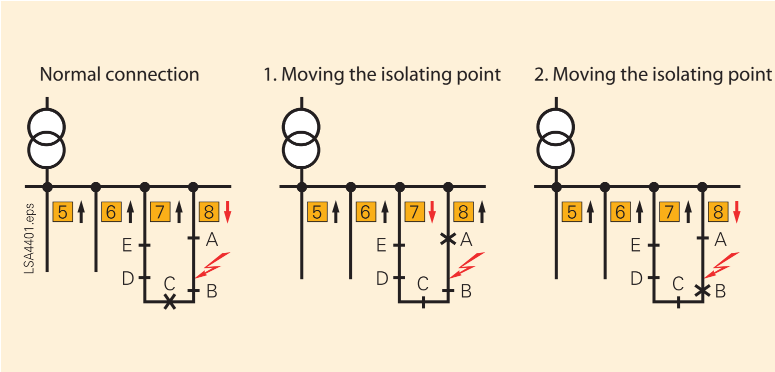


Fig. 10 Searching for the earth fault in a ring system

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) 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.

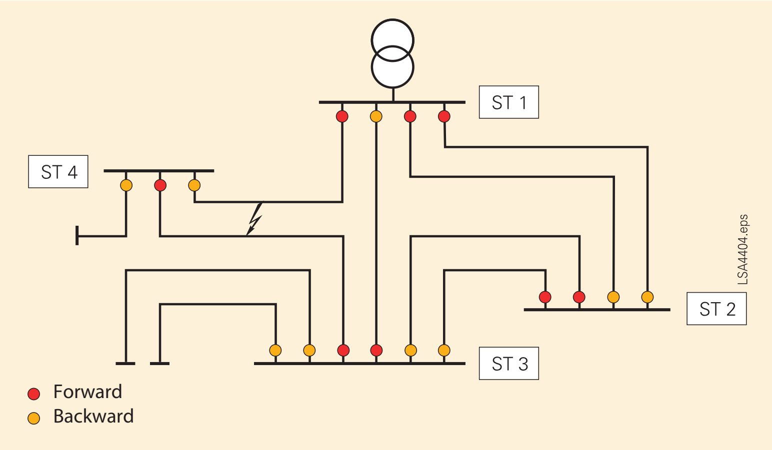


Fig. 11 Transient earth-fault relay indications

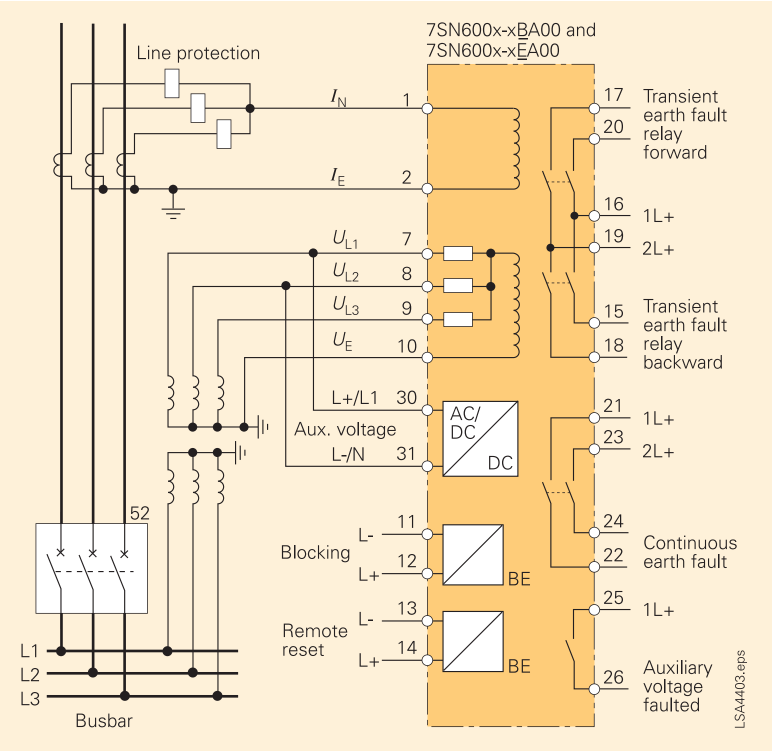


Fig. 12 Transient earth-fault relay connection

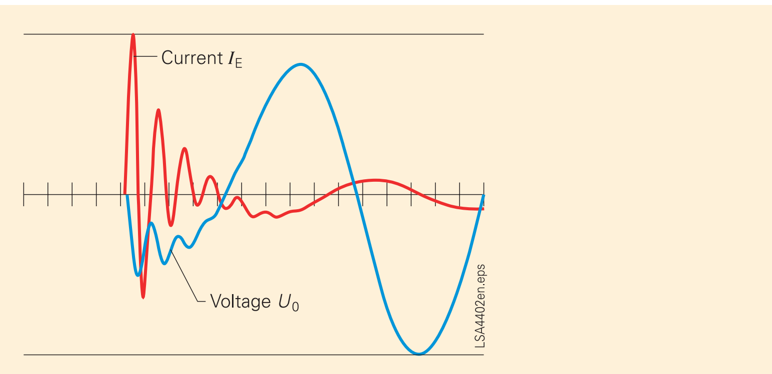


Fig. 13 Transients in an earth fault

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

If the system is meshed, no clear direction indication can be obtained from the sine φ measurement. The current direction in the case of an earth fault cannot be definitely detected. Good locating results are achieved using transient earth-fault relays. These relay 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 power system with an isolated star point. 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.