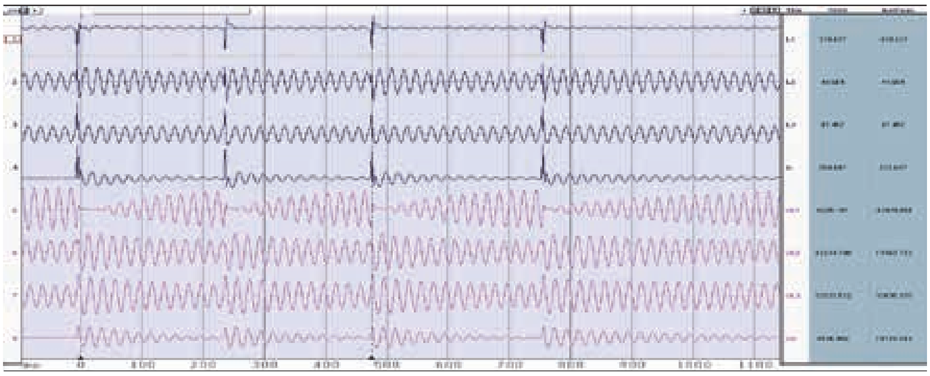
Earth science

A new digital earth-fault detection method improves reliability

ARI WAHLROOS, JANNE ALTONEN – Temporary earth faults cause the majority of outages in power networks. Compensation coils connected to the neutral point of the network can significantly reduce these outages but they do nothing to help detect the faults themselves. Indeed, the benefit of reduced fault currents that coils bring, inherently complicates fault-finding. In addition, faults may be intermittent and manifested as high transient currents and voltages. Earth-fault detection and directional determination in compensated distribution systems are the two most challenging and important tasks taken on by protection relays. After years of intensive research, development work and field testing, ABB has now introduced a reliable digital solution that accomplishes these tasks. This obviates the need for an additional and separate analog transient relay and its associated costs. The new functionality is integrated into the very popular Relion® 615 series protection and control relays for distribution networks and, in particular, in the REF615 for feeder protection and control.

1 Typical voltage and current waveforms during a restriking earth fault



Statistics show that the majority of faults in unearthed and compensated medium-voltage networks are earth faults. According to studies made in the Nordic countries, about 50 to 80 percent of all faults are in this category [1]. These faults are very often characterized by current and voltage transients.

It is common for national regulatory models to require consumers to be compensated for failures in power provision (or for poor power quality). Also, the consequences of short outages have become more significant as society has become increasingly dependent on high quality and reliability of supply. It is, therefore, clearly in the interests of utilities and distribution system operators (DSOs) to minimize supply interruption caused by earth faults.

In recent years, resonant grounding has become a growing practice worldwide in neutral point treatment of medium-voltage networks. Such grounding reduces the capacitive earth-fault currents produced by the network to close to zero and alleviates the conditions for self-extinguishment of earth faults without the need to trip breakers and cause customer outages. However, such low fault currents, which do not even trip breakers, make it difficult to detect the fault and its direction. In addition, faults can be intermittent, ie, they can self-extinguish very rapidly but then reignite due to degradation of the insulation dielectric at the fault location. Such intermittent faults create highly nonsinusoidal and irregular voltage and current waveforms, which conventional relay algorithms are not designed to handle ➔ 1. This can cause relays that trigger on persistent fault signals to either fail to operate or trip nonselectively. This can lead to the disconnection of an entire primary substation.

Therefore, up until now, utilities and DSOs have always required, and preferred, earth-fault protection that is based not on steady-state measurement signals, but on initial fault transients. Analog measuring relays are considered to be the only reliable way to measure transients so these have been enshrined in utilities' internal guidelines – regardless of the additional work, cost and space requirements that these devices bring with them.

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The reliable digital solution

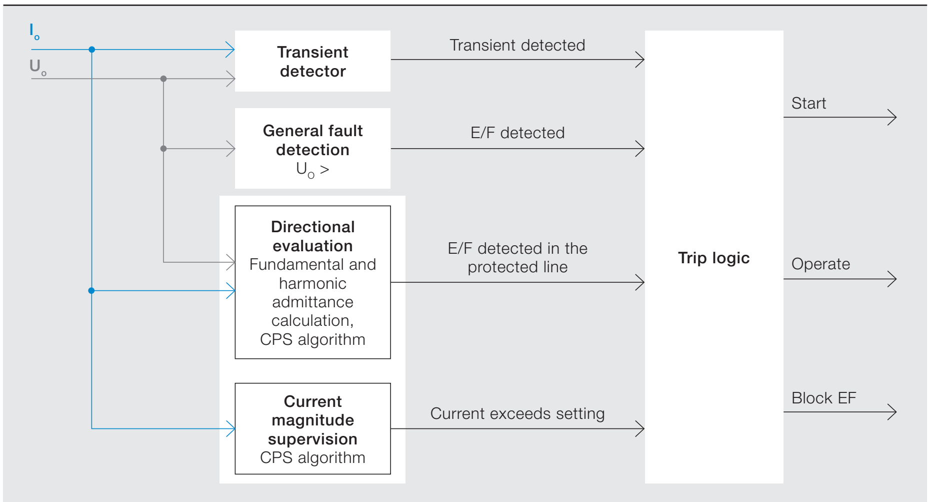
After years of intensive research, development and field testing, ABB has succeeded in producing a reliable digital alternative to the analog approach. This takes the detection of transient and restriking earth faults to a new and more sophisticated level. The patented algorithm utilizes the latest developments in protection algorithm design, including multifrequency neutral admittance measurement and sophisticated filtering techniques. The principle functional diagram of the algorithm is illustrated in ➔ 2.

The first fundamental novelty of the algorithm is the multifrequency neutral admittance measurement. This utilization of harmonics makes the protection algorithm very robust and reliable even if the measured signals are distorted or include high frequency components, as would be the case in a restriking earth fault.

A second novelty of the algorithm is its directional element, where the discrete directional admittance phasors are replaced by the accumulated values of the same quantities during the fault. This filtering technique is called cumulative phasor summing (CPS). The directional phasor calculated by the CPS technique gives a very distinct and stable indication of the fault direction as the accumulated fault phasor points in the direction of the highest energy flow, ie, in the fault direction.

Title picture
ABB's digital method of earth-fault detection and directional determination makes life a lot easier for power network operators, like the owners of this distribution station in California.

2 Principle of novel restriking earth fault (E/F) protection



4 Energizing a damaged cable initiates a restriking earth fault

3 Field testing

The latest field test took place in a 10 kV HV/MV substation owned by Vattenfall, one of Europe's leading energy companies, in Sweden ➔ 4. The test infrastructure was a large rural cable network with central and distributed compensation. The operation of the new Relion 615 digital earth-fault detection functionality was demonstrated in 51 individual test cases in which the fault type (permanent, restriking), location (of four) and the compensation degree (undercompensated, fully compensated and overcompensated) were varied. The algorithm worked in all cases. The results showed that with the novel algorithm, high-security and dependability requirements of the protection scheme could be met.

"The tests went really well. Moreover, tests performed in a real-life setting are a good opportunity for us, as a customer, to show what our needs are. I think both parties learn a lot from this kind of test," said Ulrika Uggla, protection engineer with Vattenfall in Trollhättan.

For Vattenfall, it is important that the earth-fault relay is able to detect transients in earth faults. One reason is that transients can indicate where in the grid the fault is located. Another reason is that if the relay is not triggered by recurrent transients, a greater part of the system may be disconnected than would otherwise be necessary. In the new REF615 series, the protection relay can be triggered selectively. It disconnects the correct cable and prevents fault-free parts of the system from being disconnected. This can mean, in one concrete example given by Vattenfall, that only 1,000 homes are affected by a temporary power outage rather than 8,000 homes.

Fewer and shorter outages and faster fault localization

The algorithm provides a highly robust and selective fault identification and direction determination during restriking and transient earth faults. It is sensitive enough to detect the smallest current spikes likely to occur during a restriking earth fault in today's extensive cable networks. Early detection of an intermittent fault prevents it from evolving into a more serious malfunction – for example, a double earth fault with high fault currents.

Current regulatory models motivate utilities and DSOs to minimize the number and duration of supply interruptions caused by intermittent earth faults. This new digital approach to earth fault investigation facilitates this in a simple and cost-effective way.

Reliability proven in field tests

In recent years, ABB has undertaken intensive field testing in cooperation with selected power utilities in order to test and develop new earth-fault protection functions. The novel algorithm discussed here was developed in close cooperation with the Vattenfall utility in Sweden, where it has been extensively tested with actual disturbance recordings representing a wide variety of network and fault conditions ➔ 3.

Collaboration is the key to success

Vattenfall is a good example of a close collaboration with the customer during product development leading to well received products that fulfill the customer's requirements. Collaboration agreements will continue to be an important factor in product development. Future products will assist customers to further increase power availability and thus improve the profitability of their business.

The work described here has led to a better understanding of new challenges and problems faced by modern distribution network providers. This provides impetus to further develop intelligent electronic devices and functionalities for medium-voltage networks. Already, based on the experienced gained from this cooperation, a prototype of an even more capable earth-fault detection algorithm is being developed.

Ari Wahlroos

Janne Altonen

ABB Power Products, Medium Voltage Products

Vaasa, Finland

ari.wahlroos@fi.abb.com

janne.altonen@fi.abb.com

Reference

[1] S. Hänninen, "Single-phase earth faults in high-impedance grounded networks – characteristics, indication and location," VTT Publications 453, p. 139, 2001.