COMPENSATED GROUNDED MEDIUM VOLTAGE NETWORK PROTECTION AGAINST RESISTIVE PHASE TO GROUND FAULTS

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INTRODUCTION

Electricité de France has decided to modify the neutral point connection of medium voltage rural networks by replacing the present neutral impedance grounding of these networks by an arc suppression coil (limiting the fault current to 40 amperes). The reasons for this change are:

- *the growth of the underground section of the mixed overhead -underground networks which results in an increase in the phase-to-ground capacities of the lines and thus induces the increase in the fault currents flowing in the phase-to-ground faults,*
- *greater customer sensitivity to the supply quality,*
- *evolution of the international standards (control of overvoltages).*

The implementation of an arc suppression coil makes it possible to limit phase-to-ground fault currents and to improve the supply quality by reducing the number of short supply interruption (many faults become self-extinguishing).

The evolution of the neutral point connection must not change the network operation practices. Thus the fault feeder is immediately switched off after the appearance of a fault if the high speed or delayed automatic reclosing cycles have failed. Another important, safety-linked requirement is the detection of resistive phase-to-ground faults. The presently available detection algorithms including those developed by the EDF are described in this report. However, the needs of the EDF have required the development of a new algorithm whose performances (selectivity and sensitivity) are at least equivalent to those of the neutral impedance networks.

THE PRESENT PROTECTIVE MEASURES

For the most recent impedant networks, an inverse time zero sequence protection positioned on each feeder is used to detect the resistive phase-to-ground faults and isolate the fault feeder. Selectivity is ensured since in this case the value of the zero sequence current for this feeder is above that of the fault-free feeders. This is no longer true for the compensated grounded networks due to the compensation of the phase-to-ground capacities currents and the low value of the active current of the *arc suppression coil*.

Another system of resistive fault detection, measuring the current flowing in the neutral, is also used for impedant grounded networks. This system is not selective and results in degradation of the supply quality since the fault feeder can only be localised by the sequential opening and closing of the different feeders.

In the compensated grounded networks, the neutral-to ground voltage can represent a few percent of the nominal network voltage without any faults due to the amplification of the effect of the asymmetry of the network. The sensitivity of a resistive phase-to-ground protection measuring this residual voltage is limited to a few kΩ and it is not selective.

The used discrimination criteria for the present protection are thus no longer suitable for simultaneously guaranteeing both good sensitivity and selectivity.

DESCRIPTION OF THE STUDIED SOLUTIONS

Several algorithms for detecting resistive phase to-ground faults have been studied by EDF for compensated grounded networks. The algorithms described here use the electrical quantities available in a medium voltage source substation. These quantities are represented in the equivalent model described below.

Network equivalent model

The algorithms described here are based on the analysis of the currents and voltages available in a source substation, at the industrial frequency and an steady state fault.

These currents and voltages are represented in the simplified three phase schemes in Figure 1. They correspond respectively to the residual currents of the different feeders:

- I_{rDD} for the fault feeder;
- I_{rDi} for a given fault-free feeder “ i ”.

The zero sequence voltage can be calculated from the measurements of the single network voltages (V1, V2, V3).

Each feeder is modelled by its phase-to ground admittance and a current generator representing its natural asymmetry.

The fault is represented by the resistance Rf.

The equivalent single phase schemes is shown in Figure 2.

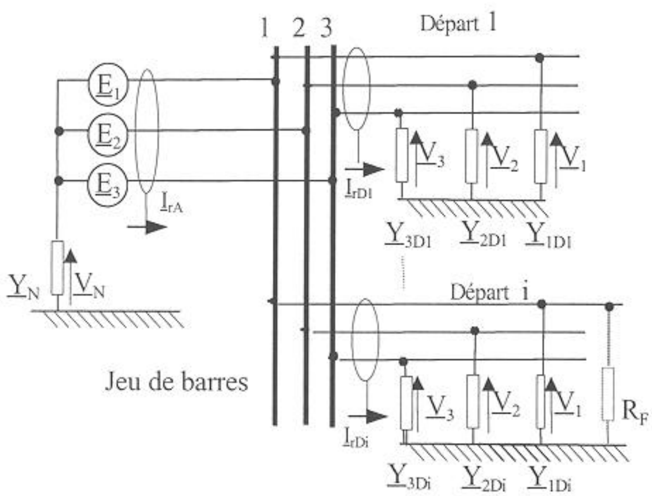


Figure 1: Simplified equivalent three phase schemes of the network.

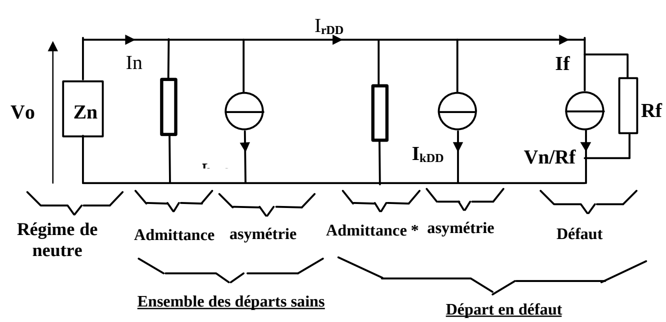


Figure 2: Simplified equivalent single phase schemes. ***Sum of phase-earth admittances of the considered feeder “ i ” (essentially capacitive).**

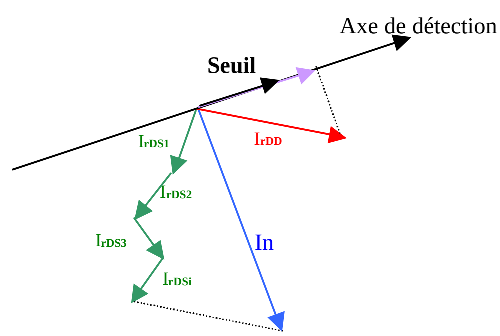
The developed algorithms use the following property: only the residual current of the fault feeder has a significant active component that essentially corresponds to the active current of the arc suppression colis. However, for high fault resistance values, the residual current of a fault-free feeder can also have a non-negligible active component due to the natural asymmetry. (Figure 2).

The algorithms take this phenomenon into consideration in order to guarantee the selective discrimination of the fault feeder.

The detection algorithms

Static “ DESIR ” system

EDF has developed and patented the **<u>D</u>**étection **<u>S</u>**élective par les **<u>I</u>**ntensités **<u>R</u>**ésiduels (selective detection by residual currents) algorithm, which makes it possible to detect resistive faults and to select the fault feeder. This is done by a vector comparison of the residual currents in all the feeders. This comparison is carried out by taking a reference phase constructed from the sum of the residual currents of all the feeders (this sum is equal to the neutral current).



$$\overrightarrow{In} = \vec{I}_{rDs1} + \vec{I}_{rDs2} + \vec{I}_{rDsi} + \vec{I}_{rDD}$$

Only the projection of the residual current of the fault feeder on the detection axis is positive. The detection is effective when this projection is above the threshold.

Figure 3: “ DESIR ”algorithm principle.

<u>Advantages</u>:

The originality of this system is in the fact that the identification of the active component of the residual current of the fault feeder is simply made by measuring the residual currents of all the feeders. This method makes it possible to avoid the difficulties linked to measurement of the zero sequence voltage (appreciable error due to the voltage transformers).

Disadvantages:

The detection threshold must be adjusted to a value above that of the feeder with the highest asymmetry and must make allowance for the detector measurement errors. This makes it possible to avoid inadvertent trips. On the other hand, the operating characteristic thus defined imposes an non-negligible limit on the protection sensitivity.
This arrangement provides only a single protection for all the substation feeders.

Dynamic " DESIR "system

This is a variant of the static " DESIR " algorithm with which the effect of the natural asymmetry of the network and measurement errors can be avoided. For this variant, the algorithm is identical to the basic version but it is applied to the variations of the measured electrical quantities.
Advantages:
The sensitivity of this system is higher (several tens of kΩ).
Disadvantages:
The detection is obtained only at the appearance or disappearance of a fault and in certain situations it is difficult to determine which of these is responsible for exceeding the threshold.
The localisation of a fault on a feeder by operations manoeuvres using this algorithm is not possible.
With dynamic DESIR the network faults can be detected but it cannot be used as it now is without additional algorithm development.

The DDA system

This algorithm enables **D**etection **D**ifferential by using the total phase-to-ground **A**dmittance.
As with dynamic "DESIR", it makes use of the variations of the residual currents. It requires, moreover, the measurement of the phase-to-ground voltages.
The prior acquisition of the sum of all the phase to ground admittances (1) of each feeder " i " is necessary. This calculation can be made in an injection induced by the automatic tuning system.
The following expression (2) is applied to each feeder:

$$\underline{Y}_{tGi} = \underline{Y}_{1Di} + \underline{Y}_{2Di} + \underline{Y}_{3Di} \qquad (1)$$

$$R_F = \frac{\underline{V}_v}{\Delta \underline{I}_{rDi} - \underline{Y}_{tGi} \Delta \underline{V}_o} \qquad (2)$$

All that is required is to compare the fault resistance calculated in this way with a threshold.
Note: The voltage $\underline{V}_v$ corresponds to the complex expression for the phase-to-ground voltage and must be selected (from the three phases) so that the argument of the complex expression (2) is close to zero.

Advantages

Identical to those of dynamic "DESIR ". Conversely to "DESIR ", this algorithm can be applied to each feeder: it is independent of the residual currents of the other feeders.

Disadvantages:

Identical to those of dynamic " DESIR " but it requires, in addition, the measurement of phase-to -ground voltages and a periodic injection of a residual current by the automatic tuning system for the arc suppression coil.
On the other hand, with this algorithm, the resistance m; fault is calculated; it thus seems easier to differentiate between a fault appearance and disappearance.

A POSSIBLE SOLUTION FOR COMPENSATED NEUTRAL NETWORKS

The EDF's requirements

The zero sequence protection plan of the compensated grounded medium voltage networks at EDF includes, for each feeder, a zero sequence power protection whose sensitivity to the tuning is around 2 kΩ. As the detection of resistive faults is a major safety issue for the EDF, the implementation of a protection against resistive earth faults is required. The desired sensitivity is equivalent to that of the protections now used in the impedant grounded networks, the order of 15 kΩ. This protection must be selective, with a very reliable discrimination of the fault feeder and must make possible the operation of the network under good conditions, in particular, in network manoeuvres for faults localisation. Its operation must be independent of the source substation-operating scheme. This assumes protection architecture for each medium voltage feeder or for each half-set MV busbars.
The protection must be compatible with the implementation of the special operating regime used for "live" maintenance work at medium voltages, by selectively protecting the concerned feeder.
Finally, this protection must respect the insertion regulations in the monitoring-control of the substations.

Tests campaign
Tests were made in 1998 on a laboratory-reconstituted, compensated neutral regime, MV network in order to verify the behaviour of the resistive earth faults (conductor in contact with different types of soils).
These tests made it possible to verify the dependability, in the operating range of present protective devices, of acquisition of the network electrical quantities at 50 Hz.

The spectral analysis of the different observed quantities shows a preponderant 50 Hz component.

A possible solution

The analysis of the description of the different algorithms, presented here shows that none of them completely answers the EDF's needs.

Only the “DESIR” system based on static measurements could be used as is. However, its sensitivity is insufficient and it provides protection solely for the entire medium voltage substation.

Additional studies in 1997 and 1998 have resulted in the development of a new algorithm adapted to the requirements. A patent application for this has been filed.

A mock-up was tested during the tests campaign and confirms the advantages of this algorithm.

CONCLUSIONS

This publication gives the reasons, which led to the development of new algorithms for detecting resistive earth faults on compensated neutral medium voltage networks. The studied algorithms are described and the advantages and disadvantages of each solution are given. These various algorithms do not completely meet the EDF’s requirements. Additional studies were thus made and we now have a suitable algorithm for which a patent application has been filed.

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