EXPERIMENTAL VALIDATION RESULTS OF THE ACTIVE GROUNDING SYSTEM FOR MV NETWORKS

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ABSTRACT

This paper presents the key questions and results of the validation of the novel active grounding system for MV networks. The system is based on a multi-frequency power converter, which combines a new power electronics device with a protection and control system.
The experiences of the first real application in a MV distribution substation conducted in Gernika– Spain will be shown along with lab testing data and field details.

INTRODUCTION

The active grounding system has the traditional advantages of a resonant network, such as arc suppression or low step and touch voltages. However, additional features are achieved by the injection of controlled current in magnitude, phase and frequency as shown in CIRED 2009 [1].

Two main tasks, described below, were considered for the system validation:

- **In the laboratory**, a scale model of the active grounding system is used connected to a MV network simulator. Ground faults are simulated on different network configurations simulating several combinations of overhead line and cable sections, and a wide range of fault impedances.
- **In the field**, real tests are held. Prior to carry on fault extinction tests, the network is checked in order to make sure that isolation level and network component rating are able to withstand the new operating conditions, which are similar to those necessary for resonant networks. The active grounding system is used to create controlled phase-to-ground overvoltages in each phase and facilitate the process. Fault detection and location is tested for provoked (intentional) faults, including those of high impedance. Finally, the active grounding system performance is tracked and recorded for stand alone operation.

SYSTEM OPERATION

The active grounding system is able to:

- Perform network zero sequence impedance calculations by means of the injection of fundamental and non-fundamental (other than 50-60Hz) frequency currents. This calculation is used, during normal operating conditions of the network, for the calculations for the detection and location of the fault by the grounding system.
- Provoke a controlled neutral voltage, not only in magnitude and in phase, but also in time, so the voltage of each phase gets the desired voltage.

During a phase-to-ground fault in a feeder, the active grounding system performs:

- Fault location, both for transient and permanent faults, by means of an innovative and enhanced protection system and fault locator based in measurements of different frequencies generated by this new system.
- Fault extinction, injecting zero-sequence power frequency current to cancel the voltage of the faulted phase, extinguishing transient faults and, as a result, avoiding the tripping of the feeder breaker.
- The reduction of faulty phase-to-ground voltage, in case of weak insulation points or partially damaged underground cables, to keep the line in service until the problem is fixed

In addition, network insulation testing, for condition based maintenance purposes:

- Controlled voltage changes are used in combination with detection and location features of insulation failures, allowing the condition based maintenance of MV feeders.
- On-line network component monitoring and diagnostic can be done in combination with partial discharge detection devices installed in substations or portable detectors can be used for weak insulation points detection.

SCALE MODEL SYSTEM

The current injection in the network for the system operation implies interacting with that network. It is not possible to operate with this active grounding system without changing any magnitude of the network, as it can be done with a protection and control system. Consequently, a model where changes in magnitudes will no have any real influence is needed.

Additionally, for the field testing, it is necessary to wait for an event to occur, with no chance of testing what in fact is needed and the number of times required to guarantee the correct response of the system. However, the validation of the active grounding system requires a range of repetitive tests.

The objective of the scale model system is guarantying the suitable response of this system and the correct operation of the network during field tests. The influence of the levels of load currents and voltages on the validation is small, since the injected currents are not present in the zero-sequence components of actual networks. Therefore, a low power model is a useful tool to validate the system, in conditions more realistic than simulations.

Thus, the model used comprises the active grounding system and the distribution network. This model allows testing the operation principles and the correct operation of the complete system. By means of the current injection of frequencies not existing in the network, measurements and calculations accuracies are checked. On the other hand, injections at network frequency are done in order to check how fault currents are cancelled and how controlled overvoltage can be provoked.

Nevertheless, field tests will be necessary to determine the behaviour of the system in a real network, given that in this model discrete components (resistors, inductors and capacitors) are used to simulate the distributed parameters of overhead lines and cables of a real network.

Description of the system

Network model is constituted by a transformer and three feeders divided into sections and different types of loads. Several network configurations can be tested modifying the type and number of sections of these lines. Besides, it is possible to simulate ground faults for each line section with resistive fault impedances and/or defective MOV surge arresters. Power electronics and the protection system model is a precise reproduction of the real one with lower rated power. Finally, feeders and grounding currents and busbar voltages are monitored to analyse the response of the whole system.

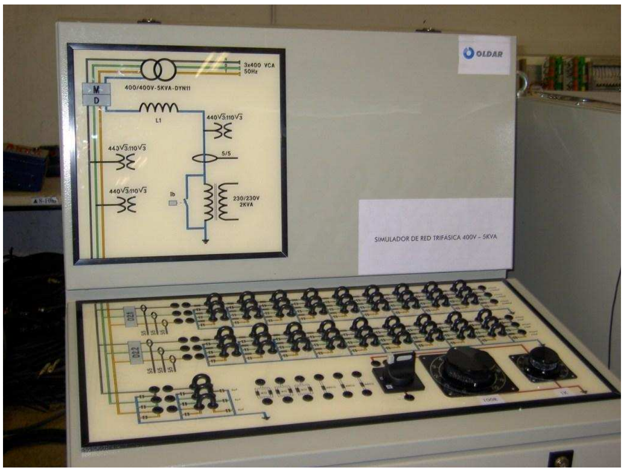

Image 1: Distribution network simulator

Image 1, shows the distribution network simulator, with its diagrams in the front, where the network is modelled. In the diagram above, the transformer of the substation, grounding impedance and the connection of the active system by means of a transformer is included. In the one below, three lines composed by different sections, loads and resistances to generate the fault where required.

Laboratory testing results

There is included a brief summary of the different result obtained during laboratory test with the scale model.

- Measurement accuracy

The first magnitude to be measured is the capacitive impedance of the network by the injection of a frecuency different to 50-60Hz. It can be done at any time and with a minimun injection.

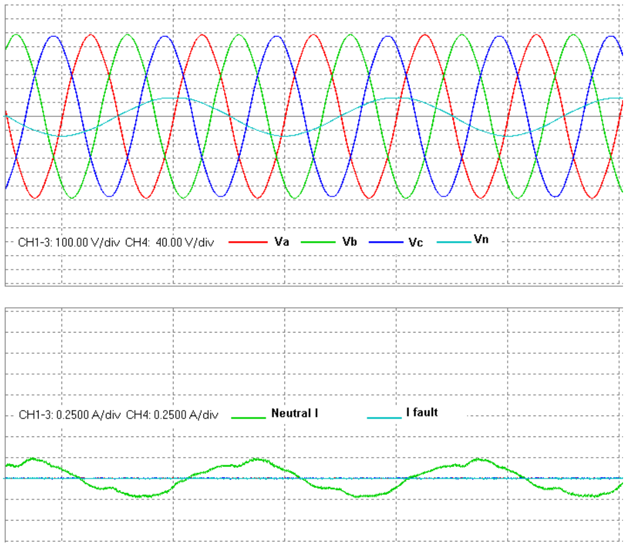

Figure1: Injection of a 25Hz current in a normal operation.

Despite the current injection of 25Hz in the neutral, what generates a low neutral voltage (in blue), phase-to-phase voltages are not affected, because the 25HZ voltage is a zero sequence voltage. The impedance calculation accuracy is about 98%, although there is a 50Hz component in the current due to the unbalance of the system.

- Controlled phase overvoltage

The injection of a 50Hz magnitude in the neutral generates a phase-to-ground overvoltage in one phase, if the angle of the neutral voltage is the same, and an undervoltage in the other two phases. At the same time, phase-to-phase voltages remain unchanged.

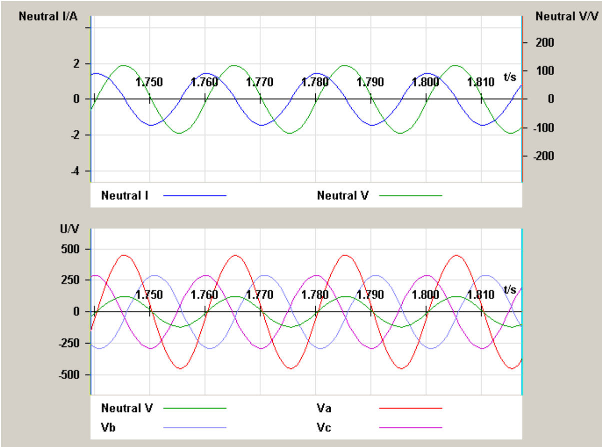

Figure 2: Injected neutral magnitudes and the provoke overvoltage in one of the single phases.

- Detection and location of weak insulation points

When a weak insulation point appears, there is no a 50Hz current through the neutral, but, anyway, this faulty situation can be detected by the neutral injection of non-fundamental frequency.

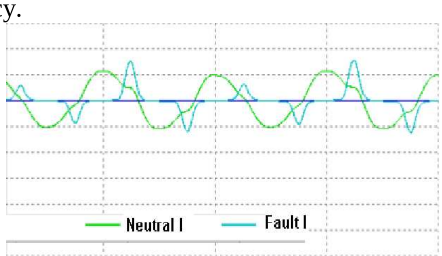

Figure 3: The shape of the current during isolation failures, so it can be detected by the active grounding system.

- Fault location and extinction

Neutral current value change, depending on the operation, needs to be done with the grounding system. During fault location, 25Hz are injected, before starting with the 50Hz to try to extinguish the fault.

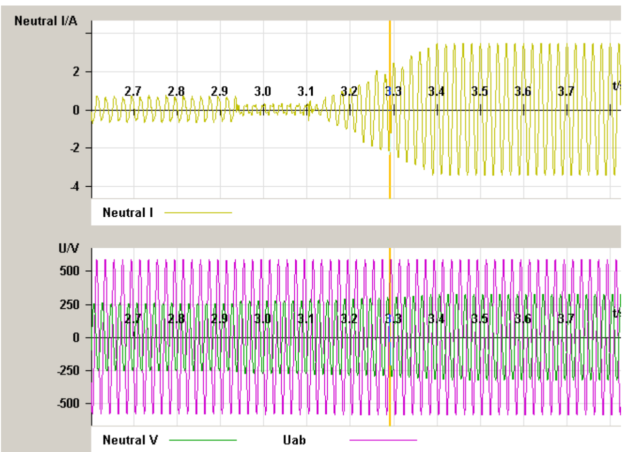

Figure 4: In the first diagram, initially neutral current is composed by 25Hz and 50z, for fault location. It finishes only with the 50Hz, for fault extinction.

- Fault extinction

For a transient fault extinction, faulted phase voltage is set to zero, so no current circulates through the fault, in order to obtain the best extinction probability.

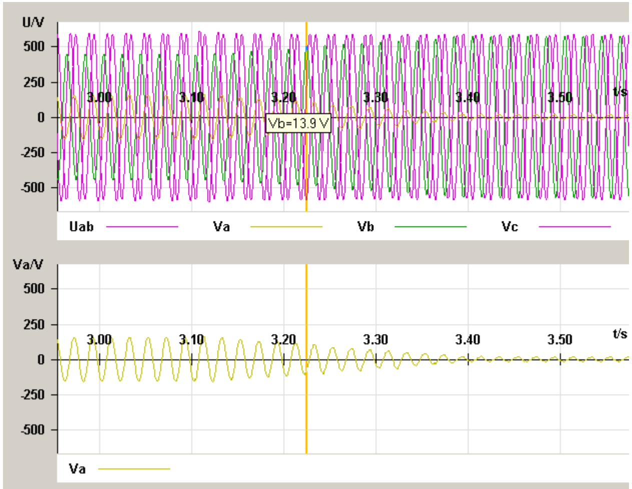

Figure 5: Faulted voltage reduction (yellow), while sound phases voltages increase less than phase-to-phase voltages.

For permanent faults, faulted phase voltage can be reduced to such a value that fault disappear. In this way, the active grounding system allows to operate networks in a safe way, minimizing the stress in the sound phases' isolation due to the overvoltage.

FIELD INSTALLATION DESCRIPTION

One of the most important issues when installing a new device, it is to **assure the correct response of the protection system** in the new situation while **maintaining highest safety standards** (low level of touch and step voltages) for personal and equipment protection.

It has to be taken into account that the network is reconfigured as high impedance grounded while in operation without faults, and it performs as resonant grounded when injecting for fault extinction.

Regarding protection system, when the active grounding system is installed in a substation with solidly or low impedance grounded, as it is the case in Gernika, no changes are expected to be required in the overcurrent protection system. This protection diagram will not operate until the active grounding system finishes fault extinction.

For isolated or high impedance grounded networks, minor changes might be needed in the protection system in order to maintain the protection operation diagram. The modification must delay the activation of the overcurrent protection about 100 miliseconds, the time needed for the active grounding system to control de current of the neutral.

Besides, overvoltage protection will be inhibited during the process of the extinction of the fault.

One of the most important issues when changing the grounding system is to ensure safety of persons and goods. This is accomplished by the correct operation of the protection system and the level of touch and step voltages for the in the new situation. It has to be borne in mind that the active network is grounded through a high impedance while in normal service, and that it behaves like a resonant grounded one when injecting for the extinction of the fault.

The use of active grounding system implies using a protection system able to work with the signals injected by the converter. This can be done at different levels:

- With feeder protection relays with adapted features for ground fault detection (normal characteristics for the rest of functions).
- With a protection relay dealing with the ground fault detection of several feeders, keeping the existing relays for the rest of functions.
- Maintaining the existing relays and installing a by-pass breaker, which will close in case of permanent fault, allowing the existing protection system to work normally. In this case, part of the protection functions (i.e. fault location) would not be available.

On the other hand, with this novel grounding system, the isolation level requirements are similar to those of the resonant networks. Isolation condition has been always an issue when changing an existing MV network from low to high impedance grounding. Typically, during the first months, or even years, the higher stress for isolation of high impedance grounding makes insufficient isolation appear in elements, with the consequent effect on power quality.

The traditional solution to this problem is a revision campaign of the whole MV system, previous to the grounding change, where any doubtful isolation should be replaced. However, this process is slow, costly and unreliable, since some failures (i.e. defective cable joints) cannot be easily detected. The active grounding systems facilitate this process, since it allows checking the network isolation during the commissioning process. A phase by phase checking process can be applied to each feeder, locating defective points either by means of the high impedance fault detection included in the system protection or using external detection based in partial discharges.

CONCLUSIONS

Laboratory tests results allow us to conclude the following:

- The network is protected having low step and touch voltages due to the system accomplishment of reducing the fault current while operating for the location and extinguishing process.
- The chance of measure magnitudes at other frequencies than 50-60Hz enables having improved accuracy to obtain the right calculations in fault detection and location
- Fault current can be cancelled almost completely, to possibility its extinction, regardless of the fault location and the fault impedance value
- The active grounding system allows to operate networks with permanent faults in a safe way, minimizing the stress to the isolation
- Response times allow carrying out the location and extinction of transient faults in less than 1 second

The results of monitoring and analyzing the field performance of the application of this innovative system will be presented at CIRED 2011.

Acknowledgments

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