IDENTIFICATION OF GROUND FAULTS ACCORDING TO THE ANALYSIS OF ELECTROMAGNETIC FIELDS OF MV LINES

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ABSTRACT

The methods of assessing the place of the ground fault in compensated MV networks are known. At present realizations, the evaluation of ground faults is usually based on using more methods specialized for the detection of individual types of ground faults. The methods used in the paper follow from the analysis of electromagnetic fields of phase conductors and lines. Ground fault indicators have been installed at points with telecontrolled section switches and reclosers. The development of communication technologies enables new system-wide solutions to be applied in this field.

A system-wide solution with telecommunicating indicators and with transmitting not only the result of evaluation but also the development of quantities being measured leads not only to increasing the reliability of determining the section of a MV line affected by the ground fault but, at the same time, it is also possible to assess the type of the ground fault including the prediction of the origination of subsequent ground faults, with the possibility of reducing the number of short-circuits to ground. The used solution enables us to telemeter the values of phase currents at the point where the indicators have been installed.

INTRODUCTION

The operation of the network with a ground fault belongs to states with an increased risk of the origination of heavy failures which would result in the interruption of electricity supply to customers. This also explains a great interest in performing theoretical analyses and in developing methods for assessing the place of the ground fault which could be as accurate as possible. Although many methods for localizing the ground fault are available, there exists no universal method which could be applied in all types of non-solidly grounded networks and to all types of ground faults. However, even appropriately chosen methods do not guarantee a sufficiently accurate localization, mainly in the case of high-impedance and/or arcing ground faults. Great stress is therefore laid on a high reliability of indicating or measuring instruments. A good sensitivity can be achieved by installing indicating equipment as closely to the place of the failure as possible. This is also a reason for the expansion of indicators operating on principle of the measurement and analysis of electromagnetic fields.
realizing a ground fault indicator with the analysis of electromagnetic fields, electromagnetic fields of individual phase conductors in as close distances of phase conductors as possible are analysed. The resulting signals corresponding to $U_0$ and $I_0$ are put together in electrical circuits of the indicator.

The placement of this indicator can be seen in Fig. 2. A defined way of summation of signals from fields of individual phases is the advantage of this method while in the case of the first method it depends on the environment which can deform the resulting field significantly and superimpose other influences. The disadvantage of the second method consists in the requirement to install the sensors of fields in such a close vicinity to individual phase conductors so that it would be possible to neglect the influence of neighbouring phases. However, when the distance between phase conductors is known and practically constant, this influence can be corrected.

The following equation is valid for a symmetrical plane arrangement of conductors:

$$I_0 = I_1 + q \cdot I_2 + I_3,$$

where “$q$” attains the values 0.6 to 0.85 for the distance of conductors within the limits 0.6 m to 1.4 m. The distance of the sensor from the conductor is 0.35 m. The constant “$q$” can be assessed, with a good accuracy, by calculation from the geometrical disposition of conductors and sensors. In general, the same relation is valid for the sensor of the zero-sequence voltage $U_0$ but the constant “$q$” of the electric field can be reliably assessed only by measurement carried out on the respective arrangement.

The indicators which use the second method are, in general, less dependent on the environment and are characterized by a higher reliability of the indication of ground faults. However, they are more demanding as far as their installation and operability are concerned.

The MEg60 indicator, e.g., represents a ground fault indicator analysing the electromagnetic field of the whole line according to the first method [2]. It is provided with the indication panel for local displaying of the direction of the ground fault and for indicating the short-circuit. As it is supplied from internal battery, the measured shapes of the components of electromagnetic fields are recorded into the internal non-volatile data memory and, at the origination of an event, only the states of resulting evaluations are transmitted by the communication SMS module.

The MEg61 indicator in version SP (field sensor) analyses electromagnetic fields of phase conductors according to the second method in distances given by composite insulators. As this indicator is installed at locations with external supply, it measures and evaluates the signals of electromagnetic fields continuously. At the origination of an event, the GPRS means transmit not only information about states but also about the development of respective quantities. A subsequent centralized evaluation of records and states of all indicators installed in the given MV network is thus enabled. This results in the increased reliability (supported by system-wide processing) of assessing the place of the ground fault. Furthermore, according to a changed configuration of the MV network and to a change of other conditions, it is also possible to change the sensitivity and the parameters for evaluating the ground faults remotely. An example of the record of the shapes of not corrected phase quantities is given in Fig. 4.

When a ground faults has been indicated, the localization of the failure is carried out and the operator will be informed. He himself can then diagnose the record of measured and additionally calculated quantities, i.e. RMS values of current or voltage, zero-sequence components of currents, higher harmonics, etc.

METHODS OF INDICATING THE GROUND FAULTS

The above-mentioned indicators make use of passive methods for the localization of ground faults [1]. These methods are based on measured parameters of voltages and currents after the origination of a ground fault. These parameters can be evaluated during the transient process called forth by the ground fault or after its stabilization (coming into steady state). For that reason, the passive
methods may be divided into methods using the steady state signal (statistical methods) and into those using the signal during the transient process (dynamical methods).

**Statistical methods**

In compensated systems with the arc-suppression coil the following methods can be applied:

- **Method of the fifth harmonic**
  The main task of the arc-suppression coil in non-solidly grounded networks is to compensate the capacitive ground current, especially its first harmonic. Harmonics can be generated due to a non-linear equipment and under the influence of a ground fault in the network. A significant role among them is also played by the fifth harmonic which is not compensated by the arc-suppression coil. The method uses this harmonic for a more sensitive localization of the failure where the fifth harmonic is greater on the faulty line than on lines not affected by the failure and has opposite direction. As the fifth harmonic of the ground current attains low values only (max. 10%) this method is highly dependent on correctness of the measurement and on balancing of current transformers. The increase of the sensitivity of this method is obtained by summation of the 3rd, 5th and 7th harmonics of the current.

- **Admittance principle of the zero-sequence component**
  The ground fault also changes the admittance of the faulty line. The zero-sequence admittance on all feeders prior to and after the failure is compared by this method. The feeder on which the greatest increase of the zero-sequence admittance takes place and/or on which the preset admittance value has been exceeded is then marked as faulty. The applicability of the above-mentioned statistical methods is not so wide as in the case of dynamical. This fact is essentially influenced by the arc-suppression coil which, in ideal cases, totally compensates the capacitive ground current called forth by the ground fault. Therefore, it may happen that the zero-sequence component of the current on the feeder not affected by the failure is higher in some cases than that on the faulty feeder. This leads to incorrect localization and to bad effectiveness of the method.

**Dynamical methods**

These are the methods using the short transient processes generated by the failure.

- **First half-wave method**
  When a ground fault originates, a short intensive transient process is generated due to the influence of capacities of individual feeders. The capacity of the faulty phase will be discharged and the phases not affected by the failure will be charged during this process. This short discharging current is recognizable in the first half-period after the origination of the ground fault. The method then compares the phases of the zero-sequence component of the current and of the zero-sequence component of the voltage. If the zero-sequence components of the current and of the voltage are in phase during the first half period after the origination of the ground fault, the matter concerns the line not affected by the failure. On the contrary, if the zero-sequence components of the current and of the voltage are in antiphase, the matter concerns the line affected by the failure. The advantage of this method consists in the possibility of its application in compensated non-solidly grounded networks and it localizes even arcing ground faults well. Higher technical demands on the realization are then caused by a short interval of time for an evaluation. Fig. 4 shows oscillographically obtained shapes of currents and voltages at the origination of the ground fault as recorded by the ground fault indicator MEg61. The discharging current can be identified in the faulty phase L2 after the origination of the ground fault. The magnitude of this discharging capacitive current is given by the extend (length) of the network.

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**Figure 4:** Record of the MEg61 indicator about the ground fault (phase currents and voltages)

- **Connection of the resistor**
  A resistor through which the neutral point is connected to ground for a short time is used for assessing the faulty feeder. After the origination of a ground fault, the resistor shall be connected, after a short delay, for the period of about 1 s and the changes of currents and voltages will be evaluated. If, after the resistor has been connected, the current of the faulty phase increases due to a change of the admittance of the failure loop, the matter concerns the line affected by the failure. In the opposite case the matter concerns the line not affected by the failure. Similarly as in the previous method, the ground fault can be localized even from the zero-sequence components of the voltage and the current. If, after the resistor has been connected, the difference of amplitudes of zero-sequence components has the same sign, the matter concerns the line not affected by the failure and if the differences of the zero-sequence voltage and the zero-sequence current have an opposite direction, the matter concerns the faulty line (feeder). The disadvantage of this method is the increase of the current loading at the place of failure and the endangering of the public. For that reason, it is appropriate to connect the
resistor only after it has been undoubtedly assessed that, e.g., the first half-period method or other methods did not identify the place of the ground fault unambiguously. In the opposite case, the connection of the resistor would be redundant and irresponsible with regard to endangering the public by the effects of the voltage.

RESULTS FROM INDICATIONS OF GROUND FAULTS
The ground fault is the most frequent failure state in compensated MV networks. Its consequences can even lead to the interruption of the electricity supply (outage) and to economical losses on the side of the supplier as well as of the consumer. The suppliers of electricity therefore apply available means for preventing such losses. One of these means is the prediction of the place where the ground fault could originate. Each indicator saves the records about the originated ground fault into internal memory. The operator reads out the data from this memory in certain intervals of time or the stored data can be instantaneously transmitted to the operator at the dispatch centre who can analyse them. All data, after having been read out, are processed and they may be used for the prediction of electrically weak places in the MV system. The operator may then be sent there for performing visual inspection.

The indicators have been installed at a chosen locality of ČEZ, a. s. since the year 2005 and at a chosen locality of ZSE, a. s. since the year 2007. The data from the installed indicators are read out and evaluated regularly. As it is evident from the results, failure states originate mostly at random and in correlation with meteorological conditions. A monthly frequency of failures inside the network being tested as given by the MEg60 and MEg61 indicators will be shown as an example.

The applicability of the data as a help for managing the failure states is given by their timely presence at the control centre. For that reason, the telecommunication and the data transmission to the centre is the necessity for all indicators installed outside the object of the substation. The indicators are equipped with a series communication interface which is capable of providing a two-way transmission of information with the centre. A software system secures the processing of information coming from individual indicators and then it hands the data over into the dispatch system. At a changed operational connection this system is also able to carry out the parameterization of individual indicators remotely.

CONCLUSION
There exists no universal method which would be applicable to all types of networks and ground faults and which would be able to localize the ground fault in these networks safely. For that reason, the most appropriate solution consists in combining more methods so as to restrain their deficiencies, respecting at the same time the frequency of origination and the importance of various types of ground faults. Thanks to the combination of methods presented in this paper and to a convenient topological dislocation of indicators, a high reliability can be achieved. It will be possible to give a tip on places with the most frequent occurrence of ground faults and thus to predict electrically weak places in the network. A software located at the control centre will serve for this purpose. By using the telecommunication it will read out the data from individual indicators automatically and collect them into a data base according to requirements of the operator. When such a complex data base will be available, it will be possible to evaluate the places with the most frequent occurrence of failures and, even based on faulty transient indications which are not used at present, it will be possible to predict electrically weak places in the network. This will decrease the frequency of outages of electricity supply to consumers and the quality of supplied electricity will thus increase.

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