Distance Location of Earthfaults in Compensated Medium Voltage Networks

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ABSTRACT

One of the most powerful techniques for the location of earthfaults in compensated medium voltage network is the admittance-method including central data acquisition of the zero-sequence currents and evaluation of their differences. This method enables an absolute reliable detection of the faulty feeder and furthermore a distance-location of the earthfault with an average accuracy of 5 % is possible. By this means no more time-consuming and risky search processes using switch-operations are necessary and the line segment, affected by the earthfault, can be switched off very fast.
This contribution describes the first operating experiences with such an earthfault-protection-system.The experiences confirm impressive the practical application and the prospects of this method.

INTRODUCTION

As operating experiences, field tests and publications [1], concerning earthfault-location, show, most of the earthfault-protection-relays used up to now work satisfactory only at earthfaults with a fault resistance under 500Ω. At fault resistances Z_F up to 1kΩ the traditional relays release only under restricted conditions and at resistances of more than 1,5kΩ they more or less don't release. Only new methods, like the harmonics-relative measurement [2] (Z_F up to 4 kΩ), DESIR (up to 5 kΩ), the admittance-method according to [3] (up to 3 kΩ) and the admittance-method according to [4] (up to 100 kΩ) are able to recognize even high-resistance earthfaults. This kind of faults cannot be excluded, especially in networks with overhead lines (backward earthfault, line falls on a tree). Moreover, the admittance-method with it's central data-acquisition of the zero-sequence-currents makes it possible to determine the fault-distance with sufficient accuracy. The time, necessary for the search of the line segment affected with an earthfault, is drastically reduced and consequently the probability of secondary faults (cross-country-fault). MEAG have been using such a system for the last 2 years; the system works successfully. This contribution gives a description of the field conditions of the earthfault-protection-system EPSY [5] and it describes the results of field tests and the first operating experiences.

DESCRIPTION OF APPLICATION

Configuration of the network

MEAG operates their medium voltage networks resonant grounded and basically as open loops (figure 1).

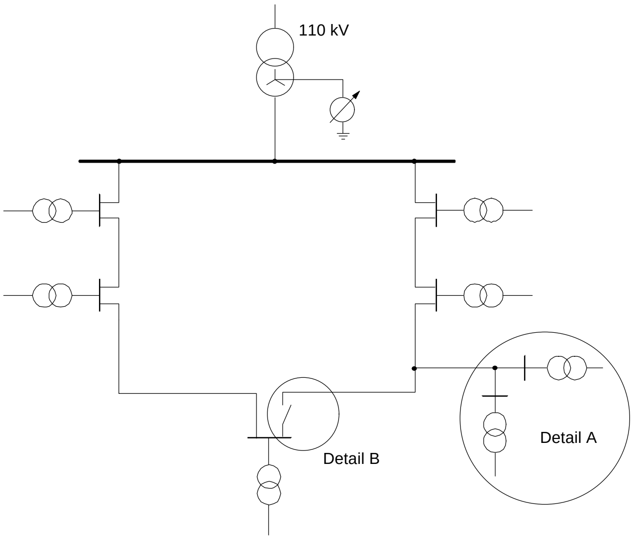


Figure 1: Typical structur of MEAG medium voltage network

Normally, these open loops are closed only in the case of an earthfault. So the disconnection of supply during the search of the earthfault-location by sectioning can be avoided. The first applications of the earthfault-protection-system were carried out in a 10 kV network and in a 20 kV network, each system with resonant grounding. The networks supply mainly rural areas and the part of overhead lines ranges between 10 and 60 %. Cables are increasingly used in the cases of network extensions and reconstructions; therefore the average part of overhead lines, which now amounts 50 %, declines. The length of a loop in this network typically amounts 24 km. On average, one loop supplies 25 substations and the average distance between these stations is 1 km. Because of the fact, that in older parts of the network up to 20 % of the stations are tree'd networks (figure 1, detail A), the location of an earthfault becomes more difficult.

Principle of the earthfault-protection system

The scheme of the earthfault-protection system is presented in figure 2.

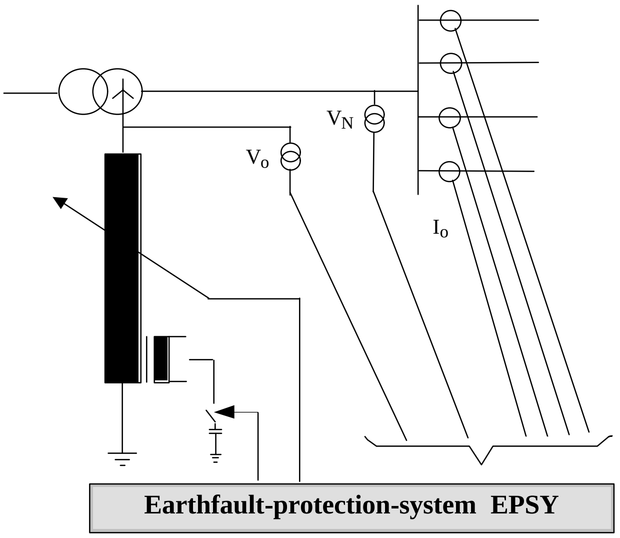


Figure 2: The scheme of the earthfault-protection system

In the protection-system the zero-sequence-currents of all feeders of the bus bar are measured centrally. In addition, the phase-voltage and the zero-sequence voltage of the system are required as reference values. Out of these values the zero-sequence admittances for each feeder are calculated and continuously monitored. If the zero-sequence admittance of a feeder changes it's value for a small amount, a check is carried out by detuning the resonant circuit (using a current injection). The purpose of this check is to find out, if the alteration is a result of switching operations in the monitored network (change of the natural asymmetry). If this is not the reason (high-resistance earthfault), or if the change of the zero-sequence admittance is very high, an earthfault is recognised. Practically, even other feeders can show changes of the zero-sequence admittance, caused by the higher zero-sequence voltage. Therefore, the feeder with the highest alteration of the zero-sequence admittance is identified as the faulty feeder.

It is possible to locate the point of the earthfault, if the feeders are connected to a loop in case of an earthfault or if they are connected to a loop during normal operation. At MEAG, in case of an earthfault, the loop is made by closing a breaker at the point of the network-separation (figure 1, detail B).

During this loop-operation, the zero-sequence currents are measured before and after a capacitor C_V has been switched on to the auxiliary winding of the arc-suppression coil for a short time, and the zero-sequence current-differences of the feeders, connected to the loop, are determined As a result of this difference-measurement particularly the error of the instrument transformers are more or less eliminated. In the best case (constant Z_o and Z_F) , the measured current differences ΔI_o of the lines A and B, which are connected as a loop, are proportional to the ratio of the zero-sequence current resp. the zero-sequence admittance up to the fault location (figure 3).

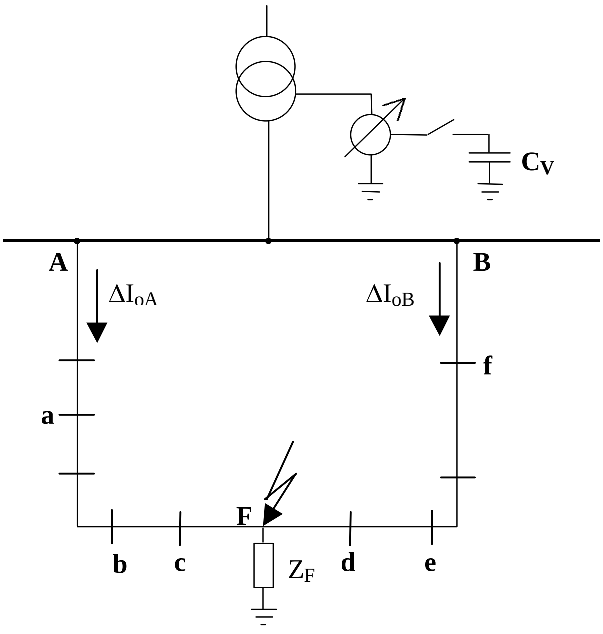


Figure 3: Ratio of zero-sequence currents

In this case the relative distance from the beginning of the line at A to the fault location amounts:

$$x_A = \Delta I_{oB}/(\Delta I_{oA} + \Delta I_{oB}) \qquad (1)$$

By the earthfault-protection-system this value is expressed on the display and provided for the SCADA as percentage. Assuming a homogeneous line the distance from A to the fault location F is :

$$X_{AF} = x_A * X_{AB} \qquad (2)$$

where X_{AB} denotes the length of the loop.

Medium voltage networks are rarely homogenous. Historical grown, they are characterized by the following :

- they consist of both, cables and overhead-lines
- tree'd lines are connected
- different conductor cross sections,
- conductor arrangement,
- and installation methods are used.

Because of this, equation (2) seems to be applicable only under conditions.

Earthfault distance location

To achieve useful results, even under inhomogeneous conditions, MEAG developed the program EEM.

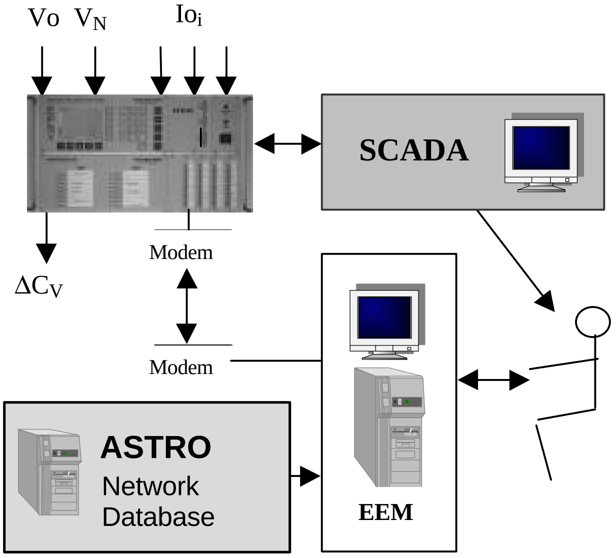
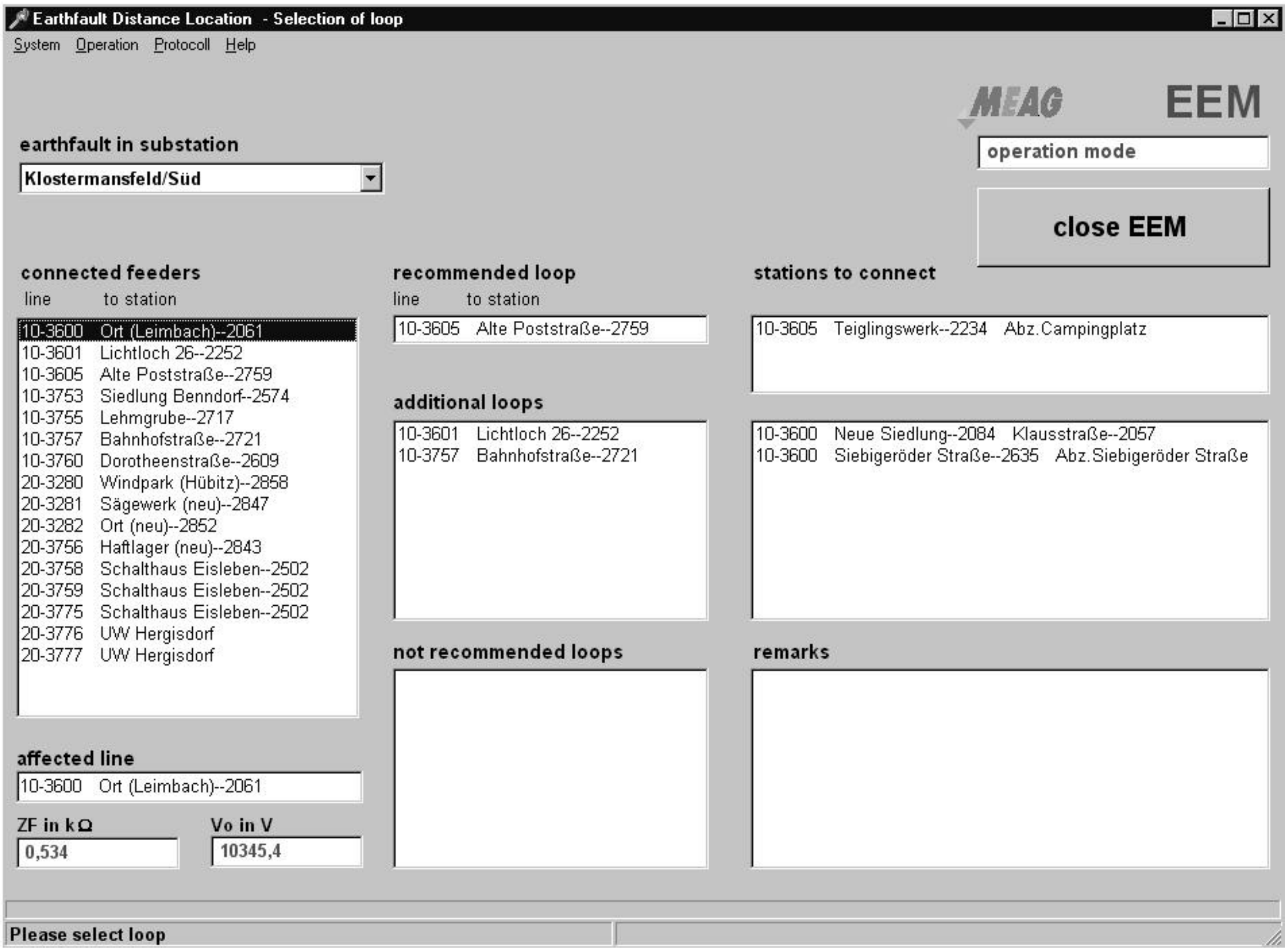


Figure 4: Connection of EEM to EPSY and SCADA

This program turns the measured relative distance x_A from the earth-fault-protection-system into a clear information for the operational staff. EEM is a prototype, implemented on a standard-PC (Windows 95...NT). If the prototype works successfully, it is planned to implement this function directly in the SCADA system and therefore the indirect way, using the modem, is no longer necessary. The actual connection of the EEM-PC is shown in fig. 4.

In the case of an earthfault and its signalling through the SCADA system, the program EEM is started by the operational staff , and the substation, affected by the earth fault, is selected. The data of the lines, linked to this substation, is read from the network-data-base ASTRO and the feeders in the substation are displayed on the screen. After that, the staff selects the feeder, affected by the earthfault and EEM measures the fault resistance and the neutral-earth-voltage U_0. EEM automatically calculates the potential connections of loops (usually one) and recommends the most suitable connection for the loop (figure 5). After the connection to a loop has been executed (either remotely controlled or manual), the modem of the earth-fault protection system is induced to switch the capacitor C_V and to transfer the zero-sequence currents to EEM before and after the switching operation of the C_V. Out of this, the relative distance x_A is determined and applied to the zero-sequence impedance of the selected loop in the following simple mode.

Figure 5: Starting screen of EEM



earthfault in substation

Klostermansfeld/Süd

operation mode

connected feeders

line	to station
10-3600	Ort (Leimbach)--2061
10-3601	Lichtloch 26--2252
10-3605	Alte Poststraße--2759
10-3753	Siedlung Benndorf--2574
10-3755	Lehmgrube--2717
10-3757	Bahnhofstraße--2721
10-3760	Dorotheenstraße--2609
20-3280	Windpark (Hübitz)--2858
20-3281	Sägewerk (neu)--2847
20-3282	Ort (neu)--2852
20-3756	Haftlager (neu)--2843
20-3758	Schalthaus Eisleben--2502
20-3759	Schalthaus Eisleben--2502
20-3775	Schalthaus Eisleben--2502
20-3776	UW Hergisdorf
20-3777	UW Hergisdorf

recommended loop

line	to station
10-3605	Alte Poststraße--2759

stations to connect

10-3605 Teiglingswerk--2234 Abz.Campingplatz

additional loops

10-3601 Lichtloch 26--2252
10-3757 Bahnhofstraße--2721

10-3600 Neue Siedlung--2084 Klausstraße--2057
10-3600 Siebigeröder Straße--2635 Abz.Siebigeröder Straße

not recommended loops

remarks

affected line

10-3600 Ort (Leimbach)--2061

ZF in kΩ: 0,534

Vo in V: 10345,4

Please select loop

The earthfault-location is found, if

$$x_{Zox} = Z_{ox}/Zo_{AB} = x_A \qquad (3)$$

is valid; Z_{ox} denotes the zero-sequence impedance, accumulated over the line segments from point A to a point X and Zo_{AB} denotes the total zero-sequence impedance of the loop. Line segments are defined as parts of the line between two substations or branches (Figure 1, detail A), which can include splices occasionally. Because x_{Zox} is determined by sections it is hardly identical to x_A, so that the zero-sequence impedance has to be interpolated within the line section. Figure 6 presents the visualisation of the results of an earthfault location with EEM.

As a first result, the calculated earthfault-location is indicated to the operational staff as the line segment between the substation c and d (fig. 3) and furthermore the distances (km, %) from these substations to the earthfault-location are shown. Because environmental conditions have a great effect upon the operational zero-sequence admittances of cables and overhead lines and even other facts (for example, temporary changes and value of the fault resistance Z_F) can affect the calculation, a wider range of variation of the location accuracy has to be expected.
Because of this, the expected range of fault location, represented as line between the substations b and e, and its distances (real length of lines to be checked) are given as second information.

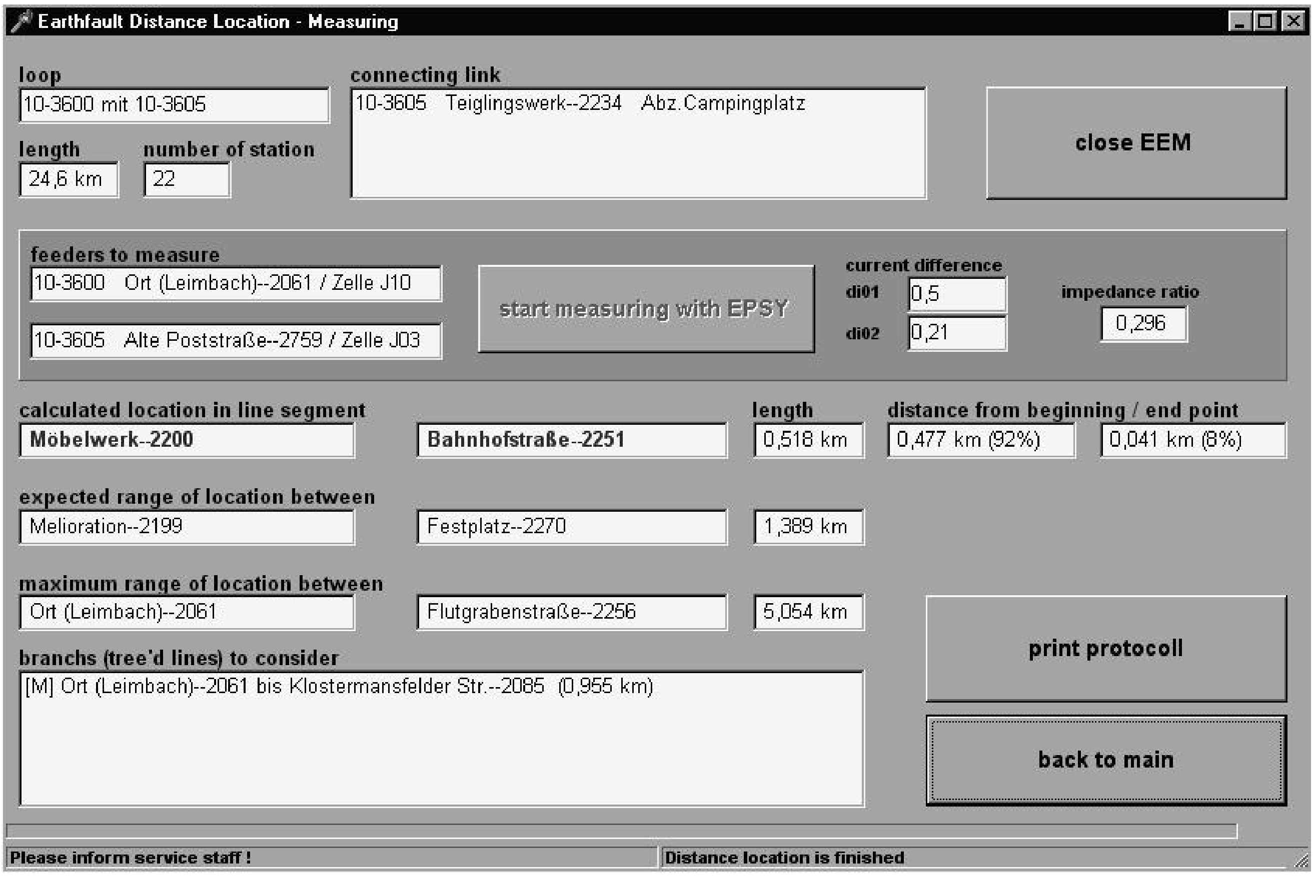
The theoretical length of the expected range of fault location is determined from the average value of all previous deviations. Actually, at MEAG this range is set to 1,2 km (± 0,6 km). To consider even extreme errors of determination, the maximum range of fault location is determined as third information, and shown analogous to the expected range. At present, the theoretical length of this range amounts about 4 km. Because it is necessary to measure from two sides, this method cannot be used in tree'd networks. (figure 1, detail A). In the best case (deviation = 0 %) the branch point is determined as fault location. Therefore the branches, situated within the maximum range of fault location are also shown, so they are taken into account for the search.

OPERATION EXPERIENCES

Earthfault-protection system

Experiences in field test and nearly two years of operating experiences with the earthfault-protection-system basically confirm the statements in [1]. The earth-fault protection system EPSY detects and selects even high-resistance and intermittent earthfaults with absolute certainty. In case of operation the sensitivity level is set to 10kΩ (warning already at 30kΩ). This level does not present the highest sensitivity, but is a result of the most disadvantageous conditions of the monitored network. In the future it should be possible, to adjust the sensitivity according the single feeder, so that earthfaults with a fault resistance up

Figure 6: EEM screen - Results of distance location



loop: 10-3600 mit 10-3605

connecting link: 10-3605 Teiglingswerk--2234 Abz.Campingplatz

length: 24,6 km

number of station: 22

feeders to measure:
10-3600 Ort (Leimbach)--2061 / Zelle J10
10-3605 Alte Poststraße--2759 / Zelle J03

current difference:
di01: 0,5
di02: 0,21

impedance ratio: 0,296

calculated location in line segment: **Möbelwerk--2200** **Bahnhofstraße--2251**
length: 0,518 km
distance from beginning / end point: 0,477 km (92%) 0,041 km (8%)

expected range of location between: Melioration--2199 Festplatz--2270 1,389 km

maximum range of location between: Ort (Leimbach)--2061 Flutgrabenstraße--2256 5,054 km

branchs (tree'd lines) to consider:
[M] Ort (Leimbach)--2061 bis Klostermansfelder Str.--2085 (0,955 km)

Please inform service staff !

Distance location is finished

to 100kΩ can be recognised under certain conditions. Practically, there might exist a problem, because high-resistance earthfaults can be recognised, but it is difficult to locate them .

Earthfault distance location

The earthfault location has been tested at MEAG 25-times in field tests and under operational conditions. Table 1 presents the measured deviations between the calculated earthfault location and the real one.

	Distance location deviations Reletad to length of the loop in %		
modell	**minimal**	**medium**	**maximum**
homogenous	0,7	4,4	17
zero-sequence	0,2	4,6	14
impedance	0,1	5,5	9

Table 1: Earthfault distance location deviations

It can be recognised, that the mean deviations are within such a range that it is absolute sufficient for the practical use. The goal of the location during ongoing supply should not be a measuring accuracy in meter but the rapid detection of the line segment, affected by the earthfault. The differences in the results of the models are remarkable small, maybe due to the well-balanced parts of cable and overhead lines. Loops with a great part of cables seem to be problematic. The maximum deviations were recorded in these cases. Furthermore, the deviations at cable-loops have been positive (calculated distance to the earthfault location greater than the real one), whereas at balanced loops the deviations were always negative. Even at high-resistance faults the deviations were positive. The reason for this, however, are the earth capacitances of the tree'd branches. Because of the small sample (25 field tests, 2 networks), the results cannot be considered as generally valid, however, they seem to be sufficient to confirm the effectiveness and practicability of this location-method.

Improvement of the earthfault distance location

Though the mean accuracy of the method is convenient in the practical operation , the maximum deviations are not yet satisfying. Improvements can be reached by using a more complex model, containing even the conductor-earth-capacities (T-equivalent circuit in the zero-sequence system [6]). This model shows better results, especially at high-resistance earthfaults and long tree'd branches. The main problem of accuracy is the great variation of the zero-sequence impedance (influence of ground conditions, defects in assembling, ageing etc.). Single measurements have shown, that the default values of line tables and real measured zero-sequence impedances may differ up to factor 2. Even the best model could not improve the accuracy. The most reasonable possibility for an improvement would be the measurement of the zero-sequence impedance for each section of the network. Practically, applicated on the whole network, this method will be too expensive.

The application of an adaptive model is a realistic approach. In this model the necessary measurement of the zero-sequence impedance is replaced by the results of real earthfaults. By means of parameter adjustment, the network model will be gradually improved. The results of the model-based tests were maximum deviations under 3%. The disadvantage of this method is, that, due to the low earthfault- rate, the model "learns" slowly and each network extension could lead to a temporary decrease of accuracy. Practically, this method would be always better than a "not adaptive" one.

CONCLUSION

In compensated medium-high-voltage systems, the application of the admittance-method with central data acquisition of the zero-sequence currents leads to a reliable earthfault detection. Using the option 'distance-location' even allows the earthfault location. Operating experiences in 2 medium voltage networks confirm, that the fault location can be determined with a mean accuracy of 5 %. Thus, no more time-consuming and risky search processes using switch operations are necessary and the line segment, affected by the earthfault, can be quickly switched off. By further development of the models, the accuracy of the distance location of about 1 % might be realised. The first operating experiences with such an earthfault-protection-system confirm impressive the effectiveness and the prospects of this method.

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