INNOVATIVE NEUTRAL POINT TREATMENT IN COMPENSATED NETWORKS

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ABSTRACT

In this paper a new approach for Innovative Neutral Point Treatment in Compensated Networks is presented.
Additionally a well known general mathematical solution for fault location is presented and the usability of this method for detection of earth faults in compensated networks is shown.
The innovative principle consists in the combined use of additional star point resistors and special distance protection relays in compensated grids. The resistors are activated for a certain limited time in order to achieve low touch voltages at the earth fault point.
Furthermore, experimental testing was done with a common distance protection relay. Results from field tests in medium and high voltage networks prove the possibility of using distance protection relays for earth fault distance protection in compensated grids.

INTRODUCTION

In electrical grids the method of neutral point treatment depends on the voltage level and the size of the electrical network. Therefore different modes of operation during earth fault appearance exist.
Earth fault compensated networks improve the power quality, due to the reason that most of the earth faults extinguish automatically and continuous operation during the fault situation is allowed.
This network operation implicates problems in localization of earth faults. Nowadays it takes time to find and locate an earth fault. During the search of an earth fault it can never be excluded, that there is an accident which should not happen.
For safety reasons earth faults have to be localized and cleared as fast as possible. Earth faults in compensated networks, which do not disappear automatically, have to be switched off manually or automatically.
Therefore, a selective earth fault distance protection is necessary.
The principle of compensated networks causes, that the existing earth fault currents have a certain restricted low limit, depending on the voltage level.
Increased use of cables in earth fault compensated grids increases the capacitances to ground in the grid so that the capacitive ground fault current I_{CE} increases, which causes problems concerning arc extinction. The ground fault current (limited due to national standards) depends on detuning, damping, unbalance, harmonics, saturation, operating voltage, harmonic resonances, and the distribution of the line inductances and capacitances (within the grid).
Expanding grids may exceed the limit of the restricted earth fault current and an innovative neutral point treatment is necessary.

LIMITS OF COMPENSATED NETWORKS

Increased use of cables in earth fault compensated grids increases the capacitances to ground in the grid so that the capacitive ground fault current I_{CE} increases, which causes problems concerning arc extinction. The ground fault current causes touch voltages and voltages that influence other systems. These voltages have to stay below certain limits in order to avoid accidents. Because of these rising voltages it is necessary to know the grid expansion reserve in order to start appropriate measures in time.

Grid expansion reserve

The harmonic influence contributes a substantial portion to the residual ground fault current. In grids, which are operated in a completely compensated (resonant grounded) mode, the residual ground fault current consists almost only of harmonics. Usually the fifth harmonic contributes the largest portion of the harmonic residual current. As a result there are only few cable-kilometers expansion reserve in existing grids. So it is useful to think about measures at an early planning stage.

Measures for further operation

There exist several measures which allow further grid expansion. These measures come along with big investments and they often take a lot of time. Some of the possibilities are:

- grid separation,
- avoiding cables,
- better compensation,
- active compensation,
- reduction of harmonics,
- changing neutral point treatment
- innovative neutral point treatment.

The innovative neutral point treatment is described in the following chapters.

INNOVATIVE NEUTRAL POINT TREATMENT

Earth fault compensated grids are favored by many European grid operators, because of their reliability. More than 90 % of occurring faults are phase to earth faults, which have no influences on power supply in these grids. So the grid operators want to keep their hitherto existing reliability when changing something. The solution for the mentioned problems is the Innovative Neutral Point Treatment explained in this paper. The idea is to upgrade the protective system in combination with additional resistances parallel to the compensation coils, to be prepared for the future when the limits are exceeded. The resistance causes slightly higher earth fault currents which can be detected more easily. Then the earth faults have to be switched off within short time (defined by standards and dependent on magnitude). As a result it is possible to fulfill national standards and to avoid endangerments. To be able to clear the fault rapidly it is necessary to establish a reliable earth fault localization.

Earth fault localization

The following equation (1) can easily be developed using the symmetrical components. This model is valid for the fundamental harmonic in steady state conditions. Transient phenomena are disregarded.

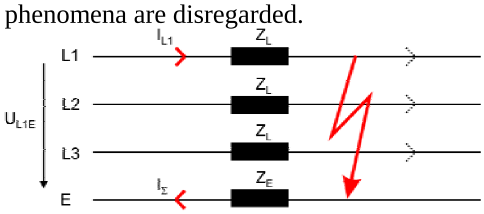

Fig. 1 Simplified model of an earth fault

In general, fault to ground impedances are calculated by distance protection relays according to equ. (1), disregarding the fault point transition impedance.

$$Z^1_{Line} = \frac{U_{L1E}}{I_{L1} + I_\Sigma \cdot k_0} = Z^{1'}_{Line} \cdot l \qquad (1)$$

Z^1_{Line}	measured impedance of the fault distance
$Z^{1'}_{Line}$	line-impedance related to one length unit
U_{L1E}	measured phase-ground voltage at the location of the relay
I_{L1}	measured phase current at the location of the relay
I_Σ	measured residual current at the location of the relay
l	distance to the fault location

The k_0-factor represents the ratio of the "earth return path" to the (positive sequence) line impedance (see equ. 2).

$$k_0 = \frac{1}{3}\left(\frac{Z^0}{Z^1} - 1\right) = \frac{Z_E}{Z_L} \qquad (2)$$

The formula (1) is acceptable for low impedance faults, which have been investigated in the first phase of the research.
As shown in the formula, the load currents have no disturbing influence on the distance computation; however they raise the current levels, so that in face of the deviation of the current transformers a more accurate distance determination is possible.
Possible error sources in this method are: inaccuracy of the voltage- and current transformers, capacity influences of the faulty line, the point of time of the measurement (after decay of the transients), high transition fault impedance, etc.
To establish safer detection levels, the influence of an additional resistance in parallel to the arc suppressing coil was investigated. The expected advantage of this method was the raise of the residual fault current and, thus, to get a more accurate fault distance estimation.

Laboratory tests

Practical tests have been done with a realistic laboratory network model. For these tests a distance protection device was used. In these relays the starter is normally blocked during single phase-to-earth faults in the operation mode "resonant grounded earth grid". To bypass this blockade the parameters for the starter have to be chosen near to the load currents.
The result of the fault distance calculation had a deviation of 1%.

Simulations

To verify the algorithm and the laboratory tests, a line model was developed in Simulink - equivalent to the network model in the laboratory and using a π-equivalent circuitry.

The results confirmed the underlying theory. The results of the fault distance variation showed a linear relation between the fault distance and the computed fault impedance.

Field Test

Tests in a 110-kV-Network

In January 2006 earth fault field tests were done in a 110-kV-network in Austria. The distance between the measurement point and the earth fault location was 4,4 km corresponding to 0,57+j1,69 Ohm connected through a double system line. The zero impedance was 1,738+j5,258 Ohm, which results in a k_0 of 0,68.

Various tests with different network situations (additional cables, etc.) have been performed:

Nr.	Description
1	Entire Network, over-compensated 60 A
2	One cable disconnected (-53 A); over-compensated 60 A
3	Entire Network, over-compensated 140 A
4	Entire Network, over-compensated 50 A

Tab. 1: Various Field-test

The results are shown in tab. 2. The values are the fault impedances in Ohm calculated by the distance protection device.

	k_0=0.68, φ=0°		
	R	X	km
1	0,3	1,8	4,7
2	0,3	1,6	4,2
3	0,1	1,9	4,9
4	0,2	1,9	4,9

Tab. 2: Results of the calculation of the relay of the field test 110 kV

Compared to the real distance of 4,4 km, the results of the tests with k_0=0,68 gave fault distances between 4,2 and 4,9 km. The relative error is -5% and +11% respectively.

Tests in a 20-kV-Network

In October 2005 earth fault field tests were done in a 20-kV-network in Austria. The measurement system was placed in a substation. The first fault point was 0.8 km apart from the substation, the second fault point was 14,7 km far away. The earth faults were low-ohmic earth faults.
The substations were connected via a combination of high voltage lines and cables forming a radial network.
The distance between the measurement point and the first earth fault location was 0,8 km corresponding to 0,2+j0,221 Ohm.
The distance between the measurement point and the second earth fault location was 14,7 km corresponding to 4,42+j4,1 Ohm.

The tests, which have been performed, are described in tab. 3. During the test an additional resistance (100 Ohm) was connected in parallel to the Petersen coil.

Nr.	Fault point	Description
1	Station 1	Only one line, no network, with an additional resistance, no load
2	Station 1	Only one line, no network, with an additional resistance, no load
3	Station 1	Only one line, small network at the same transformer (3 MVA load, I_C=46A), with an additional resistance
4	Station 1	Load current on the faulty line, small network at the same transformer (3 MVA load, I_C=46A), with an additional resistance
5	Station 1	Load current on the faulty line, small network at the same transformer (3 MVA load, I_C=46A), without an additional resistance
6	Station 2	Load current on the faulty line, small network at the same transformer (1,5 MVA load, I_C=42A), with an additional resistance
7	Station 2	Load current on the faulty line, small network at the same transformer (1,5 MVA load, I_C=42A), without an additional resistance
8	Station 2	Load current on the faulty line, small network at the same transformer (1,5 MVA load, I_C=42A), with an additional resistance

Tab. 3: Various Field-test
I_C …. Capacitive current of the network

Due to the reason, that the zero impedance of the line was not known, two different k0-factor settings were chosen to test the algorithm.

	k0=0.6, φ=0°			k0=0. 8, φ=0°		
Nr	R	X	km	R	X	km
1	0,37	0,44	1,59	0,34	0,39	1,41
2	0,37	0,45	1,62	0,33	0,4	1,44
3	0,36	0,45	1,62	0,32	0,39	1,41
4	0,33	0,42	1,52	0,31	0,38	1,37
5	0,17	0,51	1,84	0,16	0,43	1,55
6	4,09	5,72	20,5	3,35	5,18	18,5
7	3,86	4,36	15,6	3,33	4,07	14,5
8	4,07	5,71	20,4	3,36	5,22	18,71

Tab. 4: Results of the calculation of the relay of the field test 20kV

The tests have shown that the accuracy gets better with growing fault distance and the higher k_0-factor.

Effect of the additional resistive current

The first tests with a resistor have been done in a 20-kV-network (see tab.4). In the first run a more accurate result could not be observed. The differences may be caused by fault point transition impedances or grounding impedances in substations or switching stations. These resistances are not included in the classic k_0-factor and the influence of these resistances increases with higher earth fault currents.

Improvement of electrical systems

When further expansions are planned it is possible that one comes to the point where the safety standards are not able to be fulfilled. Then it is necessary to upgrade some stations earthings in order to lower the occurring touch and step voltages in combination with reducing the fault time by tripping the faulty lines.

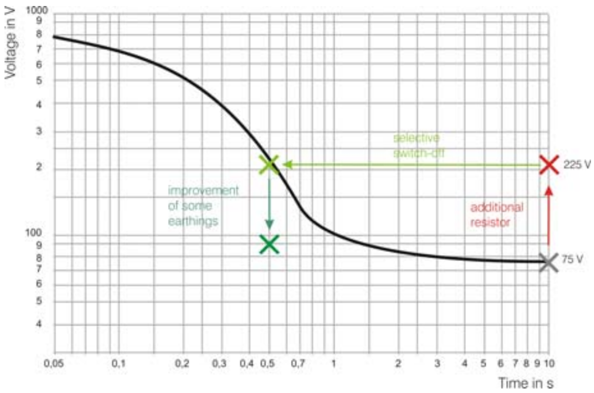

Fig. 2 Allowed touch voltages

A very interesting aspect of the presented method is that it is not necessary to improve all stations at once, but step by step. In the first period only the worst earthings have to be replaced.
Anyhow a good knowledge about all earthings is needed.

SUMMARY

In this paper an innovative way of neutral point treatment for earth fault is presented. This is a possibility if the limits of residual earth fault currents in compensated networks are exceeded and further grid expansions are planned.
An additional resistor is installed in parallel to the Petersen coil. This resistor raises the earth fault current to reach a safer detection level in combination with earth fault tripping. Because of this small additional current only some (perhaps none) earthings have to be improved.
This could be an interesting method for fast and easy upgrading of the network.
Furthermore it is shown, that the algorithm of distance protection relays, which usually is used for short circuit protection, is also valid for the detection of low impedance earth faults in compensated networks.
Simulations and field tests verify the usability of the presented method.
Further investigations are necessary to define the limitations of this method concerning the fault impedance, the influence of the earth factor k0, the influence of capacitances etc. Special investigation will be done to define the influence of the earth impedance at the fault point and to find out if there is an influence of the impedance at the substation, where the Petersen-coil is located.
Further investigations to increase the accuracy of the distance computation are under way.

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