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Earth Faults in Isolated and Compensated Medium Voltage Networks and Their Identification with Numerical Protection Relays

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Earth fault, neutral earthing, numerical protection relay, medium voltage networks.

1 INTRODUCTION

The subject of this study is concentrated in the following directions:

- Earth fault processes in networks with different type of power transformer's neutral earthing;
- Methods and algorithms for different types of earth fault protection functions and their application in the numerical relays;
- Results from the algorithms operation.

The investigations of many authors regarding the neutral earthing in the medium voltage networks resulted in different suggestions for the development strategy in this field. On the final decision mainly financial and technical arguments have influence.

Finally three basic types of neutral earthing are approved – isolated, compensated through Peterson coil and resistance earthed.

The investigation of the earth faults has a long history. During the last 25 years a considerable data base and studies are developed through the digital oscilloscopes. Due to the complicated processes and the lack of the suitable technical devices the problems concerning the algorithms for the earth faults identification are solved in parallel with the development of the digital technique.

The most of the modern numerical protection devices have limited possibilities regarding the sampling rate of the analog and binary inputs. The usual frequency that is normally used is 800Hz or 1000 Hz.

With the development of the microprocessor technique during the last years the increasing of the sampling rate began to be more admissible due to the prices of the hardware. Due to this tendency some companies made successful attempts in putting on the market the protection relays with sampling frequency in the range of 3 – 5 kHz. This permits the application of already existing and the development of new algorithms using transient phenomena information. The appearance of the new protection relays with high sampling rate provokes at the moment the development of the investigations into two main directions – transient phenomena initial moment analyzing and high harmonic content monitoring during the power system steady state mode of operation.

During the development of the algorithms using the high harmonic content and the magnitude of the earth fault current $3I_0$ during the steady state mode two tendencies are approved – data acquisition and decision functions centralizing [3] and more actual with decentralization on a local level.

Searching the universal algorithm, which operates during the transient and the steady state earth fault process also persist as an approach for the numerical protection devices. It finds an application in

some countries with strongly developed power systems like Russia and is recommended by many authors [3][4][5], which present good results from its application. This approach is especially effective when is applied in devices oriented mainly or only to the functions of earth fault protection.

Another tendency [9], currently more propagated is the usage of separate algorithms for every protection function. They can be in operation simultaneously or in different moments of the earth fault process. This approach creates a possibility for choosing and combining the operation of different protection functions and algorithms depending on the specific features of the fault and the network.

In connection with the above mentioned conclusions the basic purposes of the paper are oriented towards the following:

- To present and analyze the data from transient and steady state earth fault processes in medium voltage networks registered by numerical protection devices;
- To present and analyze different algorithms for earth fault protection functions which are realized in the modern numerical relays;
- To analyze the results from the algorithms' operation;
- To present final conclusions.

2 INVESTIGATION OF THE EARTH FAULTS IN THE MEDIUM VOLTAGE NETWORKS

2.1 General Information

During the development of the algorithms for the earth fault detection the analysis of the processes with different parameters and types of neutral earthing has been performed by the authors. Because of the process complexity and the problems with its detection the study of the authors is directed mainly to the analyzing of the earth faults in the compensated networks. In the paper is also presented an analysis of the earth faults in the isolated networks.

Because of the presence of already established algorithms for the resistance earthed networks they are not a subject of the discussion in this paper.

2.2 Earth faults in isolated networks

Isolated networks find application in Russia and some other European and Asian countries like Italy, Spain and Japan.

In Figure 1 is shown accordingly a record of $3U_0$ (first signal), $3I_0$ (second signal) and $9Q_0$ (third signal from the top) during the single phase earth fault with the resistance to the earth $R=0$ and initial angle for the faulty phase at the moment of the earth fault occurrence $\varphi=200^\circ$.

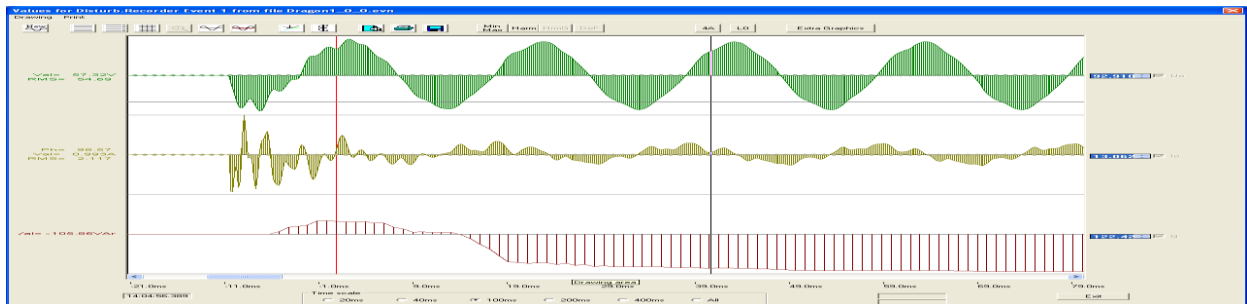


Fig. 1

As can be seen a pronounced transient phenomena for a time period of 20-30 ms is observed, whereupon the process becomes steady state with a significant high harmonic content mainly in the current. Reactive power values show that to the end of 30 - 40 ms they are not with an established characteristic.

In Figure 2 a relatively high resistance earth fault record for the isolated network and initial phase angle of 90° is shown.

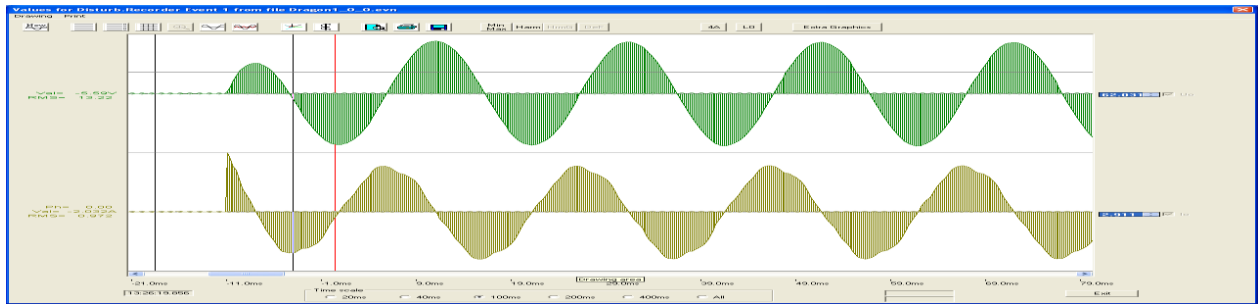


Fig. 2

The shape of the curves for $3U_0$ and $3I_0$ shows that the transient phenomena includes only a short and not very high peak value of the current $3I_0$ with the duration of several milliseconds. The steady state process is characterized with the significant decreasing of the high harmonic content in the current $3I_0$ and its practically missing in the residual voltage $3U_0$.

These and other experiments of the authors and the results of a lot of investigations confirm, that even relatively low earth fault resistance of about $1 \text{ k}\Omega$ has a considerable effect at the first moment of the transient phenomena. Initial angle for the faulty phase of the earth fault also influences mainly on the magnitude of the first peak value of the current $3I_0$.

2.3 Earth faults in compensated networks

The compensated networks are wide spread in many countries of Eastern and Northern Europe. It is well-known that this kind of neutral earthing uses Peterson coil, whose reactance has to correspond to the network capacitance. In Figure 3 is presented a record with data for $3U_0$, $3I_0$ and P_0 during the process of earth fault in compensated network at initial phase angle of 40° and a value of the earth fault resistance $R = 0$.

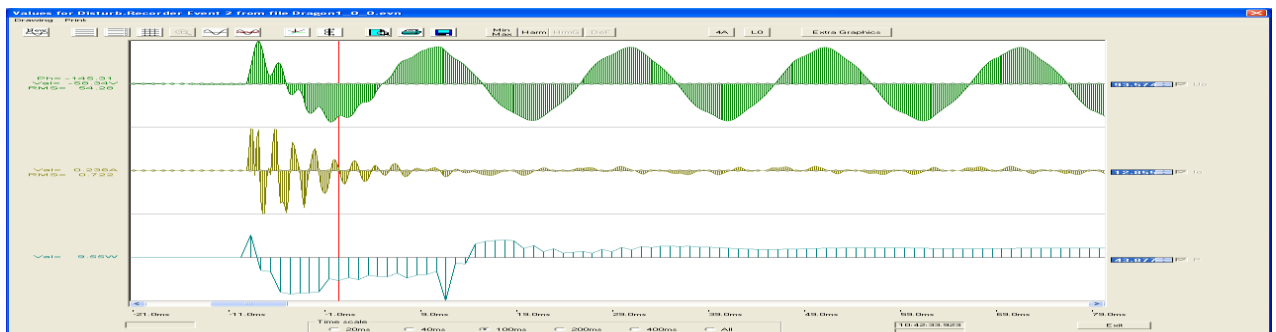


Fig. 3

The analysis shows, that as for isolated networks the transient phenomena in compensated networks has short duration and is characterized mainly with high initial peaks in the earth fault current during the first 15 - 20 milliseconds.

In Figure 4 are presented the curves for $3U_0$, $3I_0$ and $9P_0$ during the earth fault through the relatively high resistance and initial angle of 0° .

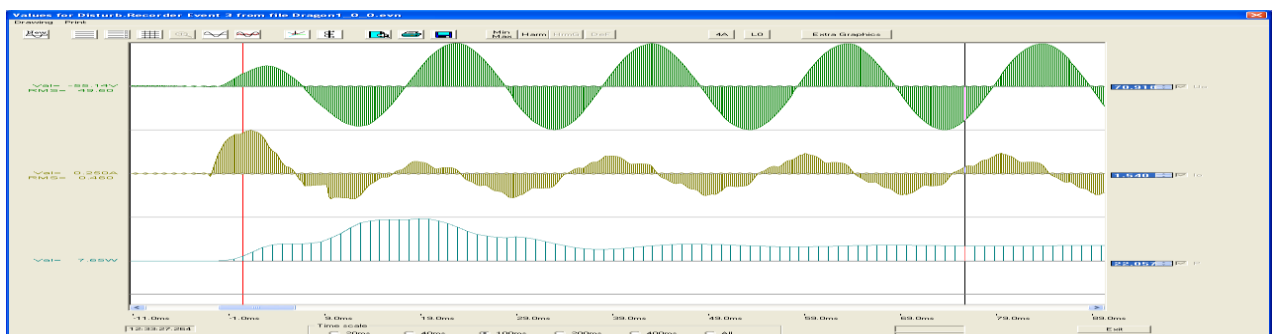


Fig. 4

As can be seen from the record the influence of resistance value on the earth fault parameters is obvious – practically missing transient phenomena with an exception of initial not very high peak value of the current $3I_o$. At the same time the analysis of the results shows that in case of high ohmic earth faults the active power P_o has a stable behaviour even in the initial moment of the earth fault.

2.5 Intermittent earth faults in medium voltage cables

The process of this kind of earth faults is characterized with very short repetitive peaks of the current $3I_o$ which forms a thermal effect and with the peaks in the neutral voltage that may cause the insulation breakdown in the other points of the cable and subsequent double point earth fault. This type of faults is encountered especially in compensated networks.

The intermittent earth fault in progress is presented in Figure 5.

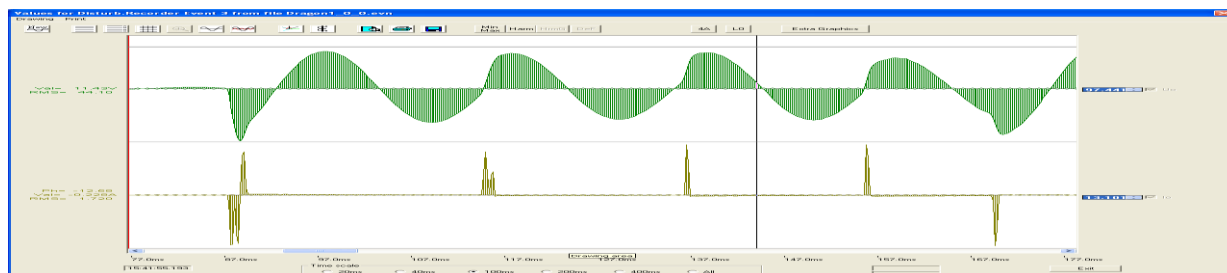


Fig. 5

The view of the process in Figure 5, investigations of the authors and of other papers [9] show that the magnitude of the current peaks is in the range of 0.1 – 5 kA, the duration is 400-800 μ s and the pause between them is 5 – 300 ms.

All records that are shown in the Figures 1, 2, 3, 4 and 5 are registered with a numerical protection relay and sampling frequency of 5 kHz for analog and binary inputs.

3 EARTH FAULT DETECTION ALGORITHMS FOR THE NUMERICAL PROTECTION RELAYS

3.1 General information

On the basis of the preliminary analysis of the existing situation presented in item 1, the methods for the earth faults detection can be classified into several categories.

Methods using the information from the transient phenomena:

- Transient method with usage of information for the first moment of the fault process in compensated and isolated medium voltage networks;
- Intermittent method for detection of repetitive ground faults occurring in underground cables in compensated networks.

Methods using the information from the steady state mode of operation:

- Wattmetric method – for compensated networks.
- Admittance method (conductance, susceptance) – for compensated and isolated networks.
- Methods using the high harmonic content in the earth fault currents.

3.2 Protection functions using transient phenomena during the earth fault

3.2.1 Transient protection

The operation of the transient protection algorithm is based on the residual current $3I_o$ and voltage $3U_o$ during the first moment of the transient phenomena.

As can be seen from the information concerning the investigations of the earth faults given in items 2.2 и 2.3 on the current magnitude during the transient phenomena influences mainly earthing resistance in the fault point and to the certain degree initial phase angle of the faulted phase. Transient phenomena investigations in the compensated networks as can be seen from the analysis given in the item 2.3, shows that the initial transient earth fault current $3I_o$ at the first moment is with very high magnitude reaching more than 10 times nominal value for the feeder current. Another specific feature, which can be seen in Figure 3 and Figure 4 is its very short duration, which is under 1 ms. The

analysis also indicates, that the basic criterion for the earth fault location is the sign of the neutral current $3I_0$ and neutral voltage $3U_0$ at the first moment.

On the basis of the investigations of the authors and additionally analyzed information from a number of papers [7][8][9] the algorithm for the protection operation is developed. The algorithm checks $3I_0$ and $3U_0$ values in the first moment of the fault and their sign. Depending on the information about the sign (both are with the same sign or not) the algorithm defines the fault location – in the protected feeder or out of it.

Another important feature is the detection of the type of earth fault regarding its duration – permanent or transient. This is monitored through the voltage fundamental harmonic values and at the same time is necessary to be insensitive to the moment of the feeder closing.

The term “first moment” used in the paper includes current and voltage instantaneous values and their signs for the first scan after the moment when the neutral current overreach the setting threshold.

The analysis of the authors concerning transient protection operation in a real numerical device shows that this type of protection algorithm is reliable and sensitive for the detection of low ohmic transient and steady state earth faults.

In Figure 6 are given the data from the process and the protection operation in case of steady state low ohmic earth fault in compensated network. The data from the earth fault includes the progress of $3U_0$ and $3I_0$ values and the protection „start“ output operation activated at the first moment of the transient phenomena.

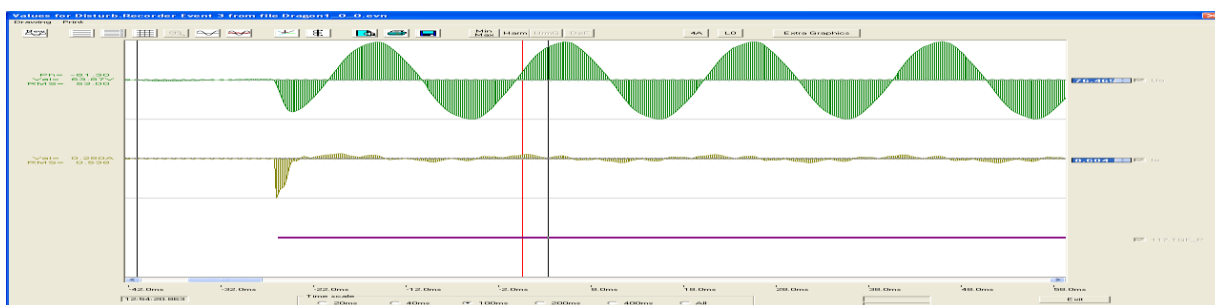


Fig. 6

A relatively low ohmic earth fault in progress occurred in the isolated network is presented in Figure 7.

A lot of experiments that are fulfilled by the authors and the curves in Figure 7 show that the transient earth fault protection is appropriate not only for compensated but also for the isolated networks.

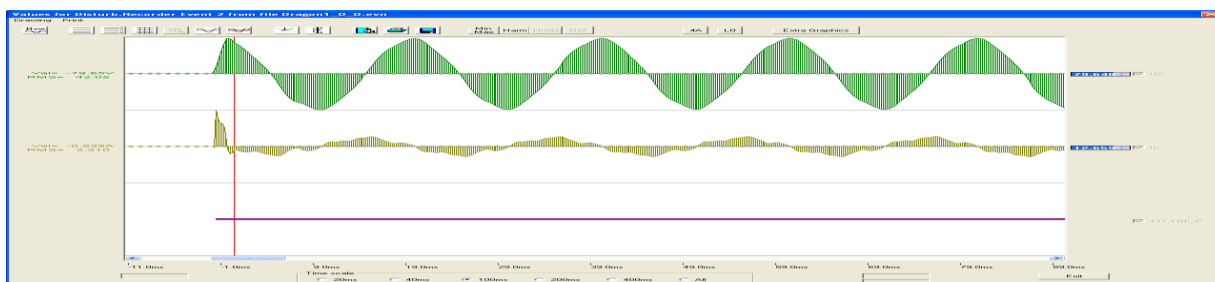


Fig. 7

Earth fault transient detection function is able to activate except alarm output also another output which can be intended for a tripping command. This will be in case of fault duration more than the respective time delay setting. For that purpose the second stage is provided.

3.2.2 Intermittent earth fault protection

This type of protection is dedicated to protect the underground medium voltage cables against the repetitive earth faults caused by insulation deterioration. The investigations show, that the earth

fault resistance in this case is with low value in the range of several ohms and very high peak values of the earth fault currents – up to several kA.

In case of repetitive insulation break down in the medium voltage cables it is typical that the current peaks are presented not only in the faulty feeder but also in the others. The difference is that in the faulty feeder the values can be several times higher than in the healthy feeders. Neutral current $3I_o$ and voltage $3U_o$ peaks at the first moment of every subsequent break down in the faulty feeder are practically in phase (the signs are the same – for both variables they are positive or negative).

The protection operates using an algorithm which reads presence, sign, number of impulses and distance between them. The protection is activated by the special functional block for identification of transient earth faults, which uses $3U_o$ and $3I_o$ values. There is an impulse counter for the intermittent earth faults in this block. The counter increases the number with 1 if the functional block registers new transient earth fault impulse which responds to the preliminary set criterion.

As for the transient earth fault protection the successful operation of the algorithm is strongly depending on the sampling rate which has to be high enough to register sufficient number of points for the reliable identification of the magnitude and duration of the impulses. Data for $3I_o$ and $3U_o$ and for the operation of the function during the intermittent earth fault in compensated network are given in Figure 8.

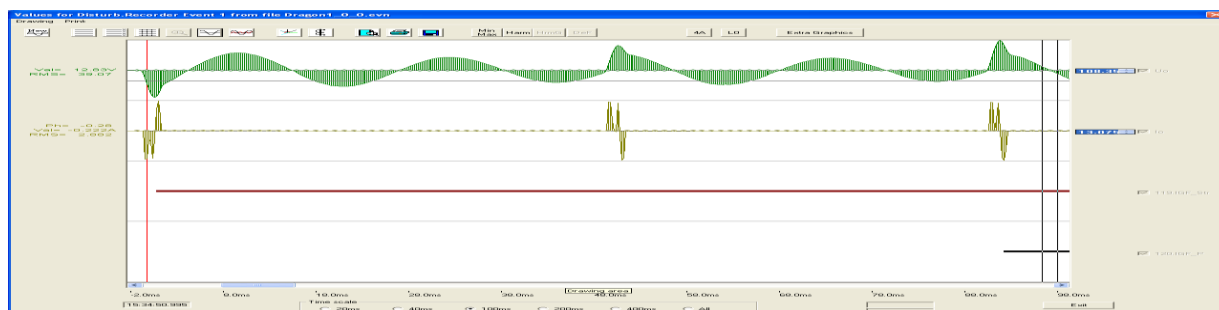


Fig. 8

The moment of the protection starting from the first peak and its continuously picked-up after definite number of impulses – in this case three, can be seen from the Figure 8. Depending on the number of the counted impulses the protection is able to start additional second stage which can be used for tripping command initiation to the faulty feeder circuit breaker.

3.3 Protection functions using the information from the steady state process of the earth fault

3.3.1 Protection with an evaluation of the high harmonic content in the earth fault current $3I_o$

The main criterion for this type of protection is that in the faulty feeder the magnitude of the neutral current with filtered fundamental harmonic is with the highest value. Application of this algorithm is limited because of the different values for the current high harmonic magnitude and content in the different cases. Algorithm developed by the authors limited to a considerable degree these disadvantages through the relative comparing of the high harmonic current in the different feeders at the same moment. It is not necessary to have a central device for a relative comparison of the earth fault currents, because of using the same Inverse time delay characteristics for all feeders and blocking all remaining from the feeder which high harmonic protection picks-up first.

3.3.2 Wattmetric protection for the Earth fault detection

The protection is suitable for the operation mainly in compensated networks. The algorithm that is applied by the authors in a particular numerical protection uses three main basic parameters for its operation – the magnitude and sign of the active power $9P_o = 3U_o 3I_o \cos \varphi_o$ and the magnitude of the neutral voltage $3U_o$.

3.3.3 Varmetric protection for the Earth fault detection

The algorithm for the Varmetric protection is a variety of the Wattmetric one and is suitable for earth fault detection in the isolated networks. The main difference is that the protection algorithm uses the reactive power $9Q_o = 3U_o 3I_o \sin \varphi_o$.

3.3.4 Admittance protection

The practical experience of the authors with the numerical protection devices and the papers from the other authors confirms that the algorithms using current $3I_0$ and voltage $3U_0$ fundamental harmonic values bring better results, especially for the steady state earth faults.

During the last years many authors [1][2][9] often recommend for the modern numerical relays a new effective algorithm using the information from the steady state process of the earth fault – admittance protection.

At the moment the usual variant using the admittance Y_0 has a lot of disadvantages connected with the necessity of information for Y_0 from all feeders connected to the same busbar and with the requirement for Peterson coil automatic regulation [1][2].

Some improvement of the algorithm is the inclusion of a directional node by using the conductance G_0 as a basic variable. The main disadvantage of the conductance protection, which can be observed also in the Wattmetric function is that its sensitivity is depending on the current unbalance of the network. A solution of this problem is the application of algorithm, using the conductance values calculated through the ratio of the current $3I_0$ and voltage $3U_0$ increments.

$$\Delta G_0 = \operatorname{Re} [\Delta 3I_0 / \Delta 3U_0]$$

where ΔG_0 , $\Delta 3I_0$, $\Delta 3U_0$ are the increments of the conductance, neutral current and voltage respectively.

This method is popular as Incremental conductance [1]. Additional development of the method is Adaptive Incremental conductance [2], for which the increments are between current value of ΔG_0 and its value before several periods and additionally simultaneously comparing with currently registered maximal value.

After the evaluation of the upper mentioned variants and the analysis of the results from the different investigations and experiments of the authors the algorithm on the basis of Adaptive Incremental conductance method is applied in practice. This decision considerably improved the protection sensitivity and decreased to a minimum the influence of the unbalance during the normal mode of power system operation.

4 CONCLUSIONS

The analysis of the results from investigation realized by the authors gives the reason for the following conclusions:

In case of zero or low resistance earth faults in the isolated or compensated networks it can be seen fast transient phenomena which is characterized mainly with very short current peaks with high magnitude and duration under 1 ms.

Main criterion for the detection of the faulty feeder during the transient phenomena is the magnitude and the sign of the neutral current and voltage only at the first moment of the fault.

For the successful operation of the transient, intermittent and high harmonic content protection algorithms the sampling frequency of 5 kHz or more is recommended.

According to the implemented experiments and investigation results for earth faults with different parameters it can be concluded that the transient earth fault protection has significant advantages for fast and adequate detection of short and steady state low ohmic earth faults. In this connection it can be recommended to use this protection in combination with others which are more sensitive to high ohmic earth faults like admittance or conductance protection.

The effectively combined operation of the different algorithms during the continued earth fault process can be achieved through the appropriate settings. In this way the protection device attain flexibility and possibility for fast and appropriate change of the currently operated algorithm depending on the specific features of the earth fault characteristics and the network.

It is possible to realize the high harmonic content protection function without necessity of central device. The only requirement is to have protection devices which support the same type of inverse time characteristics.

The experiments carried out by the authors confirm that the conductance protection has advantages over the other kinds of earth fault protection functions using information from the steady state process. This is especially correct in case of high ohmic earth faults, because the conductance

algorithm uses ratio between neutral current and voltage in contrast to the Wattmetric protection where their product is applied.

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