EVALUATION OF NEW EARTH FAULT LOCALIZATION METHODS BY EARTH FAULT EXPERIMENTS

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ABSTRACT

This paper presents results of earth fault field tests in a medium voltage network using new earth fault detection methods. An interpretation of voltage and current signals measured at the area of influence is provided. The pros and cons of different algorithms in different grid constellations are elaborated. The results show that new detection algorithms can provide stable directional decisions even in combination with unconventional transducers. This information is very important for the grid operator. With reliable information of the earth fault direction, especially in rural areas, the field engineers can be deployed more efficiently. Another focus of the tests was on the earthing system. At special grid components, such as dead end poles with cable link, the earth potential rise (EPR) was measured. With the signals measured throughout the tests, results of previously taken measurements to verify the earthing system could be confirmed.

INTRODUCTION

Statistic evaluations confirm that faults in electrical networks mainly start or persist as earth faults. Conventional earth fault detection methods are designed for stationary conditions at the fault location and for radiant, non-meshed grids. These methods have problems with the identification of high-impedance faults in overhead-line grids and are not capable of the identification of restriking faults in cable networks. Further, they are sensitive to the crosstalk of the load current to the zero-sequence system, which occurs in every meshed grid. As a consequence, very often an earth fault is not recognized at all or a wrong feeder is identified to be the faulty one. This maloperation considerably increases the time needed for locating and clearing the fault.

To meet these problems, new algorithms have been developed and also partly implemented in new relay technologies in recent years. In 2008, the KELAG Netz, an Austrian DSO, started a project to evaluate optimization opportunities in the field of earth fault localization. With an average percentage of about 50% cables and 50% overhead lines (OHL) in the 20-kV distribution network the challenge is to identify systems that can handle known problems with both line types.

Two basic conditions were defined for the project: that the grid should still be operated with resonant earthing and that the operation centres should be supported with state-of-the-art techniques. In a first step, the integration of these new relays in fully-automated distribution stations was standardized. The project aims at further minimizing the localization time by installing earth fault locating relays in decentralized non-automated substations. Therefore a number of substations in a representative test area were chosen. The necessary adaptations should consider the individual setup as well as reasonable expenses. Another challenge was the installation of the remote control technology in rural areas with limited communication infrastructure. In Figure 1 a schematic overview of the selected grid area is shown.

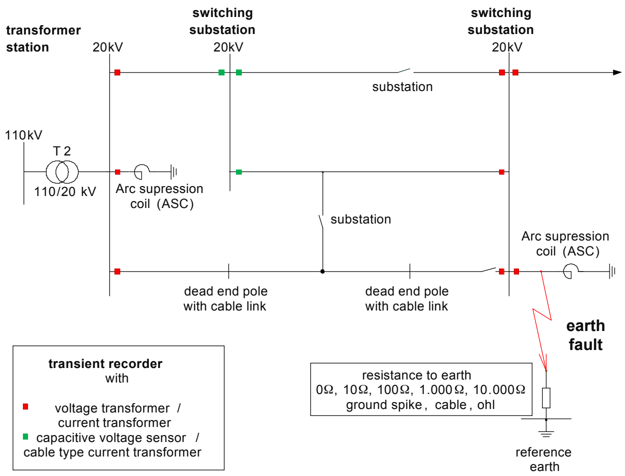

Figure 1: schematic overview of selected grid area

To confirm the measuring capabilities of the already installed new equipment and to specify the requirements for further equipment, field tests in a 20-kV grid were carried out. The arranged field tests should cover most of the known earth fault types in the observed distribution network.

SUBSTATION EQUIPMENT

To implement an earth fault localization system the zero-sequence current i_0 and the zero-sequence voltage u_0 have to be provided. Currently, most decentralized substations are not equipped with any measuring facilities and therefore have to be retrofitted. Mounting of conventional voltage transformers is not always possible, especially in substations with open design installation or in gas isolated switching stations. Therefore, various different procedures were used to make the necessary changes.

In substations in open design, using voltage sensors (constructed as capacitive divider insulator) instead of conventional transformers is an easy and affordable way to provide a voltage signal. In this case the existing insulator was replaced by the sensor. In gas isolated switching stations the capacitive test bushing was used. Testing the suitability of capacitive sensors for this application in terms of their accuracy was part of the project. To adapt such stations with current transformers is technically less demanding. In case of a cable connection, mounting cable type current transformers is not a big challenge. In overhead line stations in open design installation, one can adapt the conductor rails to mount conventional current transformers.

The predominant location of the substations is in rural areas where the communication infrastructure is poorly developed. In order to implement an area-wide earth fault locating system, a communication infrastructure to transfer the information to a control center is a determining factor. In this case the access to these stations was implemented by a mobile broadband communication via UMTS. The connection was implemented through a VPN connection with several security levels. In the substation a modem with a LAN-port was set up. With this realization a comfortable remote access to the installed equipment for maintenance is possible.

FIELD TESTS

Preparations

In the run-up to the tests, detailed preparations of the whole measuring setup were made. These preparations include decisions on the signals to be measured and the equipment needed to get signals that can be interpreted. Most of the required measuring points were already prepared because of the preinstalled relays. During the experiments voltage and current signals were measured with transient recorders in the affected network at important grid nodes shown in Figure 1. With these measurements it should be possible to define the requirements on earth fault relays to recognize earth faults and to evaluate the direction.

After choosing the needed measuring points the sampling rate for the transient recorders was chosen at 10 kHz. This high value results in a tremendous amount of data, but has the advantage to make possible reproduction easier. On the other hand these data can also be used to verify network models.

Another topic in the run-up was the fault location. It should be possible to simulate earth faults as realistically as possible. Typical fault conditions should also be covered throughout the tests. Therefore the decision was made to define the impedance at the fault location by high voltage resistors. The values of the high voltage resistors were chosen on typical resistance to earth values of known earth faults in the observed 20-kV grid. In the experiments values of 10, 100, 1.000, and 10.000 Ohms were used. With the choice of these values an interpolation of resistance to earth values can be carried out.

The device used to insert an earth fault, which was built using an automatic door-opener, is shown in Figure 2. With the use of this construction the ignition time of the arc can be guaranteed at the maximum of the phase voltage. This is necessary to reproduce realistic conditions. It is also essential for the analysis of transient incidents. The construction is mounted on an aluminium plate connected with the earthing system of the substation nearby. The connection to the network is provided via a high voltage cable (visible on the right side of Figure 2) and a circuit breaker. The circuit breaker is equipped with a protection relay. The overcurrent protection relay is set to undelayed tripping. In case of a double earth fault the test arrangement would be instantaneously disconnected from the network.

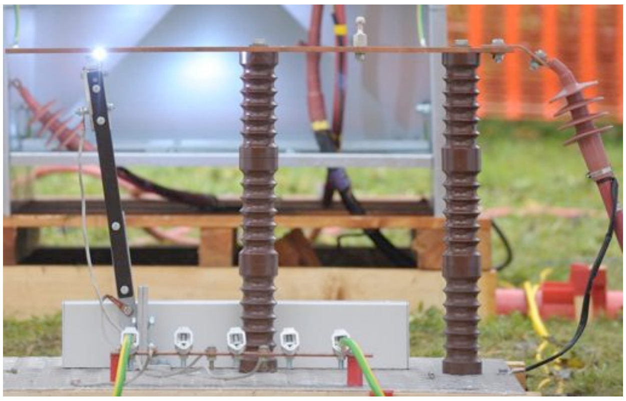

Figure 2: earth fault switch

Test Sequence

In order to get reproducible results, the resistance to earth was defined by high voltage resistors. Tests with a ground spike, an overhead line conductor, and a damaged high voltage cable (Figure 3) were conducted to verify the presumptions regarding the values of the high voltage resistors. Furthermore, the effects of looped grid status and the influence of a decentralized arc suppression coil (ASC) were analyzed.

The following tests were performed:

- Earth fault with 0 Ohm (direct connection to earthing system) and decentralized ASC
- Earth fault with 10, 100, 1.000 and 10.000 OHM via high voltage resistors

- Earth fault with ground spike (measuring the potential gradient)
- Earth fault with damaged high voltage cable (looped network status and radial network status)
- Earth fault with OHL on ground

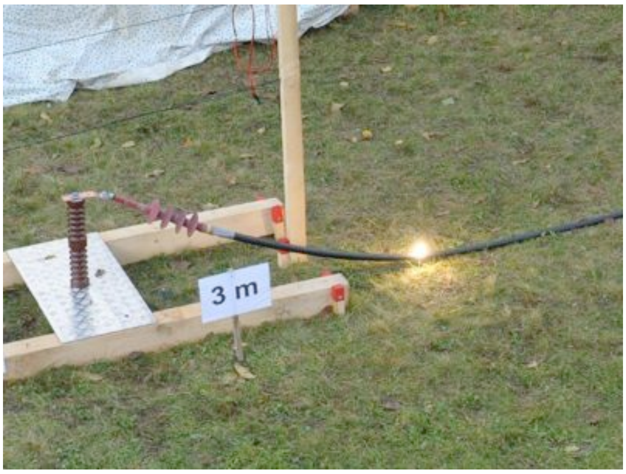

Figure 3: restriking fault at damaged high voltage cable

In every test the ASC was manually de-tuned to vary the residual current via the fault location. After about fifteen seconds all measurements needed for directional decisions were taken.
Another focus of the project was the earth potential rise (EPR) at special grid components at the area of influence. To address this, measurements were taken at remote components such as a small power plant connected by high voltage cables and at dead end poles with a cable link. Additionally, the potential gradient was measured at close range to the fault location. By means of these measurements a realistic evaluation of the earthing system can be accomplished.

RESULTS OF THE FIELD-TESTS

Due to the special construction to trigger the arc, the ignition starts at the maximum of the phase-voltage in all tests.

Comparison of tested earth fault detection methods

Transient Method (qu2) [1][2]
Depending on the available pretrigger recording, the identification of the faulty feeder was successfully in all tests, excepted the 10 kΩ. Detailed evaluation of the recorded data has shown that the method would have worked correctly up to a fault resistance of about 5 kΩ. This method also worked correctly in combination with capacitive sensors.

Intermittent-method (qui) [1][2]
During the restriking cable faults only the qui-algorithm worked correctly. Especially the cos(φ)-method delivered no correct signalization. The possibility to use capacitive sensors to calculate the zero-sequence voltage was also confirmed.

cos(φ) [3]
The capacitive current I_{CE} of the network was 115 A and the wattmetric current 2.6 A. Due to this small wattmetric current, the setting for the minimal current was 0.8 A. As a result of the angle error between u_0 and i_0 the virtual wattmetric currents of healthy feeders were sometimes higher than this starting current. The signalization of the faulty feeders using the cos(φ)- method was therefore not reliable, especially in combination with the capacitive voltage sensors. In case of the restriking earth fault a correct signalization was completely impossible.
In one test the fact of the wrong signalization, due to phase-splitting in looped configuration, was confirmed.

Harmonics method [3]
Normally the 3rd harmonic does not exist in the network. However, in one test with OHL lying on the ground, the 3rd harmonic was large enough for detection of the faulty feeder. In this small network the method worked more or less satisfactory with lower frequencies (5th harmonic).
The harmonic method also had some problems in case of restriking earth faults.
In these tests it was also observed, that the harmonics are very small in case of fault impedances over 100 Ω and could not be used for directional decisions.

Fast-pulse-method without u_0 [4][5]
This new method injects a defined current pulse-pattern into the zero-sequence system [5]. In case of a low ohmic earth fault, this current is flowing from the source to the fault location and can be identified. Figure 4 shows the current via the fault location in case of an OHL lying on ground.

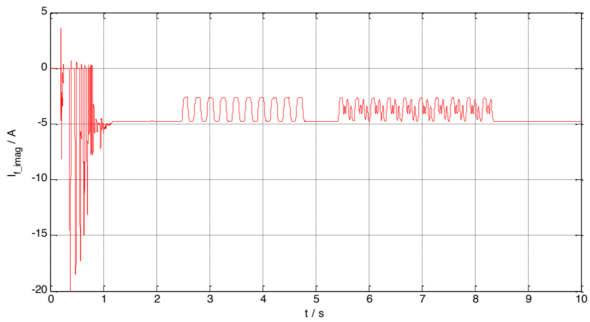

Figure 4: current via the fault location

In the new algorithm the complex current is evaluated and a directional signalization is available without measuring the zero-sequence voltage. This method is working up to fault-impedances of about 400 Ω. The complete evaluation can be done within a few seconds.
The tests confirmed the reliability of this method for stationary earth faults. It also worked in the case of OHL lying on ground.

Unfortunately, this method is not working in case of restriking earth faults.

Fast-pulse-method with u_0 [4][5]

The improved version also uses the zero-sequence voltage and can be used up to fault impedances of about 10 kΩ. This method also worked in case of OHL lying on ground, but it did not work in case of the restriking cable earth fault. Advantages of both fast-pulse methods are that they deliver directional information and that they can be used also in looped network-configurations. An additional advantage is that with the fast-pulse-method with u_0 it is no longer necessary to handle the network in a guaranteed overcompensated state for a reliable signalization. Using these methods allows also switching operations in the network during the localization of the faulty segment.

Results of earthing measurements

The fault location was placed in a global earthing system but directly at the fault location at a radius of about ten meters no active earthing element was installed. In front of the field tests the resistance to earth and the potential gradient was measured. In the test with a ground spike the potential gradient near the fault location could also be measured. Comparing these two measurements there was no difference in the resistance to earth. It could be verified that the potential gradient has its highest value within a meter from the fault.

Another measuring point was the EPR at dead end poles with cable link. In the considered grid area these facilities are built with an earthing connection of the cable sheath, the additionally installed earthing strap and the potential grading earth electrode around the pole. These poles are electrically located between the fault location and the ASC. Therefore, the residual current should have an influence on the EPR. At the field tests a maximum EPR of 13 Volts was measured. Another measuring point concerning the EPR was at an remote power plant. In this case a maximum of 3 Volts was measured. First analyses indicate an influence on the EPR by the impedance at the fault location as well as the de-tuning of the ASC.

Detailed analysis on the earthing system is part of a study which is supervised by the Institute of Electrical Power Systems at Graz University of Technology. This study aims to evaluate the existing installations and to envisage possible developments such as increased replacement of overhead lines by cables.

CONCLUSION

The results of the field test show that within the mentioned grid constellation the transient method, the intermittent method and the fast-pulse-method with u_0 can all provide stable directional information. Unfortunately, none of the methods can provide a stable decision in every fault condition. These results show that only a combination of detection methods can cover all different fault types. The transient method can be used to provide initial information in the control center. In case of looped network status, switching operations are needed. In comparison to the other mentioned methods the transient method is not repeatable. This means that it cannot provide any new information after changing the switching status of the network. Therefore, one of the other algorithms is needed to provide a directional decision. In case of networks with shares of cable and OHL, the intermittent method as well as the fast-pulse-method have to be implemented to recognize the earth fault direction. If an individual signalization of these two methods is provided, the grid operator gets additional information on the location of the fault in the network.

The use of the fast-pulse-method requires the installation of a High Power Current Injection (HPCI)[5]. However, with increased replacement of OHL by cables, the resonance curve becomes sharper. For this reason, the installation of an HPCI to tune the ASC is advantageous.

At the moment the decentralized substations are connected by a mobile broadband connection. A possible integration into the SCADA system is currently examined. Conventional methods like private mobile radio or fixed connection by optic fibre should also be considered as a possible option.

The results of the field tests can help to define future standards in terms of substation configuration. This includes decisions regarding transducers as well as earth fault detection relays.

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