EDF'S FIELD EXPERIENCE ON MV NETWORKS ZERO-SEQUENCE PROTECTION SCHEME

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ABSTRACT

This paper describes the zero-sequence protection scheme of EDF MV distribution grids and gives a feedback from the field on its effectiveness. On neutral-compensated MV networks, EDF's protection scheme is based on the feeder zero-sequence wattmetric relay and the more sensitive transformer zero-sequence voltmetric relay . The return on experience shows that the protection scheme is very well adapted to faults occurring on neutral-compensated networks, and that the sensitivity is satisfactory.

This paper finally analyses the impact of discontinuity of cable earth connections on unexpected trippings of zero-sequences wattmetric relay. This phenomenon has been observed on a few protections on our MV grids: a defective earth connection of the screens leads to zero sequence dissymmetry currents that triggers the protection relays. The paper characterizes the problem in case of:
- Discontinuities of earthing of the cable screens,
- A poor grounding at the substation.
The paper gives some recommendations on how to identify and localize cable screens problems.

INTRODUCTION

Since 2001, the French MV network's neutral earthing policy has changed as described in paper [1] in Cired 2005. As more cables are installed in France and a new touch-and-step voltage standard came into place, a new compensated grounding for capacitive non urban networks became justified. The installation of a tunable compensation coil with a high 600 Ohms resistance in parallel limiting the fault current to 40 Amps was adopted. Since then, a certain number of benefits were achieved thanks to compensated neutral grounding for the mixed overhead lines and cable networks :

- The step-and-touch voltage, and the over voltages on LV networks and Telecommunication system comply now with the standards,
- The protection scheme was consequently adapted : Wattmetric and Voltmetric relays adapted to mixed cable and overhead line feeders improved the sensitivity of the protections,
- The overall power quality was improved even if not equally on all feeders. The number of self-extinguishing faults increased, thus reducing the number of short fault elimination reclosing cycles.

In 2006, the EDF MV neutral grounding planning policy was re-written: the criteria determining which substation transformer should be equipped with a new neutral compensated grounding was put in place (the criteria is a capacitive current over 100A per transformer). Moreover, the rhythm of deployment of the neutral-compensated grounding project was increased in the two last years.

This paper gives :

- a description on the zero-sequence protection scheme of EDF neutral-compensated MV distribution grids,
- a feedback on the efficiency of the resistive zero-sequence faults elimination,
- a description of the phenomenon that occur in case of earthing poor connections and/or dissymmetry currents .

DESCRIPTION OF EDF'S MV ZERO-SEQUENCE PROTECTION SCHEME

Since 2001, EDF's protection scheme on neutral-compensated MV networks (in paper [2]) is based on the feeder zero-sequence wattmetric relay and the more sensitive transformer zero-sequence voltmetric relay (also mentioned in papers [3] and [4]).

Definitions

Most **zero-sequence faults** on neutral-compensated MV networks are generally detected and eliminated by the feeder zero-sequence wattmetric relay, which is a directional protection well adapted to the Compensated Neutral Networks (it replaces the zero-sequence maximum current relay that was no longer adequate).

- A **resistive fault** is usually eliminated by the transformer zero-sequence voltmetric relay and not detected by the feeder zero-sequence wattmetric relay .

- A **very resistive fault** is usually not detected by the transformer zero-sequence voltmetric relay, which is a non-selective protection (no identification of the faulty feeder).

The **resistive sensitivity** of a protection scheme is given in Ohms and corresponds to the highest fault resistance value that can be detected.

Description of the Zero-sequence Protection Scheme

The French MV zero-sequence protection scheme is based on zero-sequence voltmetric and wattmetric relays.

Wattmetric detection

On faulty feeders, the zero-sequence wattmetric relay detect s negative zero-sequence active power. It detects restriking faults and remaining zero-sequence faults. With a low threshold, sensitivity is very good (typically 8 kW upper feeder). Tripping usually happens within 1s. A delay is set typically at 700 ms in order to deal with self extinguishing faults.

Voltmetric Detection

The voltmetric relay detects high impedance faults. The detection threshold is set as low as possible, but should be set above the sum of :

- The existing zero-sequence substation voltage (it is due to the unbalanced feeders capacitive components : around 1% of nominal voltage),
- The existing zero-sequence voltage due to the precision of the compensation coil. Typically the threshold is set at 4%. This guarantees a detection up to 5 kΩ resistive fault for 35 Amps overtuned Neutral Compensated networks, as shown in Table 1 below.

Indeed, the theoretical protection scheme resistive sensitivity performances can be summarized as follows :

Table 1 : Sensitivity levels of zero-sequence relays

	Tuned Neutral Compensated	**Overtuned Neutral Compensated**
Zero-Sequence Wattmetric Relay	5,3 kΩ	2,5 kΩ
Zero-Sequence Voltmetric Relay	10 kΩ	5 kΩ

EDF'S FIELD EXPERIENCE IN MV NEUTRAL COMPENSATED NETWORK ZERO SEQUENCE PROTECTION SCHEME

A field experience on zero sequence protection scheme for MV neutral compensated network was launched in 2005 in 25 EDF distribution areas throughout France. The study covered 42 substations equipped with neutral-compensated transformers. The survey dealt with the recorded zero-sequence faults that occurred in year 2004.

The results can be summarized in the Table 2.

Table 2 : Statistics of Detected Faults

Number of Zero-sequence faults detected per transformer and per year	**Number of Resistive Zero-sequence faults detected per transformer and per year**	**Number of Very Resistive Zero-sequence faults detected per transformer and per year**
38,3	0,43	0,03

The results can also be expressed in percentage of zero-sequence faults (see Table 3).

Table 3 : Efficiency of the Relay Detection

Percentage of detected zero-sequence faults	**Percentage of resistive zero-sequence faults**	**Percentage of very resistive zero-sequence faults**
99,93 %	1,14%	0,07%

The origins of such resistive faults are generally MV/LV transformer faults, cable touching the ground or cable failures between tower anchor clamps.

This field experience improved our knowledge of the protection scheme used on neutral-compensated networks as follows :

- Around 0,07 % (less than 1over 1000) of very resistive faults are not detected by the zero-sequence Wattmetric and Voltmetric relays. The protection scheme is therefore around 99,9 % satisfactory. This corresponds to about 1 non-detected fault in a neutral compensated substation every 21 years.
- Around 1,1 % of resistive faults are detected by the zero-sequence Voltmetric relays and not by the zero-sequence Wattmetric relays : faults which resistance is greater than a mean value of 4000 Ω. This corresponds to 0.7 fault per year per neutral-compensated substation. This low figure can be explained not only by the improved sensitivity of the neutral-compensated protection scheme (compared to the neutral impedance protection scheme), but also by the growth of cables installation and network equipment reliability.

This field experience analysis on MV neutral compensated network zero-sequence protection scheme also highlighted the fact that cable screens discontinuity can have some impact on wattmetric protection unexpected trippings in some particular cases. One simple way to deal with this problem is to increase the inhibition time of the zero-sequence wattmetric relay in these particular cases. Another way would be to increase the tripping thresholds, but it usually decreases the sensitivity of protection relays.

PARTICULAR CASES OF CABLE DISCONTINUITIES

A few unexpected protection trippings lead EDF R&D to run a more detailed study in order to characterize the impact of cable screen discontinuity on wattmetric relay unexpected trippings and to identify ways to identify and localize such problems.

Cable discontinuity and non expected protection trippings study

Figure 1 shows the simplified equivalent circuit of a compensated distribution network with feeders.

The following simplify assumptions are made for the equivalent circuit and for the calculations below :

- ☞ The three phase source are supposed to be ideal (ie balanced, sinusoidal, no internal impedance);
- ☞ The load is not taken into account, since we consider only the residual currents that are independent of the load. The zero-sequence impedance of the load is

infinite, i.e. the load can be represented by an equivalent circuit isolated from ground. This condition is fulfilled in French distribution systems.

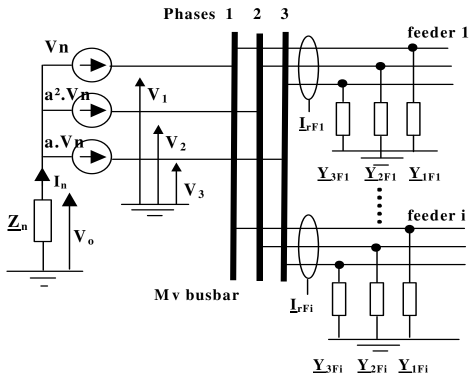

Fig 1 : Simplified equivalent circuit of a compensated distribution system

Decription of the model

The notation adopted in this paper is given hereafter, where the electric parameters are represented by :

- Expressions of the residual currents of the various feeders measured by the zero-sequence wattmetric relays are given by the following relations :

$$\underline{I}_{rFi} = \underline{V}_1 . \underline{Y}_{1Fi} + \underline{V}_2 . \underline{Y}_{2Fi} + \underline{V}_3 . \underline{Y}_{3Fi}$$

with $\underline{Y}_{1Fi} = j . C_{1Fi} . \omega$, $\underline{Y}_{2Fi} = j . C_{2Fi} . \omega$, $\underline{Y}_{3Fi} = j . C_{3Fi} . \omega$

- Expressions of the busbar voltage in the substation are :

$$V_1 = \underline{V}_n + v_o$$
$$V_2 = a^2 . V_n + v_o$$
$$V_3 = a . Vn + v_o$$

V_o = rise in potential of neutral point due to asymmetry

$$a = e^{j.120}$$

V_n = normal voltage

- We can thus deduce the expressions of the residual current:

$$\underline{I}_{rFi} = \underline{I}_{aFi} + \underline{I}_{cFi} \ (1)$$

$$\underline{I}_{rFi} = V_n.(\underline{Y}_{1Fi}+a^2.\underline{Y}_{2Fi}+a.\underline{Y}_{3Fi})+\underline{V}_o.(\underline{Y}_{1Fi}+\underline{Y}_{2Fi}+\underline{Y}_{3Fi}) \ (1)$$

- Feeder asymmetry current is :

$$\underline{I}_{aFi} = \underline{V}_n . (\underline{Y}_{1Fi}+a^2.\underline{Y}_{2Fi}+a.\underline{Y}_{3Fi}) \ (2)$$

- Feeder capacitive current is :

$$\underline{I}_{cFi} = \underline{V}_o . (\underline{Y}_{1Fi} + \underline{Y}_{2Fi} + \underline{Y}_{3Fi}) \ (3)$$

- The neutral current I_n is : $I_n = \sum_i I_{rFi} = \dfrac{\underline{V}_o}{\underline{Z}_n}$ (4)

Zn = transformer neutral grounding.

According to (1) we can establish the equivalent circuit to representative the effect of asymmetry on the feeders. This asymmetry due to the cut of a flexible braid or a cable screen. The single-phase equivalent circuit of the considered network is given in figure 2.

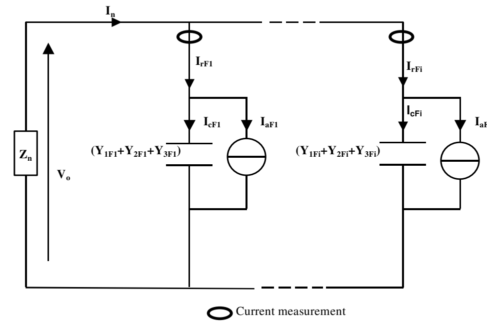

Fig. 2 : Single-phase equivalent circuit of a compensated distribution system

Fig 2 shows that the influence of an additional asymmetry due to the cut of a braid at the two cable ends or a dissymmetrical cut on the cable screens, can lead to the tripping of a zero-sequence wattmetric relay on a non faulty feeder.

Investigation on a real case in Western France

Fig. 3 and fig.4 give the example of 30 km long cable in Western France on which a discontinuity of cable screens was detected. The asymmetrical and capacitive currents were calculated, and as shown on the figures, they lead to a tripping of the feeder relay.

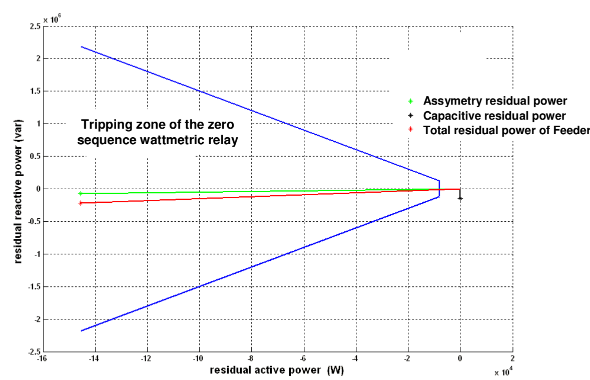

Fig. 3 : Behaviours of zero-sequence relay on feeder 1 with discontinuity of cable screen

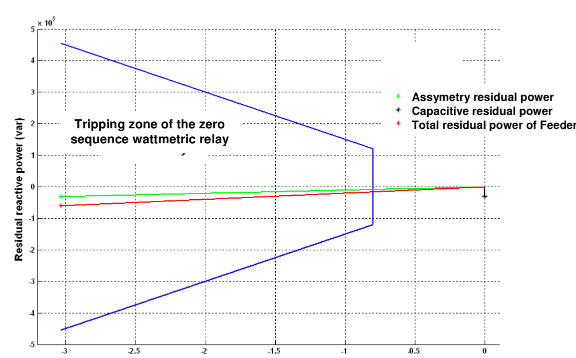

Fig. 4 : Behaviours of zero-sequence relay on feeder 1 with discontinuity of cable screen on feeders 1,2 and 3 (phases different)

Method of investigation

To avoid having negative power readings on non faulty feeders, it is recommended to check :

- that there is no discontinuity on the level of the cable screens,

- that the ground flexible cable braids are well connected,

- that the substation earth resistance is 1 Ω maximum.

Identification of cable screen discontinuities

The measurement of asymmetry thus remains an indicator to identify:

- ☞ risks of non expected trippings of zero-sequence wattmetric relays,
- ☞ discontinuities of the cable screens.

A Method for Characterizing Asymmetry Levels

Characterizing the asymmetry currents of the feeders will help identifying part of the potential problems and also detect screen discontinuities on underground feeders. In order to achieve this, we need two measurements : $\underline{I}_{rFi}$ and V_o.

The first set of measurements can be obtained with a compensation coil properly tuned. The second set can be obtained by changing the value of the compensation coils (overtuned network). We suppose that V_n is constant.

☞ Residual current for the first measurement is :

$$\underline{I}^1_{rFi} = \underline{V}^1_o \cdot (\underline{Y}_{1Fi} + \underline{Y}_{2Fi} + \underline{Y}_{3Fi}) + \underline{I}_{aFi} \quad (5)$$

☞ Residual current for the second measurement is :

$$\underline{I}^2_{rFi} = \underline{V}^2_o \cdot (\underline{Y}_{1Fi} + \underline{Y}_{2Fi} + \underline{Y}_{3Fi}) + \underline{I}_{aFi} \quad (6)$$

Asymmetry can be formulated as follows :

$$\underline{I}_{aFi} \approx \underline{I}^2_{rFi} - \underline{V}^2_o \cdot \frac{\Delta \underline{I}_{rFi}}{\Delta \underline{V}_o} \quad (7)$$

where

$$\underline{I}_{aFi} \approx \underline{I}^1_{rFi} - \underline{V}^1_o \cdot \frac{\Delta \underline{I}_{rFi}}{\Delta \underline{V}_o}$$

with : $\frac{\Delta \underline{I}_{rFi}}{\Delta \underline{V}_o} \approx (\underline{Y}_{1Fi} + \underline{Y}_{2Fi} + \underline{Y}_{3Fi})$

Localization of Cable Screens Discontinuities

The method for localizing discontinuities of cable screens is based on Time Domain Reflectometry (TDM). This method consists in sending a low voltage impulse on a cable and analyzing the signal of reflexion of this impulse.

This technique is now commonly used for the detection of cable defects and partial discharges, and EDF R&D is now investigating its application for the localization of cable screens discontinuities.

CONCLUSION

Field experience on MV compensated neutral networks

The analysis of field experience shows that the protection scheme is very well adapted to faults occurring on neutral-compensated networks, and that the protection scheme sensitivity is satisfactory.

Cable screen discontinuities

Dissymmetrical cuts of the cable screens in several points of an underground connection lead to high asymmetrical currents (different capacities between the phases-cores conductors and the various cable screens associated). As a consequence, zero-sequence wattmetric relays can measure a negative power on non faulty feeders.

The presence of a negative power on non faulty feeders leading to trippings can be explained by :

- Discontinuities of earthing of the cable screens,
- A poor grounding at the substation.
- In the most unfavourable case, the cut of flexible braids at the two ends of a cable of only one feeder. In this situation, even without fault, depending to the length of the underground connection, feeder tripping can follow.
- Rupture of the cable screens. On the other hand cuts of the cable screens in several points could also lead to unexpected trippings of zero-sequences wattmetric relays.

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[3] Jeff Roberts, Dr. Hector J. Altuve, and Dr. Daqing Hou, Schweitzer Engineering Laboratories : "review of ground fault protection methods for grounded, ungrounded, and compensated distribution systems”

[4] Final report of the Cired working group WG 03 on fault management in electrical distribution systems.