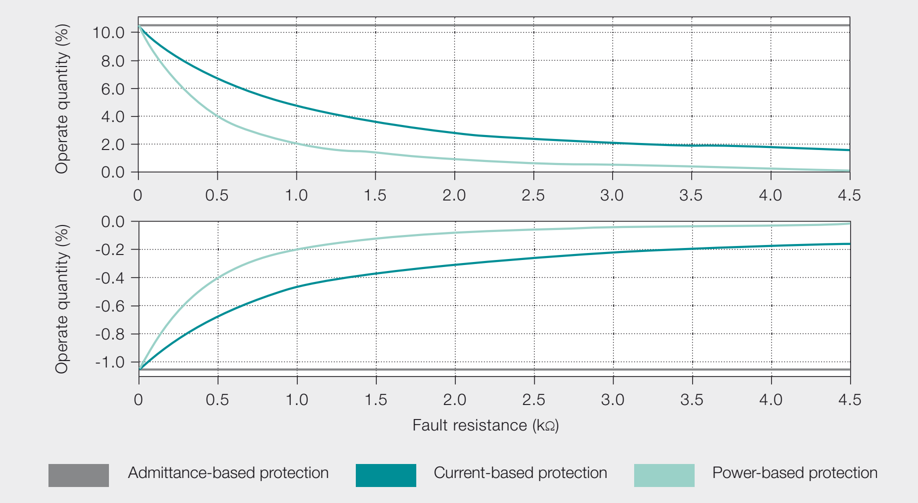
Easy admittance

The ultimate earth-fault protection function for compensated networks

ARI WAHLROOS, JANNE ALTONEN, PRZEMYSLAW BALCEREK, MAREK FULCZYK – A compensated network is a network in which the system neutral point is grounded through a compensation coil. Such grounding reduces capacitive earth-fault currents produced by the network to close to zero at the fault point and alleviates the conditions for self-extinguishment of earth faults without the need to trip breakers and cause customer outages. This is why increasing numbers of medium-voltage networks are being changed to the compensated type. However, the low fault currents in compensated networks challenge traditional earth-fault protection principles. An alternative principle, based on measured neutral admittance, was developed in the early 1980s in Poland. This simple, but very smart, principle has many advantages over traditional methods and it can be applied to all types of unearthed and compensated networks, including feeders with distributed compensation. Neutral-admittance-based earth-fault protection functionality is now available in ABB's Relion® products REF615 and REF630.

1 Different earth-fault protection principles showing magnitude of the operate quantity as a percentage of nominal value of Y_o, I_o or S_o versus fault resistance



In the early 20th century, Waldemar Petersen discovered that by connecting an inductance to the neutral point of the main transformer, the capacitive earth-fault current produced by the network could be reduced to close to zero and, thus, the majority of arcing earth faults would self-extinguish. Today, these inductance elements are called Petersen coils, compensation coils or arc suppression coils.

Temporary earth faults cause the majority of outages and using compensation coils can significantly reduce outage frequency, resulting in a more reliable and higher quality supply. Compensation also allows continuation of network operation during a sustained earth fault, assuming the conditions for hazardous voltages set by legislation and regulations are met.

For these reasons, the application of compensation coils has recently become popular in medium-voltage (MV) distribution networks worldwide.

Protection schemes challenged in compensated networks

Although compensation delivers operational benefits, earth-fault protection of the network becomes more complicated due to the extremely low fault currents resulting from the compensation effect of the Petersen coil. Often, these currents are only a fraction of the normal load current, too low to trip conventional overcurrent relays.

Traditionally, earth-fault protection in compensated networks has been based on the active component of the residual current (eg, the Iocosphi principle) or that of the residual power (the Wattmetric principle). An alternative principle, based on measured neutral admittance, was formulated in the early 1980s in Poland, where it has become a functional requirement for local utilities.

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Neutral admittance protection – concept

Neutral admittance protection, like other earth-fault protection schemes, is based on the fundamental frequency components of residual current ($\underline{I}_0$) and residual voltage ($\underline{U}_0$). But, instead of residual current or power ($\underline{S}_0 = \underline{U}_0 \cdot \underline{I}_0$) being the operate quantity, the protection is based on monitoring the value of the measured neutral admittance, $\underline{Y}_0$, defined as the quotient of residual current and residual voltage phasors:

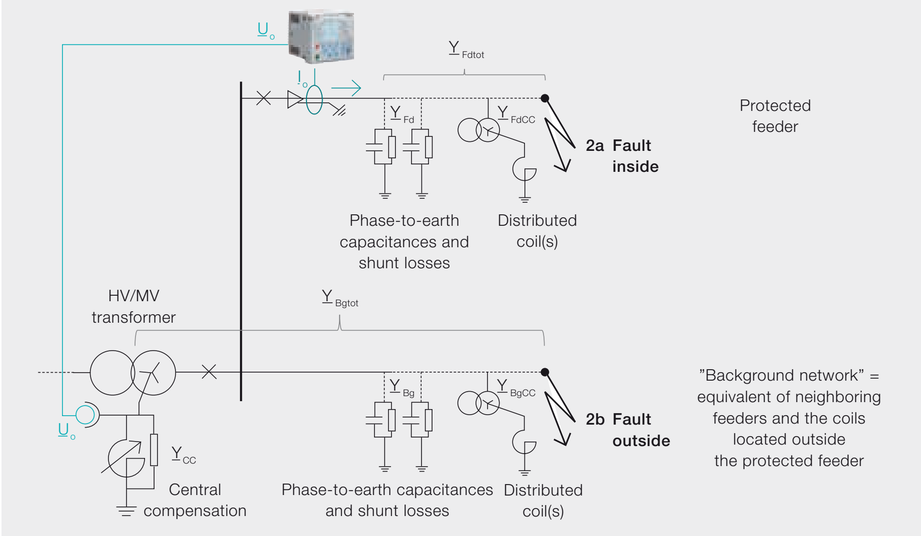
$$\underline{Y}_0 = \frac{\underline{I}_0}{\underline{U}_0} = G + j \cdot B,$$

where G is the conductance and B the susceptance. The measured admittance is directly related to known system parameters, ie, the shunt resistances, capacitances and inductances of the network. The resistive part of neutral admittance, ie, the conductance, G, corresponds to the shunt resistances and losses of the system and the imaginary part, ie, the susceptance, B, corresponds to the shunt capacitances and shunt inductances of the system. As these values are the base for earth-fault protection analysis of the network, their values are always available and are typically stored in the distribution management systems (DMSs).

The main advantage of monitoring the ratio of $\underline{I}_0$ and $\underline{U}_0$, ie, the neutral admittance, is that, ideally, this ratio remains constant with changing fault resistance as both $\underline{I}_0$ and $\underline{U}_0$ decrease with increasing fault resistance [1]. This is in contrast

Title picture
Compensated networks improve reliability of supply, but make it tough to implement earth-fault protection. How does a method invented in Poland in the 1980s save the day?

2 Simplified single-phase equivalent circuit of a compensated network with an earth fault located either in the protected feeder (2a) or in the background network (2b)



to traditional earth-fault protection, where the magnitude of the operate quantity, based on residual current or power, is greatly decreased by the fault resistance. This feature of the neutral admittance principle improves the sensitivity of the earth-fault protection and enhances discrimination between fault and nonfault conditions, especially at higher fault resistance values ➔ 1.

The main advantage of monitoring the ratio of Io and Uo, ie, the admittance, is that, ideally, the result is not affected by fault resistance in the fault spot.

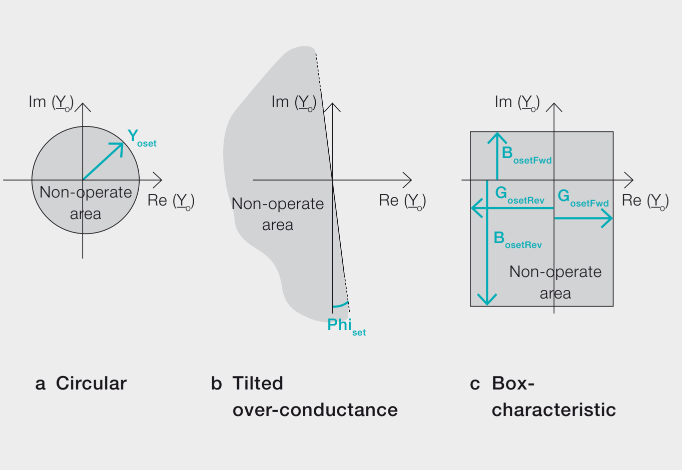
Admittance protection theory in a nutshell

In the case of a fault outside the protected feeder, the measured admittance equals the negative of the total neutral admittance of the protected feeder, $-\underline{Y}_{Fdtot}$. This admittance is the sum of the total admittances of the phase conductors of the protected feeder, $\underline{Y}_{Fd}$, and the admittances of the compensation coils located in the protected feeder, $\underline{Y}_{FdCC}$ (if applicable). The resistive part of the measured admittance corresponds to the resistive shunt losses of the feeder and the losses of the distributed coils located in the protected feeder. The imaginary part is proportional to the sum of phase-to-earth capacitances of the feeder and the inductances of the distributed compensation coils located in the protected feeder ➔ 2.

In the case of a fault inside the protected feeder, when the protection must operate, the measured admittance equals the total neutral admittance of the background network, $\underline{Y}_{Bgtot}$. This admittance is the sum of the total admittances of the phase conductors of all the other feeders of the substation, $\underline{Y}_{Bg}$, and the admittances of the compensation coils located outside the protected feeder in the substation, $\underline{Y}_{CC}$, or in the neighboring feeders, $\underline{Y}_{BgCC}$. The real part of the measured admittance is always positive but the sign of the imaginary part, ie, the susceptance, depends on the tuning of the compensation coil. Typically, the protection is set to operate with the additional resistive current component introduced by the parallel resistor of the coil. In the admittance measurement the increase of resistive current is directly measured in the real part of the admittance, ie, in the conductance.

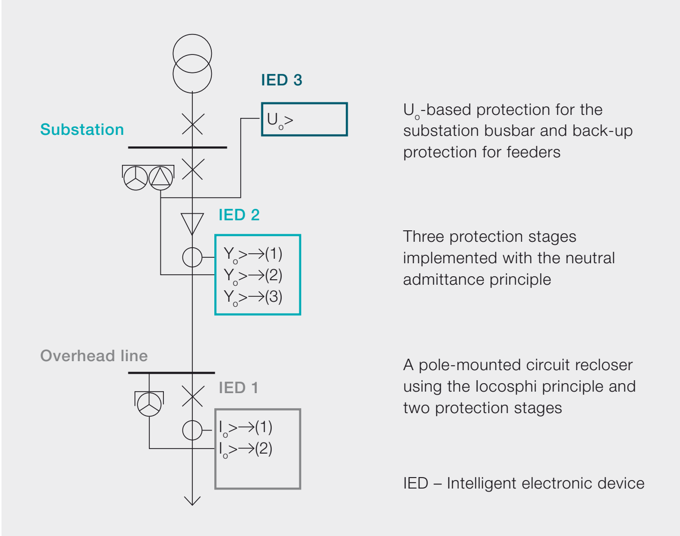
The fundamental principle of operation of admittance-based earth-fault protection is based on discriminating between the neutral admittances resulting from inside

3 Examples of real (Re) and imaginary (Im) admittance characteristics



The shaded area is the non-operate area, ie, protection operates when the calculated admittance is outside the boundary line(s).

4 Example protection diagram for an MV feeder protection applying both neutral admittance and traditional earth-fault protection functionality



and outside faults. The protection operates, ie, trips the circuit breaker, when inside fault admittance is measured but not when outside fault admittance is measured. This condition is characterized by operation boundary lines that may be circular or composed of single or multiple lines. Protection operates when the calculated admittance point moves outside these lines → 3.

The neutral admittance principle is flexible enough to be applicable to all types of high-impedance earthed, unearthed and compensated networks, including feeders with distributed compensation. These latter devices are becoming more common as weather-vulnerable overhead lines are replaced by underground

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cables. These cables multiply the earth-fault current produced by such feeders, which typically calls for local compensation implemented by distributed coils. The distributed coils may be problematic for conventional earth-fault protection schemes as their characteristics cannot be easily adapted, eg, if the feeder configuration is significantly changed.

The principle's flexibility also provides enhanced protection during restriking earth faults as there is a bigger margin before false operation can occur [2].

Fully compatible with traditional earth-fault protection

As in traditional earth-fault protection, the neutral admittance principle uses the residual overvoltage condition as a general start criterion to define basic protection sensitivity. This allows intermixing with traditional principles, convenient when various protection principles are used in one substation distribution area → 4.

Further improvement of the admittance principle

Traditionally, earth-fault protection is based on residual current and residual voltage phasors that are calculated as soon as the earth fault is detected. Where the network is mainly composed of overhead lines, there may be a high-magnitude, healthy-state residual voltage present in the network due to untransposed phase conductors. Such asymmetry of the network affects the operate quantities so that the calculation result depends on, eg, the faulty phase. This dependence increases with fault resistance and may negatively affect earth-fault protection sensitivity. With the neutral admittance principle, it is possible to

With the neutral admittance principle, it is possible to remove the effect of network asymmetry from the measurement results.

From the protection perspective, the problem of harmonics can be turned into an advantage.

remove the effect of network asymmetry from the measurement results. This is accomplished by using so-called delta quantities: Pre-fault values of the residual current and voltage phasors are subtracted from the values measured during the fault before calculating the neutral admittance. The appropriate algorithms can easily be implemented in modern intelligent electronic devices (IEDs) [1].

A problem becomes an opportunity

More higher-order harmonic components are appearing on MV networks due to increasing numbers of harmonics-generating loads and various nonlinear elements. As a consequence, there are also significantly more harmonics in the fault current during a single phase-to-earth fault.

As the compensation coil only compensates the fundamental frequency component of the capacitive earth-fault current, the other frequency components remain. Traditionally, these components have been considered to be disturbances that need to be filtered out. However, neutral-admittance-based earth-fault protection can take advantage of these harmonics to improve the discrimination between fault and nonfault conditions [3]. In modern IEDs, the harmonic admittances can be easily calculated and added to the fundamental frequency admittance in phasor format, making the discrimination between fault and nonfault conditions even more distinct.

Years of positive experience

Since its invention, the neutral-admittance-based earth-fault protection approach has spread from Poland to other European countries. It can be applied to standard directional earth-fault protection, but also to high-impedance and intermittent earth-fault detection. Recent advances in the topic have been made by ABB in cooperation with Finnish power utilities. Based on extensive field tests, it can be concluded that the technique does indeed have sensitivity superior to that of traditional earth-fault protection principles. With proper settings and accurate measurements, earth faults with fault resistances of up to 10 kΩ can be detected [2].

In comparison with traditional methods, neutral admittance protection provides several attractive features, including improved sensitivity and security for both continuous and restriking earth faults. Further, it is applicable universally, including in networks with distributed compensation, thus also making the principle a safe choice for future smart grid applications. Finally, the protection settings are easily derived from the basic system data, which enables simple and practical optimization of the operation characteristic.

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