ON LINE DIAGNOSTIC IN ERDF HV/MV SUBSTATIONS: METHOD AND RESULTS OF NETWORK EXPERIMENTATIONS.

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ABSTRACT

Since 2012, ERDF is experimenting on line diagnostic systems which aim to prevent failures on its MV underground cable distribution network. Diagnostic systems have been installed in HV/MV substations and also at EDF Lab Les Renardières Electrical Laboratories on the MV cable testing facilities. The main architecture of the diagnostic system is described and results obtained from on site measurements or EMTP simulations are presented.

INTRODUCTION

The reduction of the number of persistent faults on the distribution system is an important issue for ERDF in order to keep a high quality of service. Off line diagnostic tools are already widely used to prevent such failures and ERDF deployed 21 test vans to detect and eliminate the weakest parts of its underground MV network (20 kV).
On line diagnostic solutions for failure prevention are also under study and cases of application based on partial discharge measurement were presented [1]. A new project allowing a larger scale of investigation combining the detection of high energy transients also named pre-fault in this paper and known as self extinguishing faults, started in 2012.
This paper describes the main architecture of the diagnostic systems under experimentation and presents some field and simulation results focusing on the measurement of self extinguishing faults and research of solutions for their localisation.

MAIN ARCHITECTURE OF THE SYSTEMS

HV/MV substations

The diagnostic systems presented in this paper are installed in two HV/MV substations. The neutral of the MV network is grounded type. On this side the main power transformers are either grounded with a 12 Ω single resistance or a combination of resistance and inductance: Zn = 40 + j 40 Ω.

Measurements

The measured quantities are recorded on a local acquisition system and then stored in a central data base. The following phenomena are recorded:

- The total current of the common busbars supplying a set of feeders (I1, I2...),
- The phase to ground voltages of each power transformer,
- The current circulating in the common ground connexion of the cable screens of each feeder (I_screen).

The drawing presented in figure 1 illustrates the general arrangement of the current and voltage sensors connected to the diagnostic system.

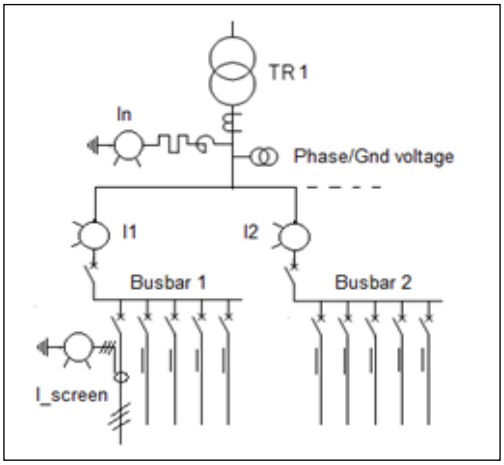

Figure 1: General arrangement of measurement sensors

Data acquisition

The data acquisition systems have been designed to record low frequency phenomenon with a 50 kHz sampling rate and high frequency transients (screen currents) with a 40 MHz sampling rate. The high frequency currents are measured by the mean of Rogowski coils.

FIELD MEASUREMENTS

Since the installation of the diagnostic systems in the HV/MV substations a high number of transient phenomena have been recorded. The main transients observed are:

- "Normal" transients provided by the network operation: load change, configuration change of the substations (transformer coupling...),
- Self extinguishing faults,
- Persistent faults eliminated by the circuit breakers of the feeders.

Self extinguishing faults

The feedback of field measurements shows that the self extinguishing faults occurred, as expected, on a

maximum of the phase to ground voltages and lead generally to a 10 ms current pulse in the neutral. Short transient self extinguishing fault as mentioned in [2] were rarely observed in the field results. Most of the self extinguishing faults are single events but some double pulses have been observed on the next peak of the voltage or the second following peak of the same polarity.
Figure 2 shows a representative example among the self extinguishing faults recorded.

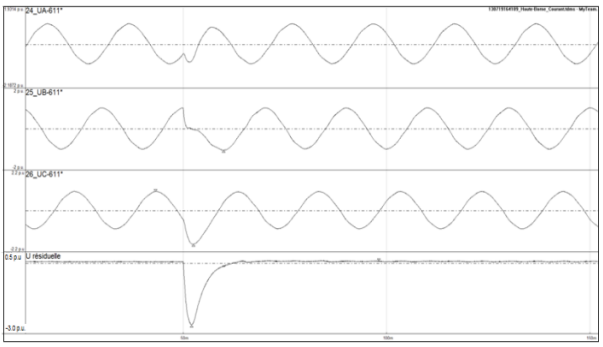

Figure 2: Phase to ground voltages and calculated residual voltage for a typical self extinguishing fault.

Figure 3 shows another self extinguishing fault "immediately" followed by a persistent single phase fault.

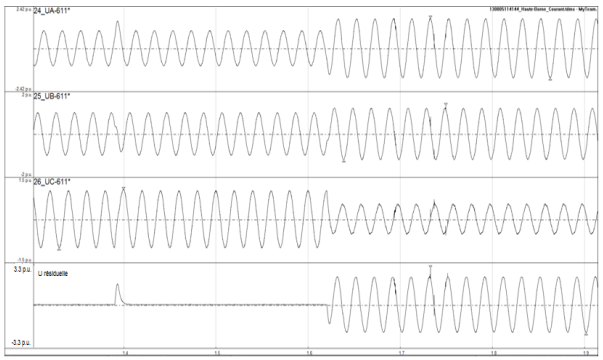

Figure 3: Phase to ground voltages and calculated residual voltage. Self extinguishing fault followed by a single phase persistent fault after 230 ms.

A detailed analysis of the transient phenomenon over 3 years showed that the delay between these self extinguishing faults and the consecutive failures varies between a few milliseconds as shown above and almost one year for the longest delay observed.

RELATION BETWEEN SELF EXTINGUISHING AND PERSISTENT FAULT

The feedback of the screen current measurements carried out since 2012 lead to confirm the link between "pre-faults" and persistent faults.
An interesting case has been recorded in July 2013 where 2 self extinguishing faults have been recorded in a 2 minutes delay. Figure 6 shows the first self extinguishing signature recorded that day.

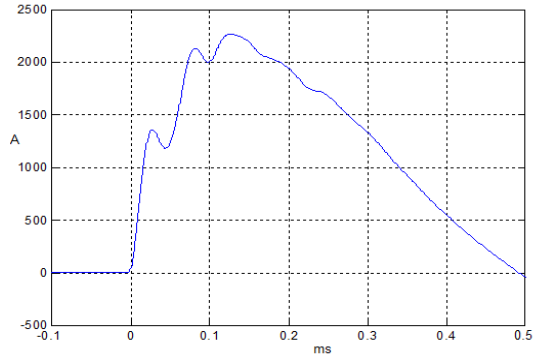

Figure 6: "screen current" for a self extinguishing fault recorded on 2013/07/19.

Figure 7 shows the fast transient recorded during the persistent fault which happened one month later on the same feeder.

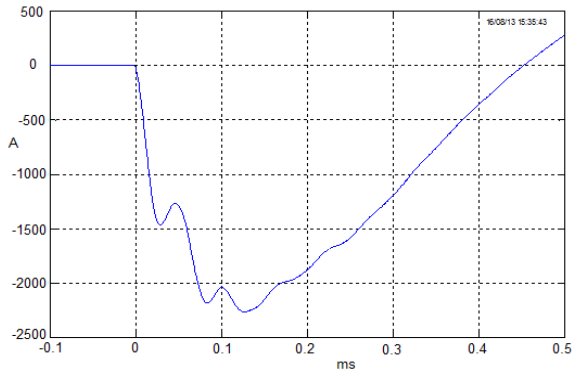

Figure 7: "screen current" for a persistent fault recorded on 2013/08/16.

We can observe on fig. 6 and fig. 7 that the waveforms of the measured screen currents of the faulty feeder during the self extinguishing fault and the consecutive persistent fault are identical in terms of amplitude and oscillation frequencies. The high amplitudes of both transient currents indicate that the fault resistance during the pre-fault and the persistent fault was low. In that case the failure become localised in a transition joint.

FAULTY FEEDER IDENTIFICATION

In order to automatically detect the feeder affected by a pre-fault, an algorithm has been developed using the calculated residual voltage (V1+V2+V3) and the current circulating in the common ground connexion of the 3 cable screens of each feeder (named as "screen current" after).
When a pre-fault (or a persistent fault) occurred between core and screen in a cable, a high level current can be measured in the common ground connexion of the faulty feeder. This current is composed of a power frequency component supplied by the power source and circulating

in the neutral impedance and a capacitive component provided by the cable capacitances of the healthy feeders connected to the same power transformer. The faulty feeder can be identified by calculating the higher peak of the screen currents, the higher initial di/dt and also be identified with its polarity which is opposite to the one of the other feeders.
Figure 5 shows the different screen currents of 15 feeders connected to a same transformer in the case of a persistent fault in a cable.

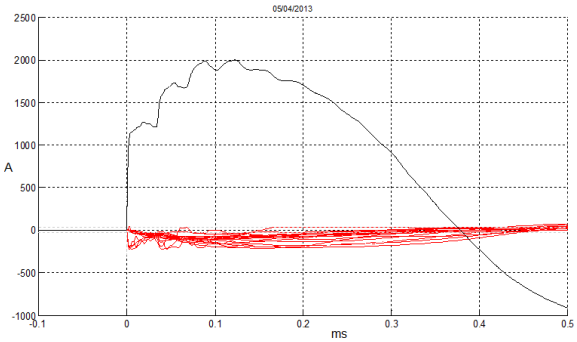

Figure 5: "screen currents" of 15 feeders connected to the same power transformers.

The positive phenomenon corresponds to the faulty feeder current.

PRE-LOCALISATION OF WEAK POINTS

The detection and identification of self extinguishing fault is a first step for an on line diagnostic system but the final objective aims to find a solution to localise, as close as possible, the weakest points in the underground network before a failure occurs.
Travelling wave technique based on the reflection of the generated waves in cables has been investigated thanks to the high frequency sampling of the measurements carried out on site. Simulations with EMTP-rv have also been carried out to analyse the influence of different parameters such as fault resistance or feeder lengths.

Field results

In order to investigate possibilities of localisation of pre-faults, screen current measurements recorded on different persistent faults have been used. In some simple configurations cases (feeders without branch circuits) it was possible to find out the part of the network where the fault occurred.
Figure 8 shows another example of a screen current waveform for a fault which was located at a distance comprised between 1260 and 1400 m from the HV/MV substation (these 2 distances are the cable lengths between the HV/MV substation and both MV/LV substations surrounding the fault location).

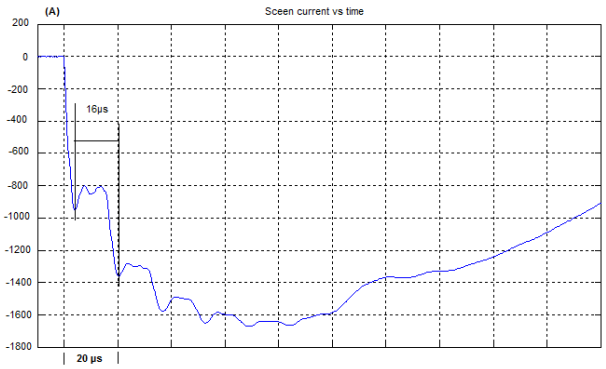

Figure 8: High frequency oscillations of a travelling wave on the screen current measurement during a fault.

As noticed on figure 8, the period of the high frequency component of the screen current is equal to 16 µs in this case. This time interval corresponds to a distance of 1280 m for an average propagation speed in the cable of about 160 m/µs.
This result which has been confirmed on several cases of similar configurations is encouraging but the feedback shows that the location is a challenge because of different parameters such as long cable lengths and variation of the fault resistance. The presence of cable branch circuits shall also be taken into account.

EMTP-rv simulations

The variation of the fault resistance is a first parameter which makes the localisation delicate. Simulations using EMTP-rv have been carried out to address that point. A simple simulation circuit with one main transformer and six feeders has been simulated first. The value of the fault resistance has been modified to analyse its influence on the waveform of the screen currents as measured on site during a fault. Different values have been used:

- A very low value: 0.1 Ω,
- A low value: 1 Ω,
- A value close to the cable impedance: 20 Ω.

The simulation results show that the oscillations may highlight either the reflections between the substation and the fault or the reflections between the fault and the end of the link. Figure 9 and figure 10 illustrate that point.

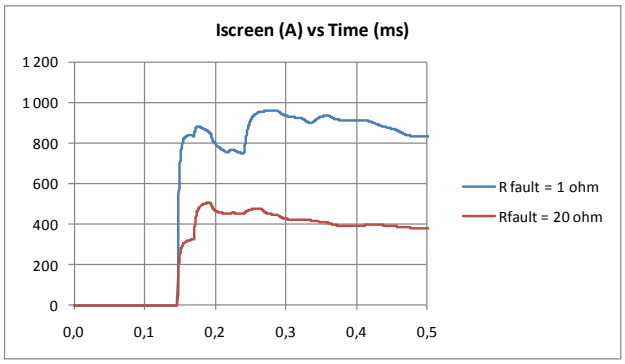

Figure 9: Simulation results: Screen currents on a faulty feeder versus time for 2 fault resistance values.

To enhance the reflections on the fault or the end of line, a calculation of the current derivative has been done as illustrated on figure 10. This calculation clearly shows the scales of the reflexions as a function of the fault resistance.

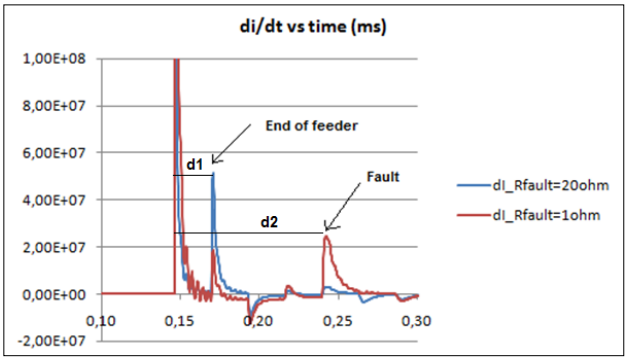

Figure 10: Simulation results: screen current derivative for 2 fault resistance values.

We can observe that the measured reflection may indicate the distance "d1" between the substation and the fault when the fault resistance is low and that the reflection may indicate the distance "d2" between the fault and the end of line when the resistance is higher.

CONCLUSION

The self extinguishing fault is a relevant indicator to anticipate the short term failures of the Medium Voltage underground cable network. Experimentations carried out in ERDF HV/MV substation with on line diagnostic systems enabled to measure many events of that type.
Thanks to an efficient measuring system with a high frequency sampling, locations of faults have been done successfully in several cases (with simple configurations) using the high frequency cable screen current measurements. The feedback and the help of simulation show that the accurate pre-fault localisation still remains a challenge considering long cable lengths, fast variation of the pre-fault resistance and also the presence of cable branch circuits.

REFERENCES

[1] T. Espilit, F. Zorzi, R. Tambrun, 2011, "On line MV diagnostic method for failure prevention: Case of application", 21st International Conference and Exhibition on Electricity Distribution.

[2] T. GU, F. Provoost, 2013, "Improving network performance by recognition and location of self-extinguishing faults", 23rd International Conference and Exhibition on Electricity Distribution.